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Designing an Agricultural Biomass Supply Chain Model Using Cross Impact Analysis

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ABSTRACT

The present study aimed to identify and analyze the factors affecting the biomass supply chain in the agricultural sector. The present study is quantitative in terms of methodology and is a survey study in terms of data collection. The theoretical population of the study was managers and consultants active in the biomass sector in the agricultural sector. Sampling was done by judgment, and the sample size was 10 people. The research questionnaires were: a screening questionnaire and an impact analysis questionnaire. The fuzzy Delphi method was used to evaluate and analyze the screening questionnaires, and the Cross Impact Analysis method was used to analyze the impact assessment questionnaires.The present study was conducted in three stages. In the first step, 34 key factors affecting the agricultural biomass supply chain were extracted through literature review and expert interviews. In the next step, these factors were screened using the fuzzy Delphi method. Eight factors had a desirable defuzzied number and were selected for impact analysis. The screened factors were evaluated using the interaction analysis method. The most important impact factors were: demand for biofuels and renewable energy, transportation infrastructure, biomass processing technologies, and integrated supply chain management. Practical suggestions were developed based on the most important influencing factors and focus group interviews. To improve the agricultural biomass supply chain in Iran, experts recommend that the government increase demand for biofuels by providing financial incentives, reducing taxes, and enacting supportive laws. In addition, investing in the development of transportation infrastructure, improving biomass processing technologies, and utilizing digital systems and artificial intelligence in supply chain management can help increase productivity and reduce costs. Implementing these solutions, along with strengthening cooperation between farmers, industries, and government institutions, will lead to sustainable development of the sector.

Keywords

Supply chain, Biomass, Agricultural biomass, Agriculture, Impact analysis.

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1. Introduction

Biomass, as a renewable energy source, plays a pivotal role in reducing dependence on fossil fuels and advancing sustainable development. These resources are derived from various organic materials, including agricultural, forestry, and industrial residues, and can be converted into diverse biofuels such as biogas, biodiesel, and bioethanol (Nunes, Causer, & Ciolkosz, 2020; Blair et al., 2021). Utilizing biomass for energy production not only mitigates greenhouse gas emissions but also contributes to maintaining the natural carbon cycle, serving as an environmentally compatible solution (Raychaudhuri and Ghosh, 2016).

From an economic perspective, developing biomass supply chains can generate new employment opportunities in both rural and industrial areas, enhance productivity, and alleviate poverty in local communities. Moreover, leveraging domestic biomass resources can reduce fossil fuel import costs and improve national energy self-sufficiency (Zandi Atashbar, Labadie, and Prins, 2018).

A major challenge in biomass supply chains is the spatial dispersion of resources and the need for adequate infrastructure for collection, transportation, and processing. Optimizing supply network design and applying advanced modeling and decision-making techniques can enhance the efficiency and sustainability of these chains (Lyu et al., 2024; Nugroho and Zhu, 2024). In addition, the adoption of innovative processing technologies, implementation of circular economy approaches, and establishment of supportive government policies are key measures to improve the environmental and economic performance of biomass supply chains (Blair et al., 2021).

The agricultural biomass supply chain, as a crucial component of renewable energy production, plays a significant role in promoting sustainable development and reducing dependence on fossil fuels. This chain encompasses multiple processes that convert biomass resources—such as forestry residues and agricultural waste—into various biofuels and other valuable products. A major challenge lies in optimizing the collection, storage, transportation, and processing of these resources to enhance efficiency and lower logistics costs (Wu et al., 2022).

Effective management of the biomass supply chain requires the use of analytical models and simulation systems to evaluate and improve processes. Linear and multi-objective programming frameworks, for example, can be applied to simulate and optimize the entire supply chain. In northern China, optimization models were developed for the agricultural biomass supply chain, demonstrating that simulation and optimization approaches can reduce costs and increase productivity (Wu et al., 2022).

Another critical strategy for improving the biomass supply chain focuses on the sustainable utilization of biomass for biofuel production. Such biofuels, including biopropane, help decrease reliance on fossil fuels and mitigate environmental impacts. Achieving these goals necessitates the formulation of supportive policies and management frameworks aimed at optimizing biomass use in renewable energy generation (Umakanth et al., 2022).

Recent studies have highlighted that utilizing agricultural and forestry residues as biomass resources can directly contribute to economic development and create employment opportunities in rural areas. These resources also help reduce agricultural waste and conserve natural resources (Chidozie et al., 2023). Implementing appropriate support policies, alongside providing training and capacity-building programs for farmers and producers, can further enhance productivity throughout the biomass supply chain (Pourelmi et al., 2023).

Compared to developed countries, Iran faces significant challenges in developing and optimizing its biomass supply chain. Limitations related to water and energy resources, particularly in second-generation biofuel production processes, pose major obstacles (Sahebi and Naseri Taheri, 2013). Nevertheless, studies are underway to assess the country's potential and improve biomass-related processes. For example, research in the Alamut region of Qazvin province has shown that biomass resources could supply a substantial portion of the required energy (Kazemi-Alamoti, 2022). However, to meet international standards, further investment is needed in research and development, infrastructure enhancement, and the optimal management of biomass resources.

This research offers a detailed examination of Iran's agricultural biomass supply chain, addressing a critical gap in the literature, which has largely focused on global or other regional contexts. Due to Iran's distinctive climate, widely distributed agricultural resources, and infrastructural constraints, direct adaptation of international strategies may be ineffective.

The study employs a novel methodological approach by integrating the fuzzy Delphi method for screening key factors with cross-impact analysis via Mic Mac software, enabling the evaluation of both direct and indirect interactions among technical, economic, social, and policy-related variables. This approach provides a more comprehensive understanding of the interdependencies within the supply chain compared to previous studies.

In addition, the research incorporates policy-relevant considerations, highlighting the roles of government support, farmer training, and market demand, and offering practical recommendations to improve efficiency, sustainability, and coordination in Iran's biomass supply chain. By combining rigorous analysis with actionable insights, this study contributes uniquely to both academic knowledge and practical policy development in the Iranian context.

2. Research background

The biomass supply chain encompasses the processes of sourcing, transporting, storing, and converting biomass derived from agricultural, forestry, and industrial residues into energy carriers such as bioethanol, biogas, and biodiesel (Benti et al., 2021; Blair et al., 2021). Efficient management across all stages of this chain is critical for minimizing operational costs, enhancing overall efficiency, and promoting sustainability (Chen and Liu, 2023; Hiloidhari et al., 2023). Key challenges, including the spatial dispersion of biomass resources, infrastructural constraints, and variability in market demand, necessitate the application of advanced modeling, optimization strategies, and integrated supply chain management approaches (Wu et al., 2022; Chidozie et al., 2023). Moreover, the adoption of innovative processing technologies, the implementation of circular economy principles, and alignment with governmental policies and support mechanisms are pivotal in improving both operational performance and environmental outcomes within biomass supply chains (Sarangi et al., 2023; Zadorozhnyi et al., 2023; Pourelmi et al., 2023). Collectively, a well-coordinated and strategically managed biomass supply chain contributes to enhanced energy security, the achievement of sustainable development objectives, and the mitigation of greenhouse gas emissions (IEA, 2018; Sims et al., 2007).

To ensure the successful development of biomass supply chains, it is crucial to pay attention to government policies and support. Governments can speed up this process by providing financial incentives, regulatory support, and creating target markets. Specifically, motivating farmers and industrialists to invest in biomass and use it for energy generation can lead to the creation of sustainable energy systems and lessen reliance on fossil fuels (Nguyen and Toan, 2024).

Agricultural biomass refers to organic resources produced in the agricultural sector that are used for industrial processes or the generation of renewable energy (Kumar et al., 2023). These resources include plant residues such as stems, leaves, seeds, and husks of crops that remain after harvest. At present, significant attention is focused on utilizing these resources to generate biofuels such as bioethanol, biodiesel, and biomass gas, since these resources are recognized as sustainable alternatives to fossil fuels without creating significant emissions (Mujtabi et al., 2023).

One of the main advantages of using agricultural biomass is decreased reliance on fossil fuels and reduced pollution from conventional energy sources (Saleem, 2022). Besides generating energy, these materials can be utilized across different industries such as producing organic fertilizers, bio-packaging, and chemicals (Saleem, 2022; Kalak, 2023). In countries such as Iran, where agriculture plays a vital role in the economy, the use of these resources serves as an option to manage agricultural waste and make optimal and desirable use of them.

However, one of the main challenges in exploiting agricultural biomass is satisfying sustainable demand and creating suitable infrastructure for collecting, transporting, and processing these materials (Benti et al., 2021). The demand for advanced processing technologies and enhancing transportation infrastructure, particularly in rural areas, is among the other challenges in this sector (Saleem, 2022). Furthermore, most farmers are reluctant to exploit these resources due to unawareness and inadequate incentives (Pourelmi et al., 2023). To address these issues, governments should implement supportive and incentive policies, such as providing subsidies and lowering taxes, to enhance the production and use of biofuels.

Agricultural biomass can significantly contribute to sustainable development (Kibria et al., 2024; Blair et al., 2021). Through the adoption of innovative strategies for biomass resource management, enhancement of processing technologies, and implementation of supportive policies, these resources can be used as an effective solution to provide renewable energy and reduce adverse environmental impacts. The most important studies conducted on the biomass supply chain in the agricultural sector are presented below.

In their study, Lyu et al. (2024) examined the role of agricultural biomass in decarbonizing supply chains. Through modeling and simulation analyses, they demonstrated that effective utilization of biomass reduced greenhouse gas emissions and enhanced the environmental performance of supply chains. The study also highlighted that identifying critical points and optimizing biomass sourcing and processing pathways lowered costs while supporting sustainable development goals and energy sustainability. Finally, the authors emphasized the importance of supportive policies, advanced technologies, and integrated resource management for the efficient use of agricultural biomass.

Nugroho and Zhu (2024) investigated strategic supply and transportation planning for agricultural biomass conversion into hydrogen and syngas. They developed an optimization model to determine the most efficient allocation of biomass sources, processing facilities, and transportation routes. The results demonstrated that proper planning reduced operational costs, improved energy yield, and enhanced the overall sustainability of the supply chain. The study also emphasized the importance of integrating supply, processing, and transportation decisions to support the transition toward low-carbon energy systems.

Hiloidhari et al. (2023) analyzed a green and sustainable biomass supply chain and explored its advantages from environmental, social, and economic perspectives. This research emphasizes the importance of efficiently optimizing and appropriately designing the biomass supply chain, as it can help reduce negative environmental impacts, such as reducing greenhouse gas emissions, decreasing waste, and improving air quality. The research additionally focuses on the social benefits of this chain, demonstrating that the exploitation of biomass resources can create jobs and strengthen the economic situation in rural areas. This study looks at the use of biomass from an economic viewpoint to deliver sustainable energy and lessen reliance on fossil fuel energy sources. Ultimately, this research emphasizes the necessity to develop supportive policies and new technologies to optimize the biomass supply chain.

Chen and Liu (2023) designed a resilient and global supply chain network to solve problems associated with sustainable biomass energy generation. They introduced an optimization model tailored to improve the performance of the biomass energy supply network, taking into account multiple aspects of economic, environmental, and social sustainability. Considering challenges like fluctuations in raw material supply and demand changes, this model designs an optimal supply network capable of handling these challenges. The research results indicate that this network can lower expenses, enhance efficiency, and improve the system's resilience to market fluctuations and supply disruptions. This study emphasizes the importance of designing resilient and global supply chains for sustainable energy generation from biomass.

Zadorozhnyi et al. (2023) analyzed innovative cost management of agricultural biomass production by accounting for and evaluating production costs. This research emphasizes methods for optimizing cost management in the biomass production process and stresses the significance of adopting modern accounting methods to reduce costs and boost efficiency. Through a careful study of the expenses linked to agricultural activities, the researchers have introduced management models that help producers and farmers optimize costs and increase profitability. Furthermore, this research points to the significance of employing innovative methods in cost accounting to facilitate the sustainable and competitive production of biomass.

Kumar Sarangi et al. (2023) investigated the use of agricultural wastes as biomass resources and the recycling process involved in the context of a circular bioeconomy. This study emphasizes the importance of using agricultural wastes as renewable resources for producing biofuels and valuable chemicals. Moreover, biorefinery processes used to convert these wastes into energy and other valuable products have been introduced as a sustainable solution to address energy crises and climate change. This study also analyzes different sources of agricultural wastes, the processes of their conversion into energy and other materials, and evaluates the life cycle of these processes to expand a circular bioeconomy.

Blair et al. (2021) examined how biomass supply chains for bioenergy could contribute to achieving sustainable development goals. They demonstrated that the effective utilization of biomass resources and the optimization of supply chains could generate economic, social, and environmental benefits, playing a significant role in reducing greenhouse gas emissions, enhancing energy security, and supporting sustainable agriculture.

Nunes et al., (2020) reviewed biomass supply chain management models for energy production. They highlighted the challenges in the collection, transportation, storage, and processing of biomass, emphasizing the need for integrated planning, optimization techniques, and decision-support tools to improve efficiency, reduce costs, and enhance sustainability across the supply chain. The study also discussed strategies for aligning biomass supply with energy demand and policy objectives to promote renewable energy deployment.

Ghasemi et al. (2019) analyzed the components of the waste biomass supply chain using fuzzy cognitive maps. At first, the different components of this chain were identified by conducting interviews with experts. Subsequently, the relationships between these components were analyzed using fuzzy cognitive maps. The results indicated that production of waste biomass, pre-processing (sorting), landfill storage, and initial transport have the most significant effect on the process, respectively. Furthermore, the analysis of different scenarios indicated that as the impact of waste biomass production rises, the effects of other components also increase. In contrast, as the impact of primary transportation and landfill storage increases, the impact of other components declines and can even turn negative. Accordingly, it can be concluded that waste biomass production plays a more significant and effective role in energy production than other components.

Nasrollahi et al. (2017) developed a mathematical model to improve the process of selecting and allocating orders to environmental suppliers in biomass power plants. The purpose of this research was to optimize the supply chain, focusing on environmental criteria, and reduce negative environmental impacts. To reach this objective, a mathematical programming model has been developed that can be used to select green suppliers and allocate orders optimally.

This model enables managers to make optimal decisions by taking into account multiple criteria, such as costs and environmental effects, which results in improved environmental and economic performance of biomass power plants.

Javadi and Manafi (2014) focused on optimizing a sustainable biofuel supply chain while taking pricing under uncertainty into account. Given the population growth and lifestyle changes that have increased the energy demand, the production of biofuels has become more important as a renewable resource. Nonetheless, managing the biofuel supply chain encounters multiple difficulties stemming from different complexities and uncertainties. This research introduces a mixed-integer linear programming model to design a sustainable biomass supply chain. This model enables managers to make optimal and efficient decisions, considering the uncertainty in raw material prices. Additionally, random and robust optimization approaches have been employed to manage the risks stemming from uncertainty. The results of this model indicated that under conditions of uncertainty, environmental goals and social welfare are in harmony; thus, improvements in environmental performance can result in greater social welfare. Moreover, changes in environmental costs significantly affect the level of social welfare.

Numerous studies have been conducted on agricultural biomass supply chains, each focusing on different aspects of the field. Some studies have considered modeling and optimizing the supply chain, whereas others have analyzed uncertainty, location, and resource allocation. Typically, these studies can be divided into three primary categories: studies that have examined the relationships between supply chain components, studies that have analyzed mathematical models and cost optimization, and research that has addressed the uncertainties and challenges related to biomass supply.

Some studies have analyzed the relationships among components of the biomass supply chain and have determined that production, transportation, and storage are the key factors in this chain. These investigations frequently employed fuzzy cognitive maps and decision-making frameworks to examine the relationships among the chain components. While these techniques are useful in understanding the cause-and-effect relationships among components, they have primarily overlooked the practical and operational details of agricultural biomass.

Another category of research has concentrated on optimizing biomass supply chains using mathematical models. These investigations have employed linear programming methods and optimization algorithms to make decisions regarding facility location, resource allocation, and cost reduction. The strength of these studies is that they provide precise and quantitative models to improve supply chain efficiency; however, many of these studies have overlooked challenges like the impact of seasonal changes on biomass availability and risks in the supply process.

The third group of studies has focused on the uncertainties and challenges linked to the biomass supply chain. These studies have indicated that factors, such as weather conditions, market changes, and transportation price fluctuations, can affect supply chain performance. Some studies have proposed models for managing uncertainty in biomass supply. The advantage of this research is its emphasis on practical challenges and real supply chain conditions, yet it has limitations in providing specific implementation strategies to reduce these challenges.

The previous studies, while addressing the topic of biomass, have rarely explored the issue of the agricultural biomass supply chain. Moreover, these studies do not have a comprehensive view being examined and have merely focused on a few of them.

3. Research methodology

The main purpose of the present research is to present a model of factors affecting the agricultural biomass supply chain in Iran. To meet this purpose, fuzzy Delphi methods and cross-impact analysis were used to analyze the effectiveness of factors. Fuzzy Delphi was employed to screen factors, and cross-impact analysis was used to evaluate their effectiveness. Given the application of quantitative techniques in the current research, it is referred to as a quantitative multi-method study. Furthermore, as the research results are practical and useful for the agricultural sector, this research is considered an applied study.

Data was collected using two tools: interviews and questionnaires. Factors affecting the agricultural biomass supply chain were identified through a review of studies about the supply chain and biomass. Subsequently, to evaluate and analyze the effectiveness of these factors, two kinds of questionnaires—one for screening and the other for impact assessment- were given to the experts. The screening questionnaires were analyzed using the fuzzy Delphi method, and the impact assessment questionnaires were analyzed through the use of a cross-impact analysis method. Given the fact that the factors affecting the biomass supply chain in the agricultural sector were extracted through a review of credible domestic and international articles regarding biomass and supply chain, and interviews with experts, both the screening questionnaire and the impact assessment demonstrated good validity. Moreover, due to the selection of an appropriate sample (10 individuals) and the screening process of the research factors, the impact assessment questionnaire showed good reliability. The sample size of this study was 10 people, making it a suitable size for expert-based judgment methods.

Techniques such as cross-impact analysis are highly sensitive to the number of factors and experts due to their reliance on pairwise comparisons. Increasing the sample size can lead to inconsistencies in the results of these methods; this was the reason why the factors were initially screened using the fuzzy Delphi method. In expert-based approaches, where sampling is judgmental, the expertise and knowledge of the participants are more critical than the sample size.

The experts in this study included active managers and consultants in the agricultural sector, as well as experienced faculty members specializing in biomass and supply chain studies. All participants held a PhD degree, and the faculty members had a minimum academic rank of Associate Professor, with significant research experience, including publications and projects related to biomass and supply chains. The selection of experts was based on their expertise, practical experience, and involvement in relevant projects, ensuring diverse and comprehensive perspectives from academia, industry, and governmental organizations. The sampling method was judgmental, and given the nature of expert-based methods such as the fuzzy Delphi and cross-impact analysis, a sample size of 10 was deemed sufficient to guarantee the validity and reliability of the results. This composition provided a representative overview of the agricultural biomass supply chain in Iran, ensuring that the insights collected were both credible and comprehensive.

The experts in this research comprised managers and consultants engaged in the agricultural industry, as well as faculty members who are experts in the study areas of biomass and supply chain. Sampling was done by judgment, and the samples were chosen according to their expertise and experience in biomass and the supply chain.

This study was carried out in three stages. In the first step, the factors affecting the biomass supply chain in the agricultural sector were extracted via a literature review and focus group interviews. In the next step, these factors were screened through the fuzzy Delphi method and the distribution of expert questionnaires. In the third step, the most influential factors were evaluated using the cross-impact analysis method.

In this research, the fuzzy Delphi technique was used to screen the factors affecting the biomass supply chain in the agricultural sector. During the screening process with this algorithm, it is essential first to choose an appropriate fuzzy scale to convert the verbal expressions of experts into fuzzy values. To meet this purpose, the common fuzzy scales can be used. This research used a five-point Likert scale to collect the opinions of experts, the details of which are shown in Table 1 (Arabi et al., 2022).

Table 1. Five-point fuzzy spectrum

Verbal variable	Fuzzy equivalent	Triangular fuzzy numbers
Very low	1~	(0.0, 0.25)
Low	2~	(0,0.25, 0.5)
Medium	3~	(0.25, 0.5, 0.75)
High	4~	(0.5, 0.75, 1)
Very high	5~	(0.75, 1, 1)

Once the research factors are screened, the cross-impact analysis stage begins. The cross-impact analysis is an important technique in future research that examines and analyzes the relationships among factors and the trends influencing a problem. This method, by evaluating the cross-impact of each factor on other factors, identifies the key factors that will impact the development of the system in the future.

In this process, a set of key factors or drivers impacting the system is initially identified. Next, a square matrix is prepared where the impact level of each variable on the other variables is assessed on a scale from zero to three. A zero indicates no impact, one represents a small impact, two indicates a medium impact, and three refers to a large impact. By analyzing these values, the degree of impact and dependence of the key factors is measured, and the relationships between them are determined.

A useful tool in this area is the Mic Mac software, which allows for a structural analysis and helps to discover key variables. This software analyzes the direct and indirect impacts of factors and provides a more profound insight into the factors, which can be useful for predicting future scenarios.

4. Research findings

Factors affecting the biomass supply chain in the agricultural sector were identified through a review of the research literature and interviews with experts in the field. Table 2 displays these factors. In order to identify these factors, studies conducted about the supply chain and biomass were carefully examined. Accordingly, studies published in reputable domestic and international scientific databases such as Scopus, Thomson Reuters, and Magiran over the past 15 years were searched using keywords related to supply chain, biomass, and agricultural biomass. Initially, the researchers examined the titles and abstracts of the selected articles, followed by an evaluation of the quality of the articles using the CASP index. Ultimately, 12 articles were chosen for a more in-depth review.

Alongside library research, five specialized interviews were carried out with experts in the agricultural sector. The data obtained from these interviews were analyzed through the thematic analysis technique. Furthermore, to assess the validity of the screening questionnaires, Lawshe's Content Validity Ratio was applied. The value obtained for this index was greater than 0.79 for all key research factors, thereby confirming the appropriate validity of the research instrument.

A total of 34 key factors were identified through a literature review and structured interviews with experts in the field of biomass supply chain. Out of these, 26 factors were extracted through a literature review, and five structured interviews were conducted to complete the list, which resulted in the identification of eight new factors.

Table 2. Factors affecting the agricultural biomass supply chain

Effective factors	Research sources	Level of content validity index
Biomass conversion processes	Martinez-Valencia et al., (2025)	8%
Biomass resources	Wu et al. (2022)	82%
Transportation costs	Blair et al. (2021)	83%
Collection costs	Wu et al. (2022), Hiloidhari et al. (2023)	81%
Transportation infrastructure	Hiloidhari et al. (2023)	85%
Biomass processing technologies	Chen and Liu (2023), Wu et al. (2022)	87%
Access to renewable energy	Umakanth et al. (2022)	82%
Access to water resources	Interview	84%
Storage costs	Hiloidhari et al. (2023)	83%
Demand for biofuels and renewable energy	Wu et al. (2022)	85%
Environmental considerations	Sarangi et al. (2023)	81%
International sanctions	Interview	8%
Government policies	Interview	82%
Government support	Interview	86%
Target markets	Wu et al. (2022)	81%
Waste management	Zadorozhnyi et al. (2023)	83%

Effective factors	Research sources	Level of content validity index
Farmer training	Zadorozhnyi et al. (2023), Pourelmi et al. (2023)	85%
Investing in research and development	Chen and Liu (2023)	82%
Adoption of new technologies, especially in the field of information technology	Hiloidhari et al. (2023)	81%
Environmental regulations	Hiloidhari et al. (2023)	84%
International partnerships		85%
Climate change	Sarangi et al. (2023)	8%
Competition in the fuel market	Wu et al. (2022)	82%
Public awareness	Pourelmi et al. (2023)	81%
Fluctuations in raw material prices	Sarangi et al. (2023)	8%
Quality of agricultural waste	Kumar et al. (2023), Mujtaba et al. (2023)	83%
Iran's climatic and geographical diversity	Interview	8%
Biomass production and conversion capacity	Interview	82%
Farmers' readiness to change production methods	Interview	81%
Integrated supply chain management	Bastos et al. (2025)	87%
Establishing quality standards for biofuels	Slade, Bauen & Shah (2011)	8%
The extent of the impact on job creation	Nunes et al., (2020)	82%
Economies of scale and their impact on costs	Wu et al. (2022)	8%
Land and agricultural optimization processes	Interview	83%

Thirty-four drivers identified through literature review and expert interviews in the electricity industry and sustainable finance were screened using the fuzzy Delphi technique. At this stage, 26 drivers were excluded from the calculations, leaving just eight drivers chosen for the final ranking. Drivers with a defuzzified number greater than 0.7 were taken into account for the final ranking stage using the Cocosu technique. In this research, eight drivers with a defuzzified number above 0.7 were chosen. The figure 0.7 was considered as the cutoff point for screening and analyzing drivers, whereas in most studies, the cutoff point is typically a value between 0.5 and 0.7. The list of final drivers affecting the future of the electricity industry from the perspective of sustainable financing, along with their defuzzified numbers, is presented in Table 3.

Table 3. Fuzzy delphi output for key factors affecting the agricultural biomass supply chain

Defuzzified number	Average expert opinions			Factors affecting the biomass supply chain in the agricultural sector
	Upper limit	Middle limit	Lower limit	
0.85	0.92	0.85	0.78	Transportation Infrastructure (B1)
0.82	0.9	0.82	0.74	Biomass Processing Technologies (B2)
0.8	0.88	0.8	0.71	Access to water resources (B3)
0.9	0.98	0.9	0.82	Demand for biofuels and renewable energy (B4)
0.81	0.91	0.79	0.73	Government support (B5)
0.85	0.96	0.84	0.75	Farmer Training (B6)
0.82	0.92	0.81	0.73	Environmental regulations (B7)
0.84	0.94	0.83	0.74	International Partnerships (B8)
0.86	0.95	0.86	0.77	Integrated Supply Chain Management (B9)

After screening the key factors affecting the agricultural biomass supply chain, these factors are evaluated using the cross-impact analysis method.

According to the results of the Delphi section, the factors affecting the agricultural biomass supply chain in Iran were identified. Now, in this section, the cross-impact of these factors is examined using the MICMAC software. In fact, this method essentially analyzes the direct and indirect influence and dependence of the factors. To meet this end, the same ten experts involved in the Delphi section were asked to express their views by filling out a 9×9 square matrix. In fact, this matrix is structured in a way that the rows reflect the degree of influence exerted by each factor. At the same time, its columns indicate the dependence of the intended variable. For instance, in the first row, corresponding to factor B1, the expert is required to specify the degree of influence this variable has on other factors using different values, i.e., zero (no influence), one (low influence), two (moderate influence), and three (high influence). However, to proceed with the analysis, the responses of the ten experts need to be aggregated. To meet this purpose, the mode statistic is used, as reported in Table 4.

Table 4. The impact of aggregated direct influences

	B_1	BB_2	BB_3	BB_4	BB_5	BB_6	BB_7	BB_8	BB_9
BB_1	0	0	2	0	3	1	3	2	0
BB_2	0	0	2	0	2	1	2	2	0
BB_3	0	0	0	0	1	0	1	0	0
BB_4	0	0	1	0	2	1	2	2	0
BB_5	1	2	0	1	0	1	3	1	1
BB_6	0	0	0	0	1	0	1	0	0
BB_7	0	1	0	1	1	0	0	0	1
BB_8	0	0	0	0	1	0	1	0	0
BB_9	0	0	1	0	3	2	2	1	0

The characteristics of the aggregated opinion matrix can be seen in Table 5. According to this table, there are 44 relationships with no influence (considering the main diagonal of the matrix, where the influence of each variable on itself is zero), 21 relationships with weak influence (one), 12 relationships with moderate influence (two), and four relationships with strong influence (three). On the other hand, the total number of non-zero cells in this matrix is 37, accounting for approximately 45.68% of the entire matrix (9×9 = 81).

Table 5. Characteristics of the aggregated direct influence matrix

Percentage of filled cells	Number of ones	Number of zeros	Number of iterations	Matrix size	Index
45.68	21	44	5	9	Value
	Total	Number of Ps	Number of threes	Number of twos	Index
	37	0	4	12	Value

The cross-impact analysis is conducted in two main phases: the first phase focuses on direct influences, while the second phase addresses indirect influences.

4.1. Direct influences

As mentioned earlier, Table 4 shows the influence of factors on other factors in rows, while the dependence and susceptibility of each factor are shown in columns. Accordingly, Table 6 displays the total influence and dependence of each factor. Referring to this table, it is found that:

- Factors B9, B4, B2, and B1 have high influence and, in contrast, low dependence. These variables are referred to as independent variables. These are essentially the drivers and key main factors of the system, and any change in them can result in widespread impacts on the system.

- Factors B8, B7, B6, and B3 have a low influence and high and/or moderate dependence, which are called dependent variables. These variables are highly dependent on other variables but exert little influence on them. They are the outcomes of the system's performance and are affected by various factors.
- It is important to note that while variables B6 and B3 have higher dependence compared to their influence, a look at their values in the table reveals that this dependence is not very significant. Therefore, it cannot be assuredly stated that they are dependent variables. They could be seen as autonomous variables in the ongoing analysis. Autonomous variables have low dependence and low influence. These factors are relatively independent of the system, and changes in them have limited effects on other variables.
- Factor B5 can be considered as the linked variable; these types of variables have high influence and dependence. They are considered the bridge between independent and dependent variables and can strengthen or moderate the effects of independent variables.

Table 6. Total direct influence of the factors

Type of Impact	**B_1**	**B_2**	**B_3**	**B_4**	**B_5**	**B_6**	**B_7**	**B_8**	**B_9**	**Total**
Influence	11	9	2	8	10	2	4	2	9	57
Dependence	1	3	6	2	14	6	15	8	2	57
Total	12	12	8	10	24	8	19	10	11	114

These findings are clearly illustrated in Chart 1, which shows the direct cross-impacts. The horizontal axis of this graph represents dependence and susceptibility, while the vertical axis represents influence and impact. Therefore, this graph, similar to a polar coordinate system, is divided into four areas as follows:

- First quadrant (northwest area): This area includes factors that have both high influence and high dependence. These characteristics are associated with linked variables. As previously mentioned, factor B5 is considered one of the system's linked factors and, in fact, serves as a bridge between independent and dependent variables.
- Second quadrant (Northeast area): This quadrant is characterized by high influence and low dependency, which is a feature specific to independent variables that serve as the main and critical drivers of the system. By increasing or decreasing these variables, the outcome of the system (i.e., the dependent and susceptible variables) can be changed. Accordingly, as previously mentioned in Table 6, the factors B9, B4, B2, and B1 are among the independent and susceptible variables of the system that fall within this quadrant and, based on expert opinions, have been identified as playing a key role in the system.
- Third quadrant (Southeast area): The factors located in this quadrant show low degrees of influence and dependence. In fact, they represent the autonomous elements of the system. According to earlier explanations and the results shown in Figure 1, it is evident that the two factors B3 and B6 are considered among the autonomous variables of the system.
- Fourth quadrants (Southwest area): the factors in this quadrant are characterized by high dependence and low influence. These are, in fact, the dependent variables, controlled by

other independent and linked variables, and constitute the system output. As previously shown in Table 6, Factors B7 and B8 represent the dependent variables of the research system.

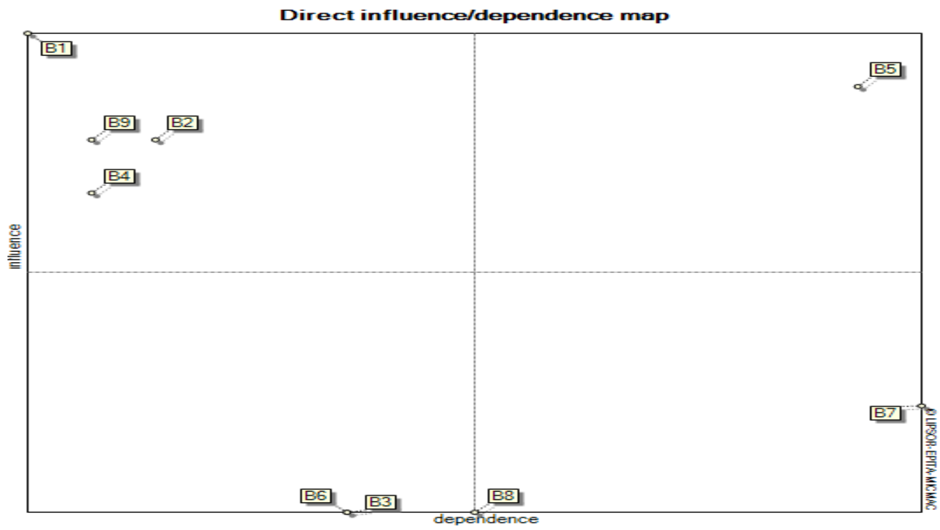

Figure 1. Influence-Dependence graph of direct influences

Moreover, Graph (2) demonstrates the direct influence among the factors, further confirming the results mentioned above.

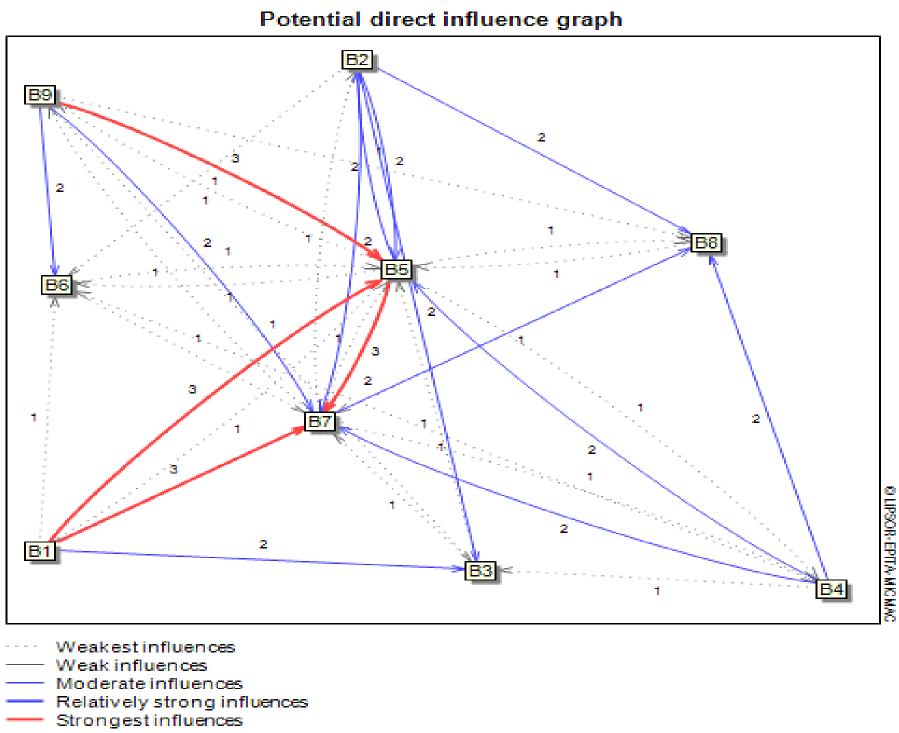

Figure 2. Direct influence graph

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4.2. Indirect influences

The indirect influence matrix is shown in Table 7. This matrix reports the total indirect influence and dependence; however, these values are clearly illustrated in Figure 3, which reflects the same results as previously indicated.

Table 7. Indirect cross-impact matrix

	B_1	B2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	Influence
B_1	2538	8126	5300	5588	15149	7040	18787	8764	5588	76880
B_2	1847	5959	4000	4112	11251	5235	13833	6541	4112	56890
B_3	691	2167	1300	1476	3898	1805	4954	2223	1476	19990
B_4	1754	5634	3720	3880	10560	4910	13048	6122	3880	53508
B_5	2511	8255	5716	5744	15743	7307	19074	9196	5744	79290
B_6	691	2167	1300	1476	3898	1805	4954	2223	1476	19990
B_7	1387	4495	2952	3108	8326	3877	10259	4846	3108	42358
B_8	691	2167	1300	1476	3898	1805	4954	2223	1476	19990
B_9	2214	7063	4544	4849	13071	6080	16281	7555	4849	66506
Dependence	14324	46033	30132	31709	85794	39864	106144	49693	31709	435402

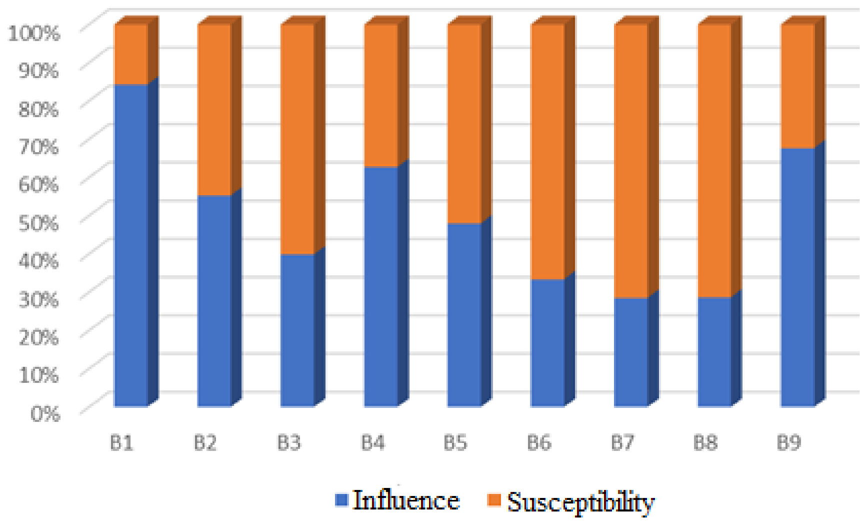
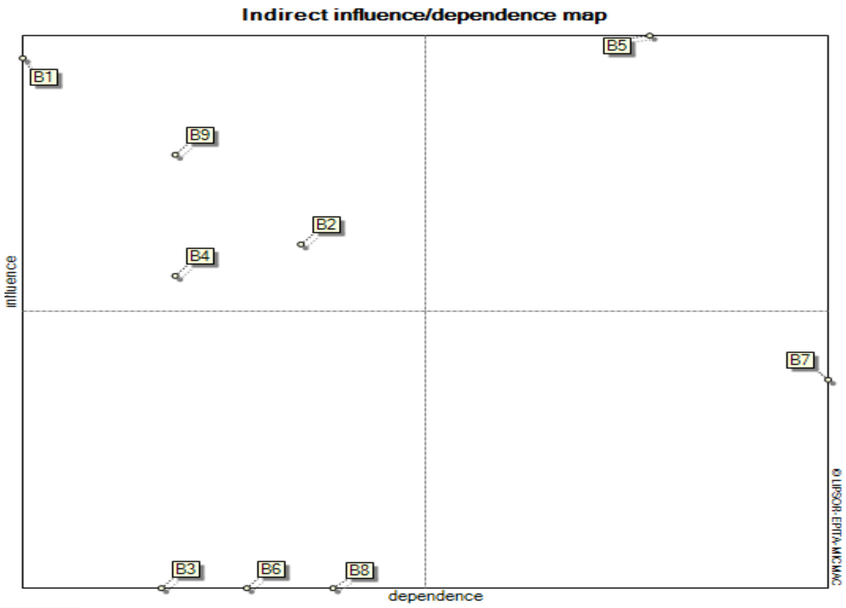


Figure 3. Total sum of indirect influence and dependence

Graph (4) displays the indirect cross-impacts. The horizontal axis of this graph represents dependence and susceptibility. In contrast, the vertical axis shows influence and impact, showing almost the same results as before, with the only difference being that here factor B8 has also been moved to the third quartile, which, taking into account the indirect influences, three factors B3, B6, and B8, can be defined as autonomous factors. This, in fact, indicates that these variables have an indirect weak influence and dependence. But still, in the case of indirect influences, the four factors B1, B2, B4, and B9 serve as the independent and influential variables that can control the output of the system, which is the dependent variable. Furthermore, the variable B5 still plays an intermediary role between the independent and dependent variables. These results are clearly shown in Graph (5).



influence-dependence

Figure 4. Indirect graph

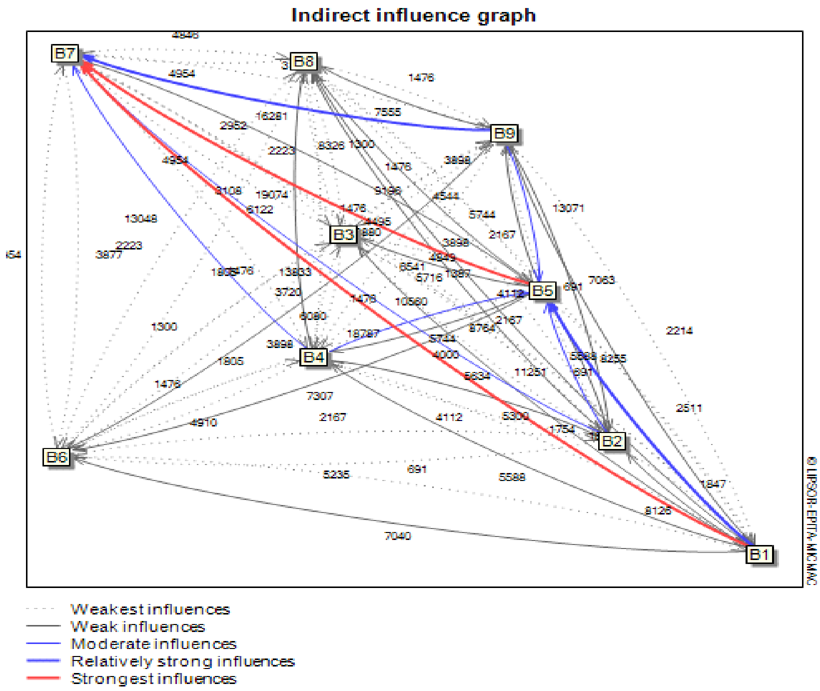


Figure 5. Indirect influence graph

4.3. Key and influencing factors

Independent factors, as the "main drivers" of the biomass supply chain, have high influence and low dependence:

- Transportation infrastructure (B1): Adequate infrastructure plays a vital role in reducing the costs and time associated with biomass transportation. A lack of proper infrastructure can lead to increased transportation costs, biomass degradation, and consequently, a decline in the economic attractiveness of the supply chain (Rentizelas et al., 2009). Road quality, rail networks, and efficient storage systems are all key factors in this area.
- Biomass processing technologies (B2): Access to advanced and efficient biomass processing technologies plays a significant role in improving efficiency and reducing the costs of converting biomass into energy and value-added products (Slade et al., 2011). Outdated technologies and a lack of access to the necessary technical knowledge can hinder the optimal use of biomass and the development of the supply chain.
- Demand for biofuels and renewable energy (B4): The presence of a market for biomass-based products provides the necessary incentive for investment and the development of the supply chain (Sims et al., 2007). A lack of demand or insufficient demand can lead to stagnation in the industry and hinder the growth of the supply chain. Demand for biofuels, renewable energy, and biomass-based chemical products is among the key determining factors in this regard.
- Integrated supply chain management (B9): Coordination and collaboration among all stakeholders in the supply chain, including farmers, processing units, transportation companies, and consumers, are essential for the efficiency and effectiveness of the supply chain (Chopra and Meindl, 2016). The absence of integrated management can lead to misalignment, delays, and increased costs within the supply chain.

4.4. Dependent factor (Environmental regulations)

Environmental regulations (B_7), as a dependent factor, are significantly influenced by other factors. This is due to the reliance of environmental regulations on supportive policies, the advancement of clean technologies, and public awareness about the importance of environmental preservation. In other words, unless independent factors such as biomass processing technologies advance towards reducing environmental pollution caused by biomass conversion processes, and government support provides the necessary incentives for compliance with environmental standards, effective enforcement of environmental regulations cannot be expected.

4.5. Linked factor (Government support)

Government support, as a linked factor, plays a crucial mediating role between independent and dependent factors. Incentive policies, subsidies, tax incentives, and government facilities can stimulate investment in biomass processing infrastructure and technologies, create demand for biomass products, and encourage integrated supply chain management. Additionally, government support can facilitate the effective enforcement of environmental regulations and mitigate the negative impacts of the supply chain on the environment. Thus, government support, acting as a catalyst, can accelerate and facilitate the development of the biomass supply chain (IEA, 2018).

Indeed, incentive policies, subsidies, tax incentives, and government facilities can reinforce or moderate the effects of independent variables. Government support, for instance, can contribute to the development of the supply chain by creating demand for biofuels and encouraging investment in biomass processing technologies. Furthermore, governments can promote the expansion of this industry through investments in transportation infrastructure and the provision of training facilities for farmers. On the other hand, a lack of governmental support or the improper implementation of relevant policies can negatively impact the whole supply chain.

4.6. The role of autonomous factors

Autonomous factors, due to their low dependence and influence, are relatively independent of the system. This could be for the following reasons :

- Access to water resources (B3): Although water is essential for cultivating biomass, in many regions of Iran, farmers have traditionally adapted themselves to limited water availability and tend to choose crops with lower water requirements. Therefore, changes in water accessibility may exert only a marginal influence on the choice of biomass type or its production volume.
- Training farmers (B6): Although training farmers to improve cultivation and biomass harvesting techniques is important, such training becomes significantly more effective when coupled with governmental support and access to advanced technologies. Otherwise, training by itself might not result in substantial improvements in farmers' performance. Moreover, empowering farmers in the areas of cultivation, harvesting, and proper biomass management is undoubtedly vital; however, its immediate impact on the entire supply chain is not readily noticeable. Training farmers should be viewed mainly as a long-term investment, with results that become evident gradually over time. Additionally, the effectiveness of such training depends on several other factors, including the availability of financial resources, suitable technologies, and access to marketing channels.
- International partnership (B8): Collaboration with leading countries in biomass technology and knowledge can facilitate the transfer of knowledge and modern technologies. Nonetheless, these partnerships are more effective when accompanied by careful and targeted planning that takes into account domestic conditions and needs. Otherwise, international collaborations might have a limited effect on the development of the biomass supply chain. On the other hand, international collaborations are usually carried out as limited and specific projects and do not have a broad effect on the entire

supply chain. Additionally, political and economic obstacles might hinder the full realization of the potential of these collaborations.

5. Discussion and conclusion

The analysis of the agricultural biomass supply chain in Iran revealed that certain factors exerted a disproportionately high influence on the system, highlighting structural priorities for policy and management interventions. Transportation infrastructure emerged as a key driver, consistent with findings from Blair et al. (2021) and Nunes et al., (2020), which emphasized that inadequate logistics networks significantly constrain biomass collection and distribution efficiency. This suggests that without targeted investment in road networks, storage facilities, and transport optimization, the potential of agricultural biomass cannot be fully realized.

Similarly, the role of biomass processing technologies proved critical. Advanced processing capabilities not only improve conversion efficiency but also reduce material loss, echoing prior studies by Raychaudhuri and Ghosh (2016) and Zandi et al., (2018). This indicates that technological modernization should be prioritized alongside infrastructure improvements, as they jointly determine the overall performance and sustainability of the supply chain.

Demand factors for biofuels and renewable energy were also identified as major influencers, demonstrating the interdependence between market pull and supply chain effectiveness. The importance of demand aligns with evidence from Lyu et al. (2024), which shows that even well-developed infrastructure and processing capacities cannot guarantee supply chain efficiency in the absence of stable and predictable market demand.

Integrated supply chain management emerged as a crucial mediating factor, reinforcing the need for coordination among farmers, processors, and government agencies. This finding aligns with Nugroho and Zhu (2024), who highlighted that fragmented operations and a lack of communication between actors lead to inefficiencies and underutilization of biomass resources.

Overall, the results suggest that the agricultural biomass supply chain in Iran is influenced by a combination of structural (infrastructure, technology), market (demand), and managerial (integration) factors. Compared to prior international studies, Iran's supply chain exhibits similar challenges to those reported in Asian and European contexts (Raychaudhuri and Ghosh, 2016), particularly regarding dispersed resources and logistical constraints, but is also uniquely affected by local institutional and policy frameworks. This underlines the need for a multi-faceted approach, integrating infrastructure development, technological upgrading, market creation, and institutional coordination to strengthen the supply chain's resilience and sustainability.

Analysis of the agricultural biomass supply chain in Iran indicated that demand for biofuels, transportation infrastructure, biomass processing technologies, and supply chain management are key drivers influencing overall performance. The lack of sustainable demand for biofuels remains a major barrier, consistent with findings from Blair et al. (2021) and Nunes et al. (2020), which emphasized the importance of stable market mechanisms. Experts suggested that targeted government interventions—such as green energy subsidies, tax incentives, and binding regulations for blending biofuels with fossil fuels—could strengthen market stability and encourage adoption.

Transportation inefficiencies and high logistics costs were identified as critical constraints, reflecting similar challenges noted by Raychaudhuri and Ghosh (2016) in both Asian and European contexts. Strategic investment in specialized biomass transport fleets, route optimization, and the development of local distribution networks was highlighted as a practical approach to enhance operational efficiency and reduce costs.

Advances in biomass processing technologies were found to have a significant impact on efficiency and waste reduction. Consistent with Lyu et al. (2024), experts recommended prioritizing R&D investment, localizing advanced technologies (e.g., gasification, anaerobic digestion), and fostering university-industry collaborations to develop context-appropriate innovations while lowering processing costs.

The integration of digital and intelligent supply chain management systems—such as AI-based demand forecasting, inventory management, and coordination platforms—was suggested as a means to optimize decision-making and increase responsiveness. Furthermore, the establishment of biomass industrial clusters and multi-stakeholder collaboration (farmers, industry, government) was emphasized to enhance coordination and system coherence.

Overall, experts concluded that improving Iran's agricultural biomass supply chain requires a comprehensive, multidimensional strategy. Recommended measures include developing supportive policies to stimulate demand, phased investment in infrastructure, targeted adoption of advanced processing technologies, and integrated management systems. Implementing these strategies is expected to enhance efficiency, reduce costs, and support sustainable development. Future research should examine the application of these strategies in other sectors beyond agriculture and evaluate long-term impacts on supply chain resilience and environmental performance.

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Disclosure statement

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

References

Arabi, S.H., Maleki, M.H. and Ansari, H., 2022. Identifying and Analyzing Influencing Drivers on the Future of Income Resources of Social Security Organization. Program and Development Research, 3(3), pp.73-106. 10.22034/pbr.2023.360877.1266 [in Persian].

Bastos, T., Teixeira, L. and Nunes, L.J., 2025. Digitalization of the residual biomass supply chain: A sustainable analysis of the current state using a hybrid model approach. Energy Sources, Part B: Economics, Planning, and Policy, 20(1), p.2572086. https://doi.org/10.1080/15567249.2025.2572086

Benti, N.E., Gurmesa, G.S., Argaw, T., Aneseyee, A.B., Gunta, S., Kassahun, G.B., Aga, G.S. and Asfaw, A.A., 2021. The current status, challenges and prospects of using biomass energy in Ethiopia. Biotechnology for Biofuels, 14(1), p.209. https://doi.org/10.1186/s13068-021-02060-3.

Blair, M.J., Gagnon, B., Klain, A. and Kulišić, B., 2021. Contribution of biomass supply chains for bioenergy to sustainable development goals. Land, 10(2), p.181. https://doi.org/10.3390/land10020181.

Chen, A. and Liu, Y., 2023. Designing globalized robust supply chain network for sustainable biomass-based power generation problem. Journal of Cleaner Production, 413, p.137403. https://doi.org/10.1016/j.jclepro.2023.137403.

Chidozie, B.C., Ramos, A.L., Ferreira, J.V. and Ferreira, L.P., 2023. Residual agroforestry biomass supply chain simulation insights and directions: A systematic literature review. Sustainability, 15(13), p.9992. 10.3390/su15139992

Chopra, S., & Meindl, P., 2016. Supply chain management: Strategy, planning, and operation. Pearson Education.

Ghasemi, A. R., Amani, M., Rajabzadeh Qatari, A., and Azar, A., 2019. A Study of Waste Biomass Supply Chain by Using Fuzzy Cognitive Maps. Strategy, 28(2), pp. 197-224. https://dor.isc.ac/dor/20.1001.1.10283102.1398.28.2.8.1. [in Persian].

Hiloidhari, M., Sharno, M.A., Baruah, D.C. and Bezbaruah, A.N., 2023. Green and sustainable biomass supply chain for environmental, social and economic benefits. Biomass and Bioenergy, 175, p.106893. https://doi.org/10.3390/su15139992.

IEA., 2018. Renewable energy: A key climate solution. International Energy Agency. Available at: https://www.iea.org/reports/renewables-2018.

Javadi, B. and Manafi, L., 2024. The sustainable biofuel supply chain optimization with considering pricing under uncertainty. Iranian Journal of Biosystems Engineering, 55(2), pp.185-206. https://doi.org/10.22059/ijbse.2024.375626.665546. . [in Persian].

Kalak, T T., 2023. Potential use of industrial biomass waste as a sustainable energy source in the future. Energies, 16(4), p.1783. https://doi.org/10.3390/en16041783.

Kazemi Alamoti, I, 2022. Assessment of Biomass Resources Potential for Bioenergy Production (Case study: Alamut region of Qazvin province). Journal of Biosystems Engineering. 2(11), pp.37-48. https://sanad.iau.ir/en/Journal/jbse/Article/952098/FullText.

Kibria, M.G., Paul, U.K., Hasan, A., Mohtasim, M.S., Das, B.K. and Mourshed, M., 2024. Current prospects and challenges for biomass energy conversion in Bangladesh: Attaining sustainable development goals. Biomass and Bioenergy, 183, p.107139. https://doi.org/10.1016/j.biombioe.2024.107139.

Kumar Sarangi, , P., Subudhi, S., Bhatia, L., Saha, K., Mudgil, D., Prasad Shadangi, K., Srivastava, R.K., Pattnaik, B. and Arya, R.K., 2023. Utilization of agricultural waste biomass and recycling toward circular bioeconomy. Environmental Science and Pollution Research, 30(4), pp.8526-8539. https://doi.org/10.1007/s11356-022-20669-1.

Kumar, J.A., Sathish, S., Prabu, D., Renita, A.A., Saravanan, A., Deivayanai, V.C., Anish, M., Jayaprabakar, J., Baigenzhenov, O. and Hosseini-Bandegharaei, A., 2023. Agricultural waste biomass for sustainable bioenergy production: Feedstock, characterization and pre-treatment methodologies. Chemosphere, 331, p.138680. https://doi.org/10.1016/j.chemosphere.2023.138680.

Lyu, R., Arisian, S., Li, Z., Taskhiri, M.S. and Mavi, R.K., 2024. The role of agricultural biomass in supply chain decarbonization. Annals of Operations Research, pp.1-39. https://doi.org/10.1007/s10479-024-05979-6.

Martínez-Valencia, L., Valle, J.A., Jessup, E., Galarza, M.P., Chejne-Janna, F. and Garcia-Perez, M., 2025. Biomass resources and supply chains. In Thermochemical Conversion of Lignocellulosic Materials (pp. 33-72). Elsevier. https://doi.org/10.1016/B978-0-323-95551-5.00002-2

Mujtaba, M., Fraceto, L.F., Fazeli, M., Mukherjee, S., Savassa, S.M., de Medeiros, G.A., Santo Pereira, A.D.E., Mancini, S.D., Lipponen, J. and Vilaplana, F., 2023. Lignocellulosic biomass from agricultural waste to the circular economy: a review with focus on biofuels, biocomposites and bioplastics. Journal of cleaner production, 402, p.136815. https://doi.org/10.1016/j.jclepro.2023.136815.

Nasrollahi, M., Hakimiasl, M., Hakimiasl, A. and Keramati, A., 2017. Provide an integrated mathematical planning model for selecting and allocating orders for biomass power plant green suppliers. Journal of Quality Engineering and Management, 7(1), pp.1-15. 20.1001.1.23221305.1396.7.1.1.6. [in Persian].

Nguyen , T.K.C. and Toan, N.Q., 2024. Developing biomass energy from agricultural by-products in the context of trade development. Energy Strategy Reviews, 54, p.101417. https://doi.org/10.1016/j.esr.2024.101417.

Nugroho, Y. K., and Zhu, L. (2024). Strategic supply and transportation planning of a supply chain for agricultural biomass to hydrogen and syngas. Computers & Industrial Engineering, 197, 110640. https://doi.org/10.1016/j.cie.2023.110640

Nunes, L. J. R., Causer, T. P., & Ciolkosz, D. (2020). Biomass for energy: A review on supply chain management models. Renewable and Sustainable Energy Reviews, 120, 109658. https://doi.org/10.1016/j.rser.2019.109658

Pourelmi, T., Shobeiri, S. M., Yazdanpanah, E., Bakhshi Khaniki, G. R., & Rezaei, M. (2023). Designing a Policy-Making Model for Biomass Energy Development Training in the Agricultural Supply Chain Sector. Discrete Dynamics in Nature and Society, 2023(1), 8463522. 10.1155/2023/8463522

Raychaudhuri, A., & Ghosh, S. K. (2016). Biomass supply chain in Asian and European countries. Procedia Environmental Sciences, 35, 914–924. https://doi.org/10.1016/j.proenv.2016.07.091

Rentizelas, A.A., Tolis, A.J. and Tatsiopoulos, I.P., 2009. Logistics issues of biomass: The storage problem and the multi-biomass supply chain. Renewable and sustainable energy reviews, 13(4), pp.887-894. https://doi.org/10.1016/j.rser.2008.01.003.

Sahebi Shaham Abadi , H. and Naseri Taheri, V., 2024. Optimization of Biofuel Supply Chain Operations Based on the Second Generation of Biomass In an Environment of Uncertainty And Considering Water and Energy Nexus: a Case Study of Iran. Quarterly Energy Economics Review, 20(82), pp.81-115. URL: http://iiesj.ir/article-1-1626-en.html. URL: http://iiesj.ir/article-1-1626-en.html [in Persian].

Saleem, M., 2022. Possibility of utilizing agriculture biomass as a renewable and sustainable future energy source. Heliyon, 8(2). URL: https://www.cell.com/heliyon/fulltext/S2405-8440(22)00193-1.

Sims, R.E., Mabee, W., Saddler, J.N. and Taylor, M., 2010. An overview of second generation biofuel technologies. Bioresource technology, 101(6), pp.1570-1580. https://doi.org/10.1016/j.biortech.2009.11.046.

Slade, R., Bauen, A., and Shah, N., 2011. The role of biofuels in the transition to a low carbon economy. Biomass and Bioenergy, 35(8), pp.2887-2902. https://doi.org/10.1016/j.biombioe.2011.05.030

Umakanth, A.V., Datta, A., Reddy, B.S. and Bardhan, S., 2022. Biomass feedstocks for advanced biofuels: sustainability and supply chain management. Advanced biofuel technologies, pp.39-72. https://doi.org/10.1016/B978-0-323-88427-3.00023-4.

Wu, J., Zhang, J., Yi, W., Cai, H., Li, Y. and Su, Z., 2022. Agri-biomass supply chain optimization in north China: Model development and application. Energy, 239, p.122374. https://doi.org/10.1016/j.energy.2021.122374.

Zadorozhnyi, Z.M., Muravskyi, V., Bila, Y. and Ivasechko, U., 2023. Innovative management of biomass cost value based on accounting and analysis of production costs of agricultural activities. Marketing i menedžment innovacij, 14(4), pp.99-111. https://doi.org/10.21272/mmi.2023.4-07.

Zandi Atashbar, N., Labadie, N. and Prins, C., 2018. Modelling and optimisation of biomass supply chains: a review. International Journal of Production Research, 56(10), pp.3482-3506. https://doi.org/10.1080/00207543.2017.1343506.

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Systematic Analysis of Medication Errors in an Indian Context Using the Swiss Cheese Model

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ABSTRACT

In the past two decades, medication errors have grown in India. During recent times, the work on medication error in the Indian context, focusing on the Swiss cheese model, is limited. Medication error interventions should be explored using the systems thinking approach. The systems thinking approach might help us to understand its necessity as a precautionary and preventive measure for medication errors. To perform a systematic analysis of medication error in the Indian healthcare setting using the Swiss-cheese Model. To understand the holistic thought in the medication errors system, systems thinking is used. We analyzed the outcomes of the system mapping with the help of the Swiss cheese model. The current work is made with the latest paper on medication errors from an Indian perspective. Common errors address interconnections and dependencies of medication errors from the systems perspective in the phases of medication errors. The results highlight the importance of the Swiss cheese model in the prevention of medication errors. Before the implementation of the causal loop diagram, consideration of the layer model of the Swiss cheese model was certainly implemented. By applying the Swiss cheese model, the study demonstrates the criticality of multiple system layers where errors can occur. The dynamic behavior of the medication error system is understood with the cluster diagram and causal loop diagram. Medication error rate and medication error capacity are critical factors in system behavior. The Swiss-cheese model predicts the critical factors of the system's behavior and provides preventive and precautionary measures in detail. The understanding of these attributes helps in the identification of medication errors in the healthcare system. Cross-functional findings of the theories, models, and principles of the medication error systems thinking can be utilized for understanding the holistic view.

Keywords

Medication error, Swiss cheese model, Systems Thinking, Causal loop diagram.

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1. Introduction

An unchanging theme of the patient-centered care approach is emerging in the healthcare systems. In an applied healthcare setting, the focus on medical error management has intensified, due to the prevalence of medical errors causing deaths, and rising cases of misdiagnosis (Keebler et al., 2022). Medication errors can be defined and characterized as the prescribing (dosage and measurement of dosage), supply, product labeling, administration, and education (Chanakit, 2013; Cohen, 2007). These errors could be linked to medication mismanagement and confusion arising from medicine naming and labelling (Brunetti and Suh, 2012). Furthermore, these prescription errors can be categorized into two diverse forms: delivered drug, which is administered to the patient, and an intended drug, which is related to the prescriber's decision (Basco et al., 2016). This categorization becomes vital in high-risk populations like the elderly, who need assistance in critical care and are more vulnerable to medication errors.

Different models and approaches have been proposed to address healthcare error-related issues. These models could be categorized as either linear or causal, based on their underlying framework. This framework defines how the underlying variables and factors interact with each other and lead to the outcomes. The systems thinking, non-linear approach provides a lens to reframe the conversations of seeing the "whole" system, not "silos" in isolation. The designers face a major challenge in changes in the system dynamics models of errors and management in real-time events (Clarkson et al., 2004; Wieman and Wieman, 2004). This approach plays a vital role in identifying vulnerabilities, particularly those arising at various levels like prescribing, dispensing, and administration (Bhowmick et al., 2020). The whole central tenet of systems thinking involves causal diagramming and policy-oriented computer simulation models (Homer and Hirsch, 2006). Despite its effectiveness, this approach has been underutilized in Indian medication industry, where anesthesia-related major concerning errors have been reported (Dave et al., 2022). Therefore, integrating systems thinking in healthcare is important for medication error flows, such as medicine naming, labeling, and other details.

System dynamics approach can further deepen insight into medication errors by uncovering the underlying causes of the errors. It enables designers to visualize and address the specific vulnerabilities, such as look-alike and sound-alike (LASA) errors, by identifying their antecedents and mapping their flow in the healthcare system.

On the contrary, the Swiss Cheese Model (SCM) is a way where the thinking and process are inappropriate for the context or issue explored (Chuang et al., 2008). Various systems thinking tools are used to understand the occurrences of the problems of likely and unlikely events in the medical error realm (Anderson and Johnson, 1997). Medication error in the Indian context is justified with confusion related to the naming of medicines. Medication errors due to look-alike and sound-alike (LASA) medicines are very common in medicine (Johnson et al., 2020). SCM plays a crucial role in eliminating label comprehension-related errors (Hussein, 2018). The labeling and design of the labels play a vital role in the communication of information to the patients, including the dosage, direction, and precautions. Any medication lapses in the medical scenario can cause an Adverse Drug Event (ADE), which apparently leads to a medical error. The vulnerabilities in the medical labeling system and the errors caused by various factors can be interlinked with the cause-and-effect relationship between the factors (Reason, 1990). Some medical errors are inevitable, even if the medical ecosystem is performed with validation and perfection (Spath, 2011). Adopting the systems thinking approach in medication errors improves patient safety (Fialová and Onder, 2009).

The occurrence of medication errors is directly proportional to the quantity of information present on the labels (Law and Zargarzadeh, 2010). The LASA name pair list is used to inform healthcare professionals about the high probability of occurrences of medication errors (Cohen, 2007; Wong, 2016). Medication errors can be defined and characterized as the prescribing (dosage and measurement of dosage), supply, product labeling, administration, and education (Chanakit, 2013; Cohen, 2007). The systems thinking approach can further help in identifying the causal factors leading to LASA errors and design solutions to address the underlying system vulnerabilities (Schnoor et al., 2015). The elements of the SCM consist of 5 layers of failure. These layers are explained in detail in Figure 1.

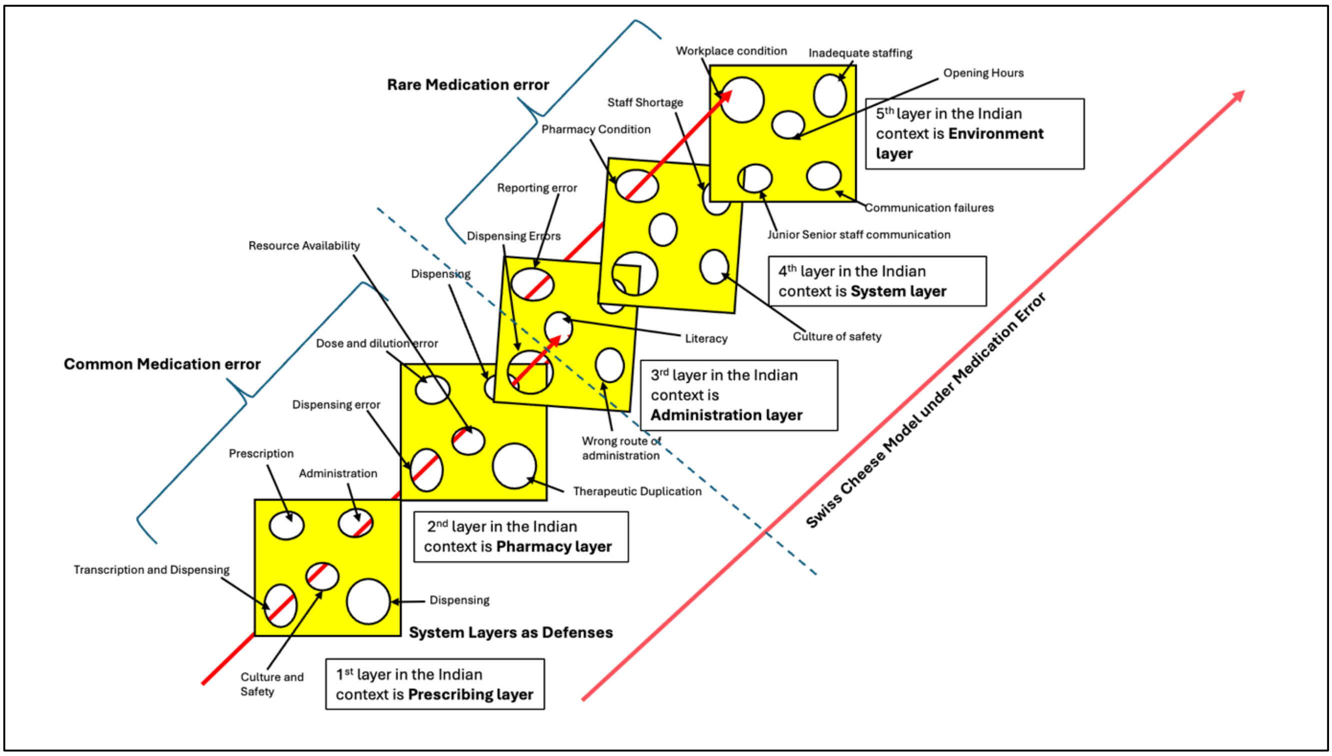

Figure 1. Case-specific demonstration of the swiss cheese model of medication error. Adopted from Reason's swiss cheese model, published in 2000

The critical information about the medicine is communicated through the prescription labels, such as medication name, dosage, directions, and precautions (Davis et al., 2006) (Institute of Medicine, 2007). Comprehending the drug indication using labeling design also involves the medicine container and the user approach in the usage of the reason for use (RFU) (Hussein, 2018). The RFU remains on the label for the entire treatment of the patients. The treatments totally depend on the type of usage during the intake of medicines. Therefore, it shows the limitations in the amount of information deployed for the services by the healthcare givers to avoid medication errors and ensure safe medication use (Institute of Medicine, 2007).

Despite the efforts of labeling the medication details, many independent or dependent older population faces label comprehension-related challenges (Szczepura et al., 2011). In the Indian context, related studies have revealed that only one in eight patients correctly comprehend medication-related information (Persell et al., 2004). Similarly, other Indian studies highlighted the alarming situation that the patient's perception of medical prescriptions is dependent on the healthcare giver's knowledge (Roy et al., 2020).

Systems thinking and causal loop diagrams are quite familiar in the healthcare domain. From an application perspective, the causal loop diagram is utilized as an effective tool in the systems thinking approach. The Swiss cheese model has proven to be appropriate for both low-and middle-income countries (Dubb et al., 2022). To be impactful, systems thinking must be planned and implemented based on fields such as quality improvement, implementation science, and operational research (Tetuan et al., 2017). The need for the systems approach is highlighted when the medication error is analyzed from the linear approach, such as root cause analysis (Peerally et al., 2017). In comparison to the systems thinking tools in the Indian context, the Swiss cheese model is quite appropriate for the system thinker to encapsulate the medication error problems.

Complementing these system-based approaches are principles from Human Factors and Engineering (HFE) and work system design. These designs interlink macro-ergonomics and sociotechnical system design to build a more resilient healthcare environment. Furthermore, the patient and healthcare interaction could be enhanced using these effective system interventions (Carayon, 2012).

Central to the development of Human Factors and Engineering (HFE) are three major factors 1) Joint design, 2) Humanized task approach, and 3) Organization's socio-technical characteristics (Carayon, 2012). Joint design refers to the amalgamation of personnel subsystems as well as the technological subsystems to generate a human-centered approach in medical system design. For the development of the design process, joint design criteria will enable an inclusive employee participation (Leape, 1997). Humanized task approach refers to the initiation of a functional model that demands a function and task allocation process. This process checks whether there is a necessity in the presence of a human to perform such a task. Unlike the joint design approach, here exists a system consideration of professional requirements and cultural psychosocial characteristics of the personnel subsystem (Carayon, 2012). Organization's sociotechnical characteristics refer to the integration of culture into the work system design (Carayon, 2012).

In view of the above deliberations, the present article explores a comparison between SCM and non-linear approaches to address medicine-related errors in the Indian context. Additionally, the paper incorporates Human Factors Engineering to evaluate how each framework responds to vulnerabilities related to labeling design, Reason for Use (RFU) integration, and Look-Alike Sound-Alike (LASA) drug errors (Hussein, 2018). Overall, the current paper intends to perform a systematic analysis of medication error in an Indian context using the Swiss-Cheese model, which may highlight some context-specific strategies.

2. Medication and medication error

A system can be understood as a pattern of interconnections between processes and elements.

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The Institute of Safe Medication Practice (ISMP) has defined 10 key system elements that significantly influence medicine use (Cohen, 2007). Therefore, it is important to approach patient information from a systems perspective (Cohen, 2007). According to the ISMP, some important variables in systems thinking are patient information, communication, drug names, labels, and packages. Among these variables, labeling plays a vital role in communication through RFU, which is a significant contributor to the proper medical care (Hussein, 2018). The systems thinking approach highlights the application of RFU depending on various interconnected factors.

The elderly population, whether dependent or independent, experiences several health-related challenges requiring multiple medications. This highlights the necessity of redesigning the healthcare delivery system that substantially provides the essence of the right information on a global scale (Crane and Crane, 2006; Vernaz, et al., 2020). The complex system interventions require various stakeholders and system variables to play a role in the context of medication errors and drug replacement. The agents are mentioned as people who have diverse roles in the complex environment, like the outpatients in the older population in Indian settings. The agent, involved in the subsystem and system within the environment, requires a patient-centered approach. Redesigning this system will require aligning communication with its meaningful interpretation.

Traditional cause-and-effect diagrams suggest that the complexity of the system has increased over time (Underwood and Waterson, 2014). The analysis of medication errors by the Swiss Cheese Model (SCM) is widely used in healthcare (Underwood and Waterson, 2014). SCM consists of defensive layers to prevent the medical hazard (Guise and Mladenovic, 2013). This model is criticized as simplified method of understanding errors (Dekker, 2007). Therefore, in order to study the fallible decisions created by the designers at a decision-making level, system design approaches should be implemented.

This model has a linear approach, which restricts the system thinkers from applying the interrelations between the model for a better understanding (Samaranayake and Cheung, 2013). The defensive layers in this specific model are elementary and implicit for the slices and holes (as shown in Figure 1) (Reason, 2000). The Institute of Medicine (IOM) has articulated a drawback of the SCM, that it demands a halt to the occurrence of medication errors due to the holes in the system lineup (Guise and Mladenovic, 2013). Unlike systems thinking, which explains the role of culture, policies, and other individual components of the healthcare environment, SCM struggles to explain these factors. Medication errors are layer-wise in nature. In order to resolve the complex medication error, an SCM approach is required (Banja, 2004).

Error propagation in the healthcare domain is constantly changing and dynamic in nature. The healthcare industry needs a few trained system interventions to help in understanding the patient-physician interactions (Oxman, 2023).

3. Indian context

Over the past 25 years, Indian research has highlighted three key fundamentals covering medicinal errors: communication skills, communication effectiveness, and error reduction. Through word frequency analysis in published studies, it illuminates factors leading to communication-related errors. These include poor supervision (Rani, 2020) attitudes and beliefs (Gautam, 2013), and issues related to labeling (Vaidya and Joshi, 2023) (see figure 2).

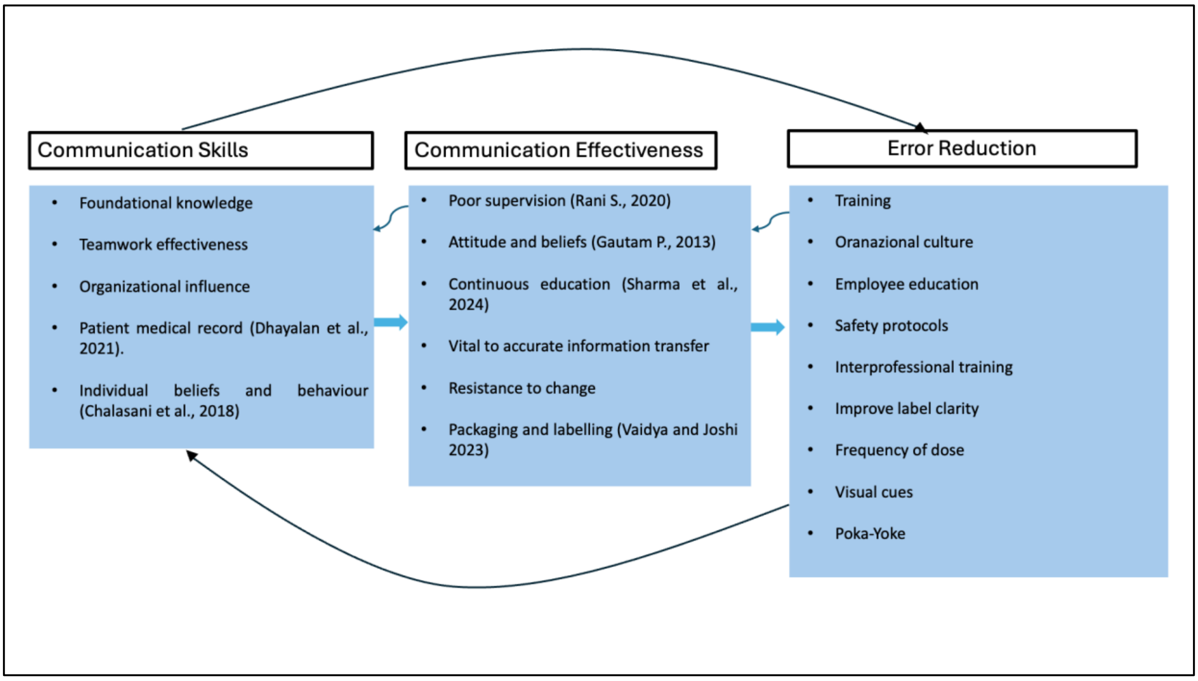

Figure 2. The interaction of the three major headings found in the word cloud of the frequency of keywords in papers

The healthcare in the Indian context takes a system-oriented approach by emphasizing the system failure rather than the human. The Quality Improvement (QI) of healthcare needs to consider the People, System, Design, and Risk (PSDR) approach to study the medication error problem from a systems thinking lens (Chada, 2022). The system evaluation requires the evaluation of skills, culture, and safety management. The sharp end in the Swiss cheese model helps in reducing the risk proactively (Cross, 2018). The Indian medical system needs to educate the healthcare professionals and patients to curb medication errors (Sharma et al., 2016).

4. Research methodology

Several systems thinking tools are available in medication error analysis. In this article, we are using the Setting, Plan, Impact, Critical event, Decision (SPICE) methodology to mark the research gaps and system lacunas. Setting- Medication errors are reported in the Indian scenario using tools such as Medication Error Reporting Program, MEDMARX, Drug-Drug Interaction Program, such as Drug Interaction Checker for Prescription (DICP) (Kulkarni et al., 2013; Zirpe et al., 2020). Plan- Digitalization efforts to check the medication errors, but the problem persists in the medication system. To address the complex problem, a mixed approach of systems thinking tools is used. These tools are the Swiss cheese model and the causal loop diagram. Impact-For the right impact, focusing on the linear approach and layered approach, such as the Swiss cheese model, is needed (Karmakar and Das, 2025). A causal loop diagram addresses the complex recurring nature of the medication error. Critical- The medication error propagation and patient harm are critical areas of Intervention. Decision- For decision-making, the layered approach of the Swiss cheese model is utilized, which addresses the holes and problems at the layer level and later propagates to the system level and causes patient harm in the end.

4.1. Fragments of SCM

Introduction to the SCM for medication errors in the Indian context is important because of the various communication factors, such as prescribing, pharmacy, administration, system, and environment. The SCM perspective of medication error in the Indian context is important because of the causal factors. Hence, emphasis should be placed on understanding the application of systems thinking in the healthcare system of primary caregivers (Rodziewicz et al., 2024). Investigating the contributing factors of patient safety and medication error is important. These factors are environment, workplace, visual design of labeling, and medication error rate (Guise and Mladenovic, 2013). These factors are connected to the SCM of medication error. The factors of medication errors are environment, workplace, visual design, and medication error under the head of communication skills, communication effectiveness, and error reduction.

This common repetitive pattern emerged from the problem (Monat and Gannon, 2023). Such issues include error prevention, mitigating adverse effects, information on the label, and cognitive load (Nolan, 2000). A systems-level approach provides valuable insights towards understanding multi-faceted healthcare factors in medication errors (Maidment et al., 2006). Better health at low cost can be achieved with systems knowledge in healthcare (National Academies of Sciences, Engineering, and Medicine [U.S.], 2018). The categorization of medication errors with respect to system behaviors is dynamic and constantly changing (Anderson and Webster, 2001). According to the Institute of Medicine (IOM) report 2016, safety programs are being launched to prevent and mitigate adverse drug effects (Johnson et al., 2020). SCM is not enough to answer the medication error factors and interrelationships of the causes and effects of the medication factors (Buist and Middleton, 2016). The barriers that exist in the SCM model are not random. The holes and layers in the SCM model for medication error are dependent on the Indian context of medical practitioners. Medical practitioners in the Indian context are facing the challenges of communication. These factors are interconnected and must be addressed by systems thinking (Kohn et al., 2000). The SCM model limitations can be explained by limitations when applied to medication error and the healthcare system. SCM is a relatively simplistic approach that fails to adequately capture the complex interrelation between the individual and the hospital system (Buist and Middleton, 2016).

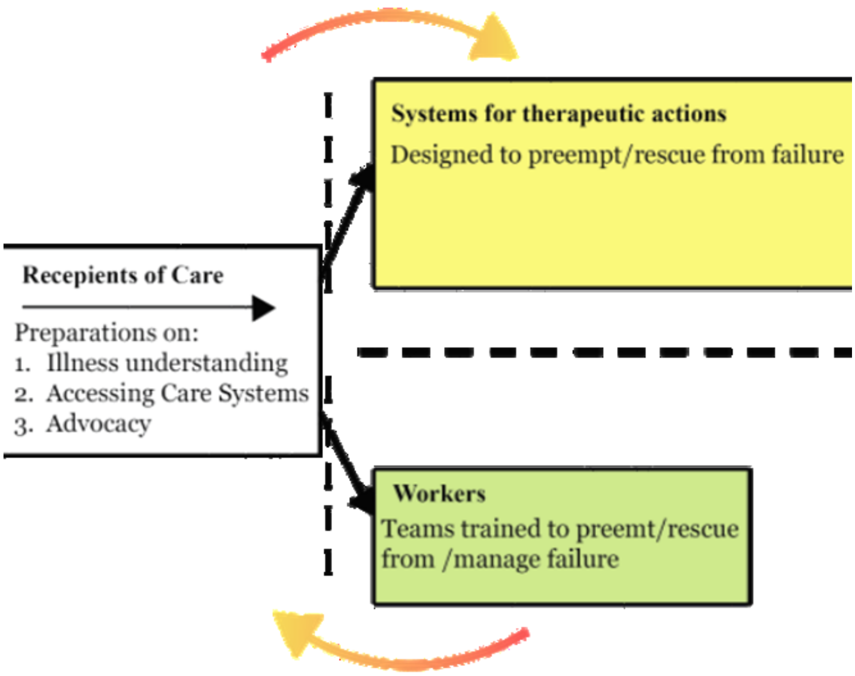

Figure 3. Adopted from the patient safety system model (Johnson et al., 2020)

The model consists of feedback loops to monitor performance. The patient safety model explains the interactive elements, such as Patients (the recipients of care) and healthcare

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workers (the primary caregivers) (Johnson and Anderson, 2017). The dotted line represents the permeability between the patient safety system (see figure 3) and the stakeholders. Continuous quality improvement (CQI) in healthcare connects the patients, plant, processes, and policy to facilitate safer healthcare (Johnson et al., 2020). These interlinks help to understand patient safety as a system (Johnson and Anderson, 2017). Workers such as the high-functioning teams with adequate knowledge of medication, healthcare, and technology need to understand the non-technical competencies such as care, empathy, and inclusivity.

4.2. SCM Layers

The SCM in the medication error of the healthcare system, where the medication error of look-alike and sound-alike names is the reservoir of the problem (Koelling and Schwandt, 2005). The observation of medication error from a system's perspective gives the behavior of the system over time. Layers in SCM, medication error failures, socio-technical factors, and adaptation over time are studied by a layered analysis of error prevention (Leveson, 2004).

SCM is useful in the analysis of design problems where interrelationships between causal factors are required. The interrelationship between the causal factors of the medication error system needs a holistic understanding from a systems perspective.

4.3. SCM and medication error

Medication error systems go beyond the organizations and create their own characteristics overall time (Kapp et al., 2017). The system may collapse due to the following medication error factors of look-alike and sound-alike medicine names. Therefore, the system interventions in the area of medication errors are relevant (Isherwood and Waterson, 2021). The results identified by the SCM can be better analyzed using the system dynamics.

The exponential decay observed here is a common occurrence in various fields, such as population dynamics and radioactive decay. Here, the pattern of the behavior of the Medication error capacity shows the characteristic pattern of rapid initial decline followed by a slowing rate of change. The logarithmic curve reveals the constant decline rate, which is important for understanding the hidden pattern of system behavior. This metric indicates the system's resilience and can become informative in the analysis of the complex, time-dependent phenomena (Badiru and Ijaduola, 2009).

Explanation of factors in SCM starts with education on medication errors. In India, this is crucial in the field of medication error. The application of medication errors is in the label design of the medicine, the medical education cost on patient safety, quality of care, and healthcare costs. Medical education in the causal loop diagram can help in the causality of the medication label information. The foundational knowledge of medical anatomy, physiology, and product inspection can be studied using the cluster diagram from an educational perspective, as shown in SCM, which helps the designers analyze the holes in the system and how they align with the weaknesses in the system. Medication errors occur at multiple levels, which is highlighted in the SCM of the medication errors. These defenses, as layers, act as systems, and holes represent the weaknesses.

In the education domain of medication, errors are foundational knowledge, skill development, and competency. Cultural competence, teamwork, communication, and patient education are important for medication errors from the medication perspective. Simulation of medication errors is concerned with the training and education of the nursing staff.

4.4. SCM and holes

In the Indian context, the medicine used depends on the infrastructure, hospital and pharmaceutical infrastructure, medical label, and skills of the healthcare workers.

Culture plays a competent role compared to medical education in label design. The medical knowledge of the error possibility in the label design propagates with errors in the medication error system.

Strategically, the system-level interventions of the Swiss cheese model consist of communication skills, communication effectiveness, and error reduction in the SCM model of the medication error from an Indian perspective.

SCM and layer-wise attributes can be broken into the model's function, task, and description. The functional aspects of the system include risk management, Error prevention, and Quality improvement (Correia et al., 2023).

4.5. The system

SCM and application to the Medication error requires the development of a new approach in SCM for the medication error (Keating et al., 2021).

1. Using systems thinking to provide layer-wise analysis of the medication error and error propagation. The first layer consists of the holes that explain and represent the error related to the transcription, culture, prescription, dispensing, and administration (see figure 2). As illustrated by Sameera et al. (2021), the fundamental issues of the medication error from

the SCM perspective are errors related to transcription, culture, prescription, dispensing, and administration.

2. The second layer of SCM, which is the pharmacy layer, comprises the medication errors related to the employees in the pharmacy. These medication errors arise from the latent and active errors (Sameera et al., 2021). These active errors are changing as per the Indian context, which is the second layer. In the Indian context, the pharmacy layer is the biggest source of medication error related to communication-related errors. In such scenarios, dispensing errors, duplication, dose-dilution errors, and communication errors occur.
3. The next layer explains that the SCM errors arise due to the following causes: communication, inadequate staffing, defective equipment, and reporting literacy of the pharmacy professional involved (Alharbi et al., 2018; Tariq et al., 2024).
4. The subsequent layers, i.e., the third layer, represent the healthcare organizations and medication management errors from the administration level. Elaborately, these errors reduce the quality of care, increasing the risk of patient harm and poor reporting systems. Drug labeling, shortage of storage facilities, and lack of medical education are factors in this layer (Sewal et al., 2014).
5. The system layer and its failure occur due to uneven distribution of healthcare facilities, pharmacy infrastructure lacking in resources, untrained pharmacies, unmet quality standards, and medication handling (Mitra and Basu, 2020).
6. The environmental layer in SCM for Indian medication error stands for the noise, interruptions in the pharmacy, poor pharmacy reporting system, language barriers, and hierarchy of reporting in the medication error reporting system (Mitra and Basu, 2020), see Table 1.

Table 1. Perspective on indian medication error table on the Swiss cheese model and system dynamics in relation to medication errors

Characteristic	Swiss Cheese Model	Systems Thinking
Focus	Identification of system-level defenses and their weakness.	Understanding the complex, dynamic, and interconnected factors that contribute to medication errors.
Strength	Proposes a clear and intuitive framework for understanding error causation.	SD provides a clear and intuitive framework for understanding error causation.
Limitation	Simplify the complexity of the problem.	Challenging in terms of implementation due to the need for in-depth analysis and stock and flow modeling.
Application	Identification of multiple factors that lead to patient harm, medication errors, and holes in each layer.	Medication arises from interactions between various system components and elements such as communication, environment, policies, and human factors.
Key components	Organizational influence on the medication system and problems and errors in the form of holes. Unsafe supervision, unsafe acts and and organizational influence.	Stocks (medication errors), Flows(medication error rate), and feedback loops (e.g., monitoring and adjustment).

5. Results

5.1. System dynamics

The findings focus on the need for identification of the healthcare system factors of the look-alike labeling and naming medicines (To Err Is Human: Building a Safer Health System, 2000). These factors emphasize the identification of system factors from individual factors. Medication errors with confusing drug names (LASA) are caused by the weak medical system design and human error-related factors (Billstein-Leber et al., 2018; Cohen, 2017). Systems thinking helps to understand the healthcare system and medication errors in a more holistic manner (Kapp et al., 2017). These systems go beyond the organizations; they have their own characteristics over time (Kapp et al., 2017). Therefore, the system interventions in the area of medication errors are relevant (Isherwood and Waterson, 2021).

The results identified by the SCM can be better analyzed using the system dynamics. The results are enriched with the system dynamics. Healthcare organizations can better analyze the interrelated factors related to medication errors (Zanker et al., 2021).

5.2. Causal loop diagram

Causal loop diagrams are among the most used and valuable health research methods (Uleman et al., 2021). In the center of the causal loop diagram (CLD) lie the nodes and connections (Barbrook-Johnson and Penn, 2022). The positive connections show one factor increasing with another factor, a reinforced loop. Causal loop diagrams are the precursors to the system dynamics models, for example, stock and flow diagrams. To understand and classify causal factors linked to medication errors, product managers and designers should understand system dynamics. System changes can be defined and predicted by CLD (see Figure 4).

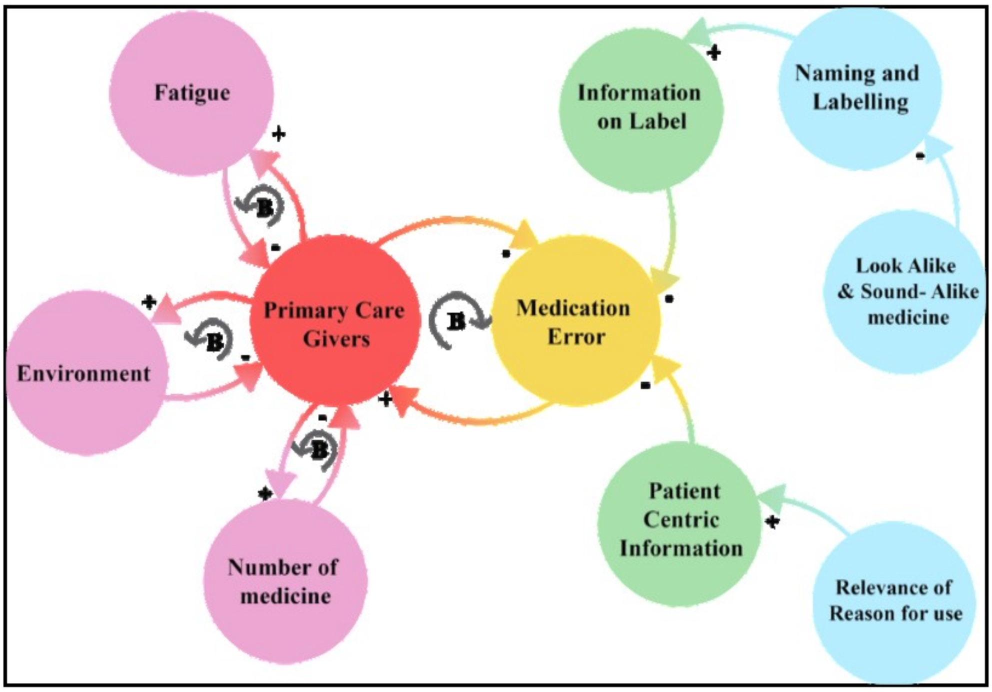

Figure 4. Causal loop diagram for medication errors (B Balancing loop)

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Avoiding blaming individuals for adverse events and medication errors simplifies the system factors (Smetzer et al., 2010). Hence, while designing a new system for the medication application, it is important to consider the SD and SCM recommendations on medication errors. The existing products should incorporate the system dynamics recommendations for better medication error reporting. System dynamics and the SCM can be applied in the error-monitoring techniques for the quality improvement of existing healthcare systems (Barker, 1995). Exploring the mental model provides details on medication errors. The mental modeling represents the cognitive detailing of the medication error (McDowell et al., 2009). Systems thinking is the foundation of the medical system world.

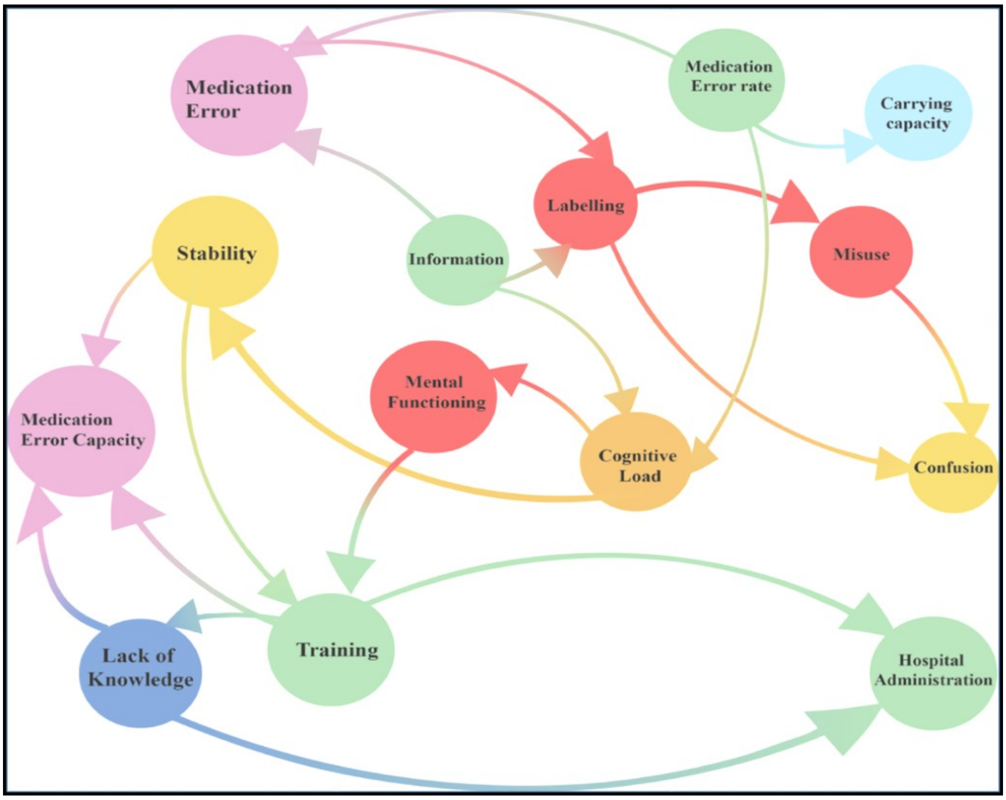

Figure 5. *Cluster diagram*

Such outcomes could help designers deliver the right amount of information on the labeling. System dynamics certainly aids product managers in understanding and identifying medication error patterns. The model shall help in predicting meaningful steps to better understand and curb medication errors.

The CLD illustrated in Figure 4 shows two clusters: the primary caregivers and medication errors. The primary caregivers' challenges are of the human factors, such as fatigue, environment, and the number of medicines to be given to the patient. On the contrary, the medication error cluster has information on the label that shows the negative (inverse) relationship with the medication error. The patient-centric information also shows a negative relation with medication error, meaning the better the patient-centric information, the less the medication error (see Figure 4). Four reinforced loops exist in the CLD. Loop 1, which is between the fatigue and primary care givers, has a negative relationship with each other (balancing loop). Loop 2 is between the environment and primary caregivers, which shows that they have a negative relationship with each other (balancing loop). Loop 3 between the number of medicines and primary caregivers, which is balancing in nature.

The Second cluster of the causal loop diagram shows a negative relationship with the first cluster of the primary caregivers (balancing loop). Within the second cluster, important factors such as information on the label and patient-centric information have a negative relationship with each other (balancing loop). On the contrary, the naming and labeling hold a positive relationship, because the more the naming and labeling, the more information is on the medicine label.

The process of creating the CLD diagram starts with defining the cluster diagram. The cluster diagram helps in revealing similar groups (see Figure 5). A cluster diagram also simplifies the CLD and elaborates the causal relations between the interacting groups. Further, the cluster diagram has nodes that help in the creation of the CLD and loops. Contrary to the CLD cluster diagram, it does not have a polarity relation; it represents the relation of connectedness of various factors in the medication error system (or any system).

The findings here specify the need for the Swiss cheese model in understanding medication errors. The layered approach of the Swiss cheese model helps in finding the various holes or error-prone possibilities in the medication system. Our conceptualization is based on the James model (2000) of the Swiss cheese model for error propagation (see Figure 1). This model is modified as per the Indian medication errors. This model guides the reader on how multiple holes and errors align to cause patient harm. The layered approach in the Swiss cheese model for medication error is Layer-1.) prescription layer, the problem starts from transcribing errors, Layer-2.) pharmacy layer, where the error of wrong medicine is given to the patient, Layer-3.) administration layer, where the wrong route to administration and literacy is critical, Layer-4.) system layer, the role of culture of safety and staff shortages, Layer-5.) Lastly, the workplace environment, the workplace condition, inadequate staffing, and staff communication are addressed. The sequential explanation of the Swiss cheese model is important to communicate with the stakeholders. The decision-making in medication error is further plotted based on the key factors, which are highlighted in the cluster diagram (see Figure 5). Contrary to the standard procedure of creating the cluster diagram from participants and stakeholders, this diagram is created based on literature data, such as Patel et al. (2016).

6. Discussion and scope of this review

The current paper examines a comparison between SCM and non-linear approaches to address medicine-related errors in the Indian healthcare context. We used the SCM to analyze the temporal, dynamic, and causal perspectives of trends and patterns in medication error. Over the last 9 years (2016-2025), medication error-related perspectives were accumulated. The layers of the Swiss cheese model and the causal loop diagrams were constructed using the data from Patel et al. (2016), where they researched the cases of medication error in the western state of Gujarat, India. The study highlighted the types of medication errors in various stages of medication treatment. Factors related to the medication label and associated factors are derived from the context of the study done by (Patel et al., 2002). This study emphasizes the role of medicine labeling in preventing medication errors. As stated by researchers in the Indian context, medication errors are like an iceberg because healthcare workers see only a fraction of medication errors (Ambwani et al., 2019). As shown in Figure 1, the majority of medication errors are in prescribing (layer 1 SCM), documentation (layer 2 of SCM), administration (layer 3), and dispensing (layer 4) (Parthasarathi et al., 2021).

Previous studies utilizing SCM have highlighted the following factors: (a) Medication error in India, (b) Private services, (c) Resource Availability, (d) Facilities, (e) Public Sector, (f) Public education, (g) Reporting, (h) Pharmacy system.

The factors to be addressed in the medication error system are causal in nature. These factors need systemic intervention to address the rate of change in medication errors. Systems thinking has various methods to bring a collective change in the medication error problem. One such approach is SCM, which is more comprehensive in addressing the wide range of contributing factors that are barriers to the reduction of medication errors.

Institutional support from bodies like IOM and India’s Drug Technical Advisory Board (DTAB) could assist in establishing guidelines and strategies to curb medication errors. These errors, along with adverse drug events, are the areas where systemic failure exists Vernaz, et al., 2020). Adverse drug events and medication errors are the areas where existing systems have failure problems (Vernaz et al., 2020) even though the new medication policy and medication regimen are not considered for the medication error analysis the rise in complicated medication practices, more effective ways to curb medication errors and guarantee medical safety for individuals should be focused upon. Examples in the Indian context showed how the system tools, along with SCM, helped in reducing the medication error (Paul et al., 2023). The system dynamics model offers valuable insights into medication errors associated with look-alike and sound-alike over-the-counter medicines. Employing system modeling and the iceberg model facilitates the analysis of emerging and complex medication-related issues.

Solutions should be developed based on effective interception strategies and policies that regulate and monitor medication labeling and naming information (see Table 2).

Table 2. Systems thinking skills, Source: Modified from (Adam and De Savigny, 2012)

Swiss cheese model (A classical approach)	System dynamics (Systems thinking approach)
Linear Thinking	**Dynamic Thinking**
Focus on the linear chain of events	Framing the problem with respect to behavior over time
Events as a cause of thinking	**Systems as a cause of thinking**
Viewing the error outcomes the cause of chain process	Thinking system as the cause of events
Layer-by-layer thinking	**Forest thinking**
SCM gives a prediction in terms of layers of the defence mechanism	Thinking of the interlinking of the problems as the cause of the problem
Has application in healthcare and aviation	**Has application in business, ecology, and social systems**
Focuses on error and adverse event	**Focuses on the mental models, mission, and vision**
Straight line thinking	**Loop thinking**
A linear approach, assuming causality moves in a linear direction	The feedback loops exist for the system behavior to be updated over time

Medication error documentation and previous studies of root cause analysis highlighted the need to shift away from individual blame. Alternatively, underlying system-level factors should be explored. A combined approach to address medication error from person-centered and system-centered is needed to minimize administration errors (Jones, 2009).

The limitations of knowing the medication errors in detail require a field survey to gather data on medication errors in a hospital setting. Further, problem formulation in such cases requires a quantification of the latent factors influencing the medication error system.

7. Limitations

A broader perspective is required to study the medication error from the SCM perspective. To implement such processes, a considerable amount of time and effort must be invested in health systems (Teo et al., 2023). The Indian context of the medication error is way more complex than its Western counterparts (Singh et al., 2025). The public-private hospital setting of the

Indian hospital needs an understanding from the communication perspective of the health setting (Bhowmick et al., 2020). With the requirement of an adequate amount of time, these studies also help in understanding the vision and mission of the organisation. The SCM method can help only in analyzing situations from the mental models, but it cannot give tangible or working solutions, such as a user interface or a product designed to avoid medication errors. The SCM method to study medication errors is insufficient to capture the factors such as noise, workload, environmental conditions, equipment, and related protocols on occurrences of medication errors (Carayon, 2012). Some elements and factors, such as data reliability and quantifying complex behavior, are difficult to understand with the help of SCM. These factors must be taken into consideration when designing for medication errors. The medication system, when analyzed with SCM, shows several vulnerabilities that lead to harm penetrating through its layers (Banja, 2004). Each layer of SCM represents a layer of mechanism, such as organizational policies and procedures, clinical protocols and guidelines, technology safeguards and tools, supervision and oversight, and individual vigilance (Perneger, 2005). To better understand the healthcare defenses, designers should analyze the layers of SCM. Under some conditions, as discussed in the example, see Figure 2, the holes in the problem of medication errors need a clear understanding of the complexity of infrastructure, resources, and the attitude of patients. Hence, the Indian healthcare setting needs the SCM and other resources for the logistics and critical evaluation of the holes in the medication error (Singh et al., 2025). Hence, the layers are one policy, two nurse workloads, three cognitive biases, and four visual inspections. This comparison will give a comprehensive perspective on error propagation at a higher level (see Figure 1).

The layer-wise structure of SCM has many barriers, and it is difficult to predict the one-to-many causal mapping for medication errors (Wiegmann et al., 2022). A prospective study on the applicability of SCM for the prediction of medication errors and medication policy making. Even though SCM can predict medication errors, it cannot address the causal factors. These interventions help in a prospective study of reducing medication errors in domains such as medication management, medication error management, and medication safety for the nursing staff. Exploring the dynamics and interdependencies from a system perspective will help develop insightful, detailed, and comprehensive strategies for addressing the complex, multifaceted nature of medication errors.

Overall, SCM suggests a layered approach to address the complex issue of medication errors, comprising look-alike and sound-alike medicine labeling and naming (Crane and Crane, 2006).

These approaches help practitioners add government agencies to address the incidence of medication errors (Bogner, 1994).

8. Outcomes

In this overview, we have discussed and defined the perspective of the application of the Swiss cheese model for the comprehensive understanding of medication errors and the preventive targeted interventions. SCM comprises various layers; within these layers, the holes represent the errors. The propagation of the errors in the layers represents the errors that can cause harm to the patient (see Figure 2). The checks on the system-level error propagation. These factors are communication skills, communication effectiveness, and error reduction. The SCM helps explain the organizational factors that influence medication errors. Poor supervision of the behavior of the household and primary caregivers is a hidden factor for the medication errors. The holes in the layers of the SCM are human errors, equipment malfunctions, or environmental hazards that result in the accident and have the potential to damage the system.

Hence, while designing a new system for the medication application, it is important to consider the SCM recommendations on medication errors. The Swiss cheese model can be applied in error-monitoring techniques to improve the quality of existing healthcare systems (Barker, 1995). SCM came up as a model for system safety, where a single layer penetrates the end of the medication system. This model reveals the complexities in a health system. It also illuminates vulnerabilities like gaps between system layers, which could aid in building error-related solutions. The ambiguity and lack of understanding of the medical labels represent the potential holes in the first layer of defence. The holes are caused by a variety of factors, including communication effectiveness and error reduction. SCM is a snapshot of the proactive (possible) errors that can happen. SCM offers a layered perspective on how the failures interact and evolve. In conclusion, it can be stated that SCM helps in the identification, layering, and mapping of medication errors in the Indian context.

Such outcomes related to the medication error system help deliver the right amount of information on the labeling. System dynamics certainly helps product managers in understanding the underlying causes and patterns of medicine-related errors. This results in enhancing the medication naming and labeling quality. The model shall help in predicting meaningful steps to understand better and curb medication errors.

9. Conclusions

The present research findings underscore the significance of a hybrid approach in understanding medication error in the Indian context. This comparative study establishes the most effective theoretical framework for addressing Indian medication errors. The variables in this theoretical framework consist of factors such as organizational culture, resource availability, healthcare worker training, education, communication, and regulatory environment. SCM and its methodology help in understanding the factors in medication errors. The SCM highlights how multiple layers of defense can fail during ADE, emphasizing that errors are never caused by a single event; rather, they are caused by a chain of events. SCM establishes the correlation between various factors that cause medication errors (Cohen, 2017). It is also a well-established tool to identify medication errors, but the interrelationship and cause-and-effect relation between various factors of medication error have not been studied solely by using the SCM. The function of the medication error system is to work within the system's limitations, predict the system capacity. If the system capacity is not enhanced, then medication errors will overtake the number of right medicines given in any scenario. Medical labeling problems significantly affect the factors related to medication error. These factors link to issues of medicine disposal and administration. A systems perspective will prevent the users and patients from blaming the individual for the medication error.

System mapping starts with the cluster model, which comprises the group interactions between the elements of medication error. The cluster model in systems thinking is recommended to be considered before creating a causal loop diagram. The causal model and cluster model tell the context of the system modeling and help the system designers for future interventions.

Challenges related to error encapsulation span both system and subsystem levels. The medication error is related to the various aspects of medication skill acquisition, training, decision-making, and feedback and debriefing. The debriefing section of the medication error is necessary to highlight and emphasize the importance of strategies such as education, debriefing, constructive feedback, peer support, and mentorship in the process of learning from medication errors.

Understanding the interdependence of SCM contributing to medication errors can help improve patients' adherence to medical information. One of the primary challenges in addressing the medication errors lies in the complex interconnected elements of the healthcare system (Lauffenburger and Choudhry, 2018). Therefore, the designers should take into consideration SCM factors to understand the medication errors holistically (Anderson and Webster, 2001).

The medication system is already under huge pressure to prevent medication errors (Crane and Crane, 2006). Adopting a systems thinking approach is necessary to address the complex challenges of medication errors. Medication errors are not avoidable, but can be forecasted and avoided by proper system redesign (Crane and Crane, 2006). The SCM helps reduce error rates and the cost of medical care (Bogner, 1994).

Reducing medication errors using factors of SCM will benefit the whole Indian healthcare system. Medication errors need a systems-thinking approach to comprehend SD factors instead of blaming human errors.

Integration of such complementary methodologies helps in comprehensively understanding the design interventions and policies to reduce medication errors (Da Silva and Krishnamurthy, 2016).

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References

Adam, T. and de Savigny, D., 2012. Systems thinking for strengthening health systems in LMICs: need for a paradigm shift. *Health policy and planning*, *27*(suppl_4), pp.iv1-iv3. https://doi.org/10.1093/heapol/czs08.

Alharbi, W., Cleland, J. and Morrison, Z., 2018. Assessment of patient safety culture in an adult oncology department in Saudi Arabia. *Oman medical journal*, *33*(3), p.200. https://doi.org/10.5001/omj.2018.38.

Ambwani, S., Misra, A.K. and Kumar, R., 2019. Medication errors: Is it the hidden part of the submerged iceberg in our health-care system?. *International Journal of Applied and Basic Medical Research*, *9*(3), pp.135-142. https://doi.org/10.4103/ijabmr.IJABMR_96_19.

Anderson, V. and Johnson, L., 1997. *Systems thinking basics: from concepts to causal loops*. Cambridge, Mass: Pegasus Communications.

Anderson, D.J. and Webster, C.S., 2001. A systems approach to the reduction of medication error on the hospital ward. *Journal of advanced nursing*, *35*(1), pp.34-41. https://doi.org/10.1046/j.1365-2648.2001.01820.x.

Badiru, A.B. and Ijaduola, A.O., 2009. Half-life theory of learning curves for system performance analysis. *IEEE Systems Journal*, *3*(2), pp.154-165. https://doi.org/10.1109/JSYST.2009.2017394.

Banja, J.D., 2004. *Medical errors and medical narcissism*. Sudbury, Mass.: Jones and Bartlett.

Barbrook-Johnson, P. and Penn, A.S., 2022. Causal loop diagrams. In *Systems mapping: How to build* *and use causal models of systems* (pp. 47-59). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-01919-7_4.

Barker, K.N., 1995. Ensuring safety in the use of automated medication dispensing systems. *American journal of health-system pharmacy*, *52*(21), pp.2445-2447. https://doi.org/10.1093/ajhp/52.21.2445.

Basco Jr, W.T., Garner, S.S., Ebeling, M., Freeland, K.D., Hulsey, T.C. and Simpson, K., 2016. Evaluating the potential severity of look-alike, sound-alike drug substitution errors in children. *Academic pediatrics*, *16*(2), pp.183-191. https://doi.org/10.1016/j.acap.2015.06.014.

Bhowmick, S., Jana, S., Bandyopadhyay, A., Kundu, D., Banerjee, M., Das, A. and KarPurkayastha, S., 2020. Medication errors reported in a tertiary care private hospital in Eastern India: A three years experience. *International J Basic Clin Pharmacol*, *9*, p.937. https://doi.org/10.18203/2319-2003.ijbcp20202186.

Billstein-Leber, M., Carrillo, C.O.L., Cassano, A.T., Moline, K. and Robertson, J.J., 2018. ASHP guidelines on preventing medication errors in hospitals. *American Journal of Health-System Pharmacy*, *75*(19). https://doi.org/10.2146/ajhp170811.

Bogner, M.S. (ed.). ,1994. *Human error in medicine*. Hillsdale, N.J: L. Erlbaum Associates.

Brunetti, L. and Suh, D.C., 2012. Medication errors: scope and prevention strategies. *Journal of Hospital Administration*, *1*(2), pp.54-63. https://doi.org/10.5430/jha.v1n2p54.

Buist, M. and Middleton, S., 2016. Aetiology of hospital setting adverse events 1: limitations of the 'Swiss cheese'model. *British Journal of Hospital Medicine*, *77*(11), pp.C170-C174. https://doi.org/10.12968/hmed.2016.77.11.C170.

Carayon, P., 2012. *Handbook of human factors and ergonomics in health care and patient safety*. 2nd ed. Boca Raton, FL: CRC Press.

Chada, B.V., 2022. The systems engineering approach to quality improvement in the NHS. *Future Healthcare Journal*, *9*(3), pp.330-332. https://doi.org/10.7861/fhj.2022-0016.

Chanakit, T., Napaporn, J., Chiempattanakajohn, T., Sangkhawan, S. and Wichakot, S., 2013. The survey of look alike/sound alike (LASA) drugs available in hospitals in Thailand. *Afr J Pharm Pharmacol*, *7*(6), pp.227-39. https://doi.org/10.5897/AJPP11.812.

Chuang, S.W., Pan, C.Y. and Huang, C.Y., 2008. A system-oriented analysis model to enhance patient safety in healthcare organizations. *Systems Engineering*, *12*(3), pp.218-232. https://doi.org/10.1002/sys.20120.

Clarkson, P.J., Buckle, P., Coleman, R., Stubbs, D., Ward, J., Jarrett, J., Lane, R. and Bound, J., 2004. Design for patient safety: a review of the effectiveness of design in the UK health service. *Journal of Engineering Design*, *15*(2), pp.123-140. https://doi.org/10.1080/09544820310001617711.

Cohen, M.R. (ed.), 2007. *Medication Errors, 2nd Edition*. 2215 Constitution Avenue, N.W. Washington, DC 20037-2985: The American Pharmacists Association. https://doi.org/10.21019/9781582120928.

Cohen, M.R., 2017. Medication Errors, *Nursing*, 47(3), pp. 72–72. Available at: https://doi.org/10.1097/01.NURSE.0000512892.42073.9d.

Correia, T., Martins, M.M., Barroso, F., Pinho, L., Longo, J. and Valentim, O., 2023. The family's contribution to patient safety. *Nursing Reports*, *13*(2), pp.634-643.

https://doi.org/10.3390/nursrep13020056.

Crane, J. and Crane, F.G., 2006. Preventing medication errors in hospitals through a systems approach and technological innovation: a prescription for 2010. *Hospital topics*, *84*(4), pp.3-8. https://doi.org/10.3200/HTPS.84.4.3-8.

Cross, S.R.H., 2018. The systems approach at the sharp end. *Future Healthcare Journal*, *5*(3), pp.176-180. https://doi.org/10.7861/futurehosp.5-3-176.

Da Silva, B.A. and Krishnamurthy, M., 2016. The alarming reality of medication error: a patient case and review of Pennsylvania and National data. *Journal of community hospital internal medicine perspectives*, *6*(4), p.31758. https://doi.org/10.3402/jchimp.v6.31758.

Dave, N., Yaddanapudi, S., Jacob, R. and Varghese, E., 2022. Quality improvement and patient safety in India—Present and future. *Pediatric Anesthesia*, *32*(11), pp.1185-1190. https://doi.org/10.1111/pan.14431.

Davis, T.C., Wolf, M.S., Bass III, P.F., Thompson, J.A., Tilson, H.H., Neuberger, M. and Parker, R.M., 2006. Literacy and misunderstanding prescription drug labels. *Annals of internal medicine*, *145*(12), pp.887-894. https://doi.org/10.7326/0003-4819-145-12-200612190-00144.

Dekker, S., 2007. Discontinuity and disaster: gaps and the negotiation of culpability in medication delivery. *The Journal of Law, Medicine & Ethics*, *35*(3), pp.463-470. https://doi.org/10.1111/j.1748-720X.2007.00168.x.

Dubb, S.S., Oeppen, R.S., Svoboda, T. and Brennan, P.A., 2022. Human factors application for healthcare teams in low-and medium-income countries (LMIC) to help improve patient safety and performance. *Journal of Oral Biology and Craniofacial Research*, *12*(1), pp.77-79. https://doi.org/10.1016/j.jobcr.2021.10.013.

Fialová, D. and Onder, G., 2009. Medication errors in elderly people: contributing factors and future perspectives. *British journal of clinical pharmacology*, *67*(6), pp.641-645. https://doi.org/10.1111/j.1365-2125.2009.03419.x.

Gautam, P.L., 2013. Minimizing medication errors: Moving attention from individual to system. *Journal of Anaesthesiology Clinical Pharmacology*, *29*(3), pp.293-294. https://doi.org/10.4103/0970-9185.117037.

Guise, J.-M. and Mladenovic, J., 2013. In situ simulation: Identification of systems issues, *Seminars in Perinatology*, 37(3), pp. 161–165. https://doi.org/10.1053/j.semperi.2013.02.007.

Homer, J.B. and Hirsch, G.B., 2006. System dynamics modeling for public health: background and opportunities. *American journal of public health*, *96*(3), pp.452-458. https://doi.org/10.2105/AJPH.2005.062059.

Hussein, T., 2018. *Exploring the Requisites and Design Requirements for Adding 'Reason for Use' Information to Prescription Labels*. Master of Applied Science in Systems Design Engineering. University of Waterloo. Available at: https://uwspace.uwaterloo.ca/bitstream/handle/10012/13965/Hussein_Thana.pdf?sequence=3andisAllowed=y.

Isherwood, P. and Waterson, P., 2021. To err is system; a comparison of methodologies for the investigation of adverse outcomes in healthcare. *Journal of Patient Safety and Risk Management*, *26*(2), pp.64-73. https://doi.org/10.1177/2516043521990261.

Johnson, J.A. and Anderson, D.E., 2017. *Systems thinking for health organizations, leadership, and policy: think globally, act locally*. Austin, TX: Sentia Publishing.

Johnson, J.A., Anderson, D.E. and Rossow, C.C., 2020. *Health systems thinking: a primer*. Burlington, MA: Jones and Bartlett Learning.

Jones, S.W., 2009. Reducing medication administration errors in nursing practice, *Nursing Standard*, 23(50), pp. 40–46. Available at: https://doi.org/10.7748/ns2009.08.23.50.40.c7213.

Kapp, J.M., Simoes, E.J., DeBiasi, A. and Kravet, S.J., 2017. A conceptual framework for a systems thinking approach to US population health. *Systems Research and Behavioral Science*, *34*(6), pp.686-698. https://doi.org/10.1002/sres.2420.

Karmakar, A. and Das, M., 2025. Approach To Reduce Repeated Medication Error (REREME) In A Multispecialty Tertiary Care Hospital In Eastern India, *Health Library* [Preprint]. Available at: https://www.apollohospitals.com/health-library/approach-to-reduce-repeated-medication-error-rereme-in-a-multispecialty-tertiary-care-hospital-in-eastern-india.

Keating, C.B., Katina, P.F., Jaradat, R., Bradley, J.M. and Hodge, R., 2021, July. Systems thinking: A critical skill for systems engineers. *INCOSE International Symposium*, 31(1), pp. 522–536. Available at: https://doi.org/10.1002/j.2334-5837.2021.00852.x.

Keebler, J.R., Rosen, M.A., Sittig, D.F., Thomas, E. and Salas, E., 2022. Human factors and ergonomics in healthcare: Industry demands and a path forward. *Human Factors*, *64*(1), pp.250-258. Available at: https://doi.org/10.1177/00187208211073623.

Koelling, P. and Schwandt, M.J., 2005, December. Health systems: A dynamic system-benefits from system dynamics. In *Proceedings of the Winter Simulation Conference,* pp. 1321–1327. https://doi.org/10.1109/WSC.2005.1574393.

Kohn, L.T., Corrigan, J. and Donaldson, M.S. eds., 2000. *To err is human: building a safer health system*. Washington, D.C: National Academy Press.

Kulkarni, V., Bora, S.S., Sirisha, S., Saji, M. and Sundaran, S., 2013. A study on drug–drug interactions through prescription analysis in a South Indian teaching hospital. *Therapeutic advances in drug safety*, *4*(4), pp.141-146. https://doi.org/10.1177/2042098613490009.

Lauffenburger, J.C. and Choudhry, N.K., 2018. A Call for a Systems-Thinking Approach to Medication Adherence: Stop Blaming the Patient, *JAMA Internal Medicine*, 178(7), p. 950. https://doi.org/10.1001/jamainternmed.2018.0790.

Law, A.V. and Zargarzadeh, A.H., 2010. How do patients read, understand and use prescription labels? An exploratory study examining patient and pharmacist perspectives. *International Journal of Pharmacy Practice*, *18*(5), pp.282-289 https://doi.org/10.1111/j.2042-7174.2010.00055.x.

Leape, L.L., 1997. A systems analysis approach to medical error. *Journal of evaluation in clinical practice*, *3*(3), pp.213-222. https://doi.org/10.1046/j.1365-2753.1997.00006.x.

Leveson, N., 2004. A new accident model for engineering safer systems. *Safety science*, *42*(4), pp.237-270. https://doi.org/10.1016/S0925-7535(03)00047-X.

Maidment, I.D., Lelliott, P. and Paton, C., 2006. Medication errors in mental healthcare: a systematic review. *Quality and Safety in Health Care*, *15*(6), pp. 409–413. https://doi.org/10.1136/qshc.2006.018267.

McDowell, S.E., Ferner, H.S. and Ferner, R.E., 2009. The pathophysiology of medication errors: how and where they arise, *British Journal of Clinical Pharmacology*, *67*(6), pp. 605–613. https://doi.org/10.1111/j.1365-2125.2009.03416.x.

Mitra, M. and Basu, M., 2020. An Analysis of Medication Errors in a Tertiary Care Teaching Hospital. *Journal of Research in Medical and Dental Science*, *8*(3), pp.17-24.

Monat, J.P. and Gannon, T.F., 2023. The meaning of "structure" in systems thinking. *Systems*, *11*(2), p.92. https://doi.org/10.3390/systems11020092.

National Academies of Sciences, Engineering, and Medicine (U.S.) (ed.), 2018. *Crossing the global quality chasm: improving health care worldwide*. Washington, DC: The National Academies Press (A consensus study report of the Natonal Academies of Sciences, Engineering, Medicine).

Nolan, T.W., 2000. System changes to improve patient safety. *BMJ*, *320*(7237), pp. 771–773. https://doi.org/10.1136/bmj.320.7237.771.

Oxman, D., 2023. A Systems Approach to Reducing Medical Error. *JAMA*, *330*(3), pp.284-284. https://doi.org/10.1001/jama.2023.8741.

Parthasarathi, A., Puvvada, R., Patel, H., Bhandari, P., Nagpal, S. and Puvvada, R.K., 2021. Evaluation of medication errors in a tertiary care hospital of a low-to middle-income country. *Cureus*, *13*(7). https://doi.org/10.7759/cureus.16769.

Patel, V.L., Branch, T. and Arocha, J.F., 2002. Errors in interpreting quantities as procedures: The case of pharmaceutical labels. *International journal of medical informatics*, *65*(3), pp.193-211. https://doi.org/10.1016/S1386-5056(02)00045-X.

Patel, N., Desai, M., Shah, S., Patel, P. and Gandhi, A., 2016. A study of medication errors in a tertiary care hospital. *Perspectives in clinical research*, *7*(4), pp.168-173. https://doi.org/10.4103/2229-3485.192039.

Paul, P., Era, N. and Paul, U.K., 2023. Need for implementation of safe medication practice to avoid medication errors–A journey through case series. *Journal of Family Medicine and Primary Care*, *12*(7), pp.1464-1467. https://doi.org/10.4103/jfmpc.jfmpc_2016_22.

Peerally, M.F., Carr, S., Waring, J. and Dixon-Woods, M., 2017. The problem with root cause analysis. *BMJ quality & safety*, *26*(5), pp.417-422. https://doi.org/10.1136/bmjqs-2016-005511.

Perneger, T.V., 2005. The Swiss cheese model of safety incidents: are there holes in the metaphor?. *BMC health services research*, *5*(1), p.71. https://doi.org/10.1186/1472-6963-5-71.

Persell, S.D., Heiman, H.L., Weingart, S.N., Burdick, E., Borus, J.S., Murff, H.J., Bates, D.W. and Gandhi, T.K., 2004. Understanding of drug indications by ambulatory care patients. *American journal of health-system pharmacy*, *61*(23), pp.2523-2527. https://doi.org/10.1093/ajhp/61.23.2523.

Institute of Medicine., 2007 *Preventing Medication Errors: Quality Chasm Series*. Washington, D.C.: National Academies Press, p. 11623. https://doi.org/10.17226/11623.

Rani, S., Bhardwaj, U. and Rani, S., 2020. To study the effectiveness of the training program on safe administration of drugs to reduce the medication error. *Indian J Holist Nurs*, *11*(3), pp.12-9. https://doi.org/10.24321/2348.2133.202003.

Reason, J., 1990. *Human Error*. 1st edn. Cambridge university press.

https://doi.org/10.1017/CBO9781139062367.

Reason, J., 2000. Human error: models and management. *Bmj*, *320*(7237), pp.768-770. https://doi.org/10.1136/bmj.320.7237.768.

Rodziewicz, T.L., Houseman, B. and Hipskind, J.E., 2024. *Medical Error Reduction and Prevention*, in. Treasure Island (FL): StatPearls Publishing. Available at: https://www.ncbi.nlm.nih.gov/books/NBK499956/.

Roy, V., Tayal, V. and Kansal, A., 2020. Patients Knowledge of Prescribed Medications and Factors Affecting it in a Tertiary Care, Public, Teaching Hospital in New Delhi, India. *MAMC Journal of Medical Sciences*, *6*(3), pp.204-210. https://doi.org/10.4103/mamcjms.mamcjms_45_20.

Samaranayake, N.R. and Cheung, B.M.Y., 2013. Medication safety in hospitals: avoiding medication errors in the medication use process. *Adv Pharmacoepidemiol Drug Saf*, *2*, pp.1-7. https://doi.org/10.4172/2167-1052.1000134.

Sameera, V., Bindra, A. and Rath, G.P., 2021. Human errors and their prevention in healthcare. *Journal of Anaesthesiology Clinical Pharmacology*, *37*(3), pp.328-335. https://doi.org/10.4103/joacp.JOACP_364_19.

Schnoor, J., Rogalski, C., Frontini, R., Engelmann, N. and Heyde, C.E., 2015. Case report of a medication error by look-alike packaging: a classic surrogate marker of an unsafe system. *Patient safety in surgery*, *9*(1), p.12. https://doi.org/10.1186/s13037-014-0047-0.

Sewal, R.K., Singh, P.K., Prakash, A., Kumar, B. and Medhi, B., 2014. A prospective study to evaluate awareness about medication errors amongst health-care personnel representing North, East, West Regions of India. *International Journal of Applied and Basic Medical Research*, *4*(1), pp.43-46. https://doi.org/10.4103/2229-516X.125694.

Sharma, S., Tabassum, F., Khurana, S. and Kapoor, K., 2016. Frontline worker perceptions of medication safety in India. *Therapeutic Advances in Drug Safety*, *7*(6), pp.248-260. https://doi.org/10.1177/2042098616665290.

Singh, G., Patel, R.H., Vaqar, S. and Boster, J., 2025. Root Cause Analysis and Medical Error Prevention. in *StatPearls*. Treasure Island (FL): StatPearls Publishing. Available at: http://www.ncbi.nlm.nih.gov/books/NBK570638/ (Accessed: 7 August 2025).

Smetzer, J., Baker, C., Byrne, F.D. and Cohen, M.R., 2010. Shaping systems for better behavioral choices: lessons learned from a fatal medication error. *The Joint Commission Journal on Quality and Patient Safety*, *36*(4), pp.152-AP2. https://doi.org/10.1016/S1553-7250(10)36027-2.

Spath, P.L. (ed.), 2011. *Error reduction in health care: a systems approach to improving patient safety*. Second Edition. San Francisco: Jossey-Bass.

Szczepura, A., Wild, D. and Nelson, S., 2011. Medication administration errors for older people in long-term residential care. *BMC geriatrics*, *11*(1), p.82. https://doi.org/10.1186/1471-2318-11-82.

Tariq, R., Vashisht, R. and Sinha, A., 2024. *Medication Dispensing Errors and Prevention*. in. StatPearls Publishing. Available at: https://www.ncbi.nlm.nih.gov/books/NBK519065/.

Teo, K.W., Hu, Y., Chew, K.T., Pek, W.Y., Chua, H.C., Matchar, D.B. and Ng, Y.F., 2023. Health System Transformation Playbook and Unified Care Model: an integrated design, systems & complexity thinking approach to health system transformation. *Frontiers in health services*, *3*, p.1157038. https://doi.org/10.3389/frhs.2023.1157038.

Tetuan, T., Ohm, R., Kinzie, L., McMaster, S., Moffitt, B. and Mosier, M., 2017. Does systems thinking improve the perception of safety culture and patient safety?. *Journal of Nursing Regulation*, *8*(2), pp.31-39. https://doi.org/10.1016/S2155-8256(17)30096-0.

Uleman, J.F., Melis, R.J., Quax, R., van der Zee, E.A., Thijssen, D., Dresler, M., van de Rest, O., van der Velpen, I.F., Adams, H.H., Schmand, B. and de Kok, I.M., 2021. Mapping the multicausality of Alzheimer's disease through group model building. *Geroscience*, *43*(2), pp.829-843. https://doi.org/10.1007/s11357-020-00228-7.

Underwood, P. and Waterson, P., 2014. Systems thinking, the Swiss Cheese Model and accident analysis: A comparative systemic analysis of the Grayrigg train derailment using the ATSB, AcciMap and STAMP models. *Accident Analysis & Prevention*, *68*, pp.75-94. https://doi.org/10.1016/j.aap.2013.07.027.

Vaidya, R. and Joshi, M.P., 2023. Analysis of Patient Benefit Information on the Labels of Non-Prescription Medicines in India. *Indian Journal of Pharmaceutical Sciences*, *85*(2). https://doi.org/10.36468/pharmaceutical-sciences.1079.

Vernaz, N., Simona, A. and Samer, C.F., 2020. The Swiss cheese prescribing model for precision medicine. *The American journal of medicine*, *133*(11), pp.1249-1251. https://doi.org/10.1016/j.amjmed.2020.06.001.

Wiegmann, D.A., Wood, L.J., Cohen, T.N. and Shappell, S.A., 2022. Understanding the "Swiss cheese model" and its application to patient safety. *Journal of patient safety*, *18*(2), pp.119-123. https://doi.org/10.1097/PTS.0000000000000810.

Wieman, T.J. and Wieman, E.A., 2004. A systems approach to error prevention in medicine. *Journal of surgical oncology*, *88*(3), pp.115-121. https://doi.org/10.1002/jso.20121.

Wong, Z.S.Y., 2016. Statistical classification of drug incidents due to look-alike sound-alike mix-ups. *Health informatics journal*, *22*(2), pp.276-292. https://doi.org/10.1177/1460458214555040.

Zanker, M., Bureš, V. and Tučník, P., 2021. Environment, business, and health care prevail: A comprehensive, systematic review of system dynamics application domains. *Systems*, *9*(2), p.28. https://doi.org/10.3390/systems9020028.

Zirpe, K.G., Seta, B., Gholap, S., Aurangabadi, K., Gurav, S.K., Deshmukh, A.M., Wankhede, P., Suryawanshi, P., Vasanth, S., Kurian, M. and Philip, E., 2020. Incidence of medication error in critical care unit of a tertiary care hospital: where do we stand?. *Indian journal of critical care medicine: peer-reviewed, official publication of Indian Society of Critical Care Medicine*, *24*(9), p.799. https://doi.org/10.5005/jp-journals-10071-23556.

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Analyzing the Key Drivers of Sustainable Academic Entrepreneurship: A System Dynamics Perspective

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ABSTRACT

Sustainable academic entrepreneurship constitutes a fundamental pillar of sustainable academic transformation, enabling universities to align their missions with environmental, economic, and societal objectives. Although global interest in this field is rising, many universities—especially in developing countries—face institutional and structural barriers that hinder the emergence of sustainable entrepreneurial ecosystems. A comprehensive, systems-based understanding of the key drivers, interdependencies, and feedback mechanisms is essential to address these challenges. This study employs a mixed-method design, integrating meta-synthesis of scholarly literature and expert interviews to identify 25 critical factors influencing sustainable academic entrepreneurship. A system dynamics model was constructed and validated by academic stakeholders. The model was simulated using Vensim software over 60 months, and seven policy scenarios were tested, focusing on variables including entrepreneurship education, financial support, industrial experience, managerial continuity, and regulatory conditions. Simulation findings demonstrate that enhancing the quality of entrepreneurship education, expanding industrial experience among faculty and students, and implementing targeted financial incentives significantly strengthen entrepreneurial capacity and foster the development of sustainable innovation centers. Moreover, scenario-specific results indicated that integrated implementation of multiple supportive policies produced the most substantial improvements, whereas isolated interventions had limited effects. Conversely, institutional constraints—including bureaucratic complexity, inconsistent policies, and limited leadership commitment—generate strong balancing feedback loops that impede long-term growth. The most effective improvements emerged from the integrated implementation of supportive policy measures. To promote sustainable academic entrepreneurship, universities must adopt systemic and forward-looking strategies that simultaneously address structural and behavioral drivers. Findings from the policy scenarios suggest that reinforcing positive feedback loops—including education, experience, and institutional support—while minimizing counterproductive constraints maximizes idea success rates, innovation outputs, and ecosystem resilience. The proposed model offers actionable insights for policymakers aiming to align institutional transformation with sustainable development goals.

Keywords

Sustainable Academic Entrepreneurship; System Dynamics Modeling; Entrepreneurship Education; Vensim Simulation.

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1. Introduction

In recent decades, entrepreneurship and the cultivation of entrepreneurial talent have become central concerns within higher education systems. The rising unemployment rate among university graduates has caused significant economic, social, and psychological consequences, including reduced self-confidence, loss of motivation, and brain drain. When graduates lack practical skills, the ability to identify market opportunities, or the creative mindset required to enter the labor market, universities cannot be said to have fulfilled their mission of empowering human capital. Today, universities are expected to go beyond theoretical instruction by creating environments that foster experiential learning, creativity, and innovation. This enables students to develop the capacity to generate employment opportunities aligned with their abilities and interests, either during or after their studies. Academic entrepreneurship has emerged as a key indicator of third- and fourth-generation universities, bridging the gap between higher education and the labor market (Guerrero et al., 2016).The concept pertains to structured activities aimed at the commercialization of knowledge, technology transfer, and the empowerment of human capital to support innovation-driven economic developmen (Breznitz and Etzkowitz , 2014). Research indicates that academic entrepreneurship is directly and significantly related to three core elements: entrepreneurship education, scientific research, and innovative activities. These elements, in turn, are indirectly linked to broader economic growth (Guerrero and Urbano, 2012). However, despite the growing body of research, several gaps remain. In particular, most studies have focused on economic outcomes, while the integration of social and environmental dimensions of sustainability within academic entrepreneurship remains underexplored. Furthermore, previous research rarely considers the dynamic interactions between multiple factors and the long-term impacts of policy interventions, limiting the ability to support evidence-based decision-making in universities. Thus, it is essential to incorporate the three dimensions of sustainability—economic, social, and environmental—into entrepreneurial planning and policymaking within academia to ensure balanced and lasting development (Fayolle and Redford, 2014). Addressing these gaps, the present study employs a mixed-method approach, combining meta-synthesis and system dynamics modeling. A systematic literature review was conducted to extract key factors influencing sustainable academic entrepreneurship, followed by the design and simulation of a conceptual model—including causal loop and stock-flow diagrams—over five years. Finally, different policy scenarios were defined and analyzed, providing a practical framework for supporting future decision-making and demonstrating the added value of integrating dynamic modeling into academic entrepreneurship research.

2. Literature review

2.1. *Sustainable academic entrepreneurship*

Numerous studies have explored the concept of sustainable entrepreneurship, each emphasizing different aspects, including sustainable entrepreneurship, economic enterprise, environmental entrepreneurship, social entrepreneurship, and green entrepreneurship (Burzyńska et al., 2018). For example, green entrepreneurship focuses on developing products and technologies that address environmental challenges; in this case, entrepreneurial activities aim to generate profit while simultaneously considering environmental concerns (Jolink and Niesten, 2015). Recent research indicates that universities are increasingly embracing the concept of green entrepreneurship, and ecological values should be integrated into university entrepreneurial support systems (Şener et al., 2018). Social entrepreneurship in the academic context is regarded as an effort to cultivate future social entrepreneurs. University-level social entrepreneurship programs are typically designed through collaboration with communities and industry, often generating significant impact on local areas. The knowledge and skills acquired from universities—regardless of academic or cultural background—can be strategically leveraged to address social problems through innovative solutions (Roslan et al., 2020). Researchers argue that social entrepreneurship can help alleviate major social issues, including poverty, homelessness, child welfare, unemployment, racial discrimination, and unequal access to education, while also reducing criminal behavior (Kaplaperis et al., 2020). Social entrepreneurs make meaningful contributions to society by creating social value and addressing both environmental and social issues through key mechanisms, including economic recovery, employment development, innovation, and the promotion of social equity (Alden et al., 2017). In general, social entrepreneurship is considered both effective and sustainable because it prioritizes environmental and social values over purely economic ones (Kaplaperis et al., 2020). Education plays a fundamental role in motivating students to pursue social entrepreneurship, highlighting the need for targeted academic programs and supportive institutional policies (Gupta et al., 2020). On the other hand, the primary goal of entrepreneurship remains economic growth and financial improvement within society. It is now widely recognized that higher education institutions, in addition to their traditional missions of research and education, play a critical role in regional economic development (Trippl et al., 2015). The entrepreneurial university model enables institutions to actively contribute to regional development by

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initiating economic, social, and environmental activities in a coordinated manner (Goddard et al., 2012).

Overall, the concept of sustainable academic entrepreneurship refers to a university model that, in addition to addressing scientific challenges facing society, government, and businesses, also fosters innovation among its members, facilitates the commercialization of academic research, and contributes to the production and dissemination of new technologies and knowledge—while simultaneously addressing the three dimensions of sustainability: social, economic, and environmental. This integration highlights the complex interactions among these dimensions, which can be effectively analyzed and simulated through system dynamics modeling.

2.2. *Review of the literature*

Studies examining academic entrepreneurship have primarily addressed topics including the role of universities in society, characteristics of entrepreneurial universities, the development of academic entrepreneurship models, entrepreneurial assessment of universities, technology transfer processes, university-government-industry interaction, the establishment of spin-offs, commercialization of academic research, and environmental factors influencing academic entrepreneurship. Today, academic entrepreneurship has become one of the most intriguing scientific domains for researchers across various countries, receiving considerable attention in recent years.

Given that the advancement of any scientific field depends on the accumulation of knowledge and the systematic review of existing research, analyzing the trends in academic output and scholarly investigations on academic entrepreneurship in recent years can provide a roadmap for future directions. In the broader field of entrepreneurship, several studies have explored various sub-domains, including entrepreneurship in family firms (López et al., 2016), international entrepreneurship (Abreu et al., 2016), social entrepreneurship (Dionisio, 2019; Rey-Martí et al., 2016), university-industry collaboration (Rybnicek, 2019), entrepreneurial organizations, entrepreneurial cognition and social constructionist approaches (Sassetti et al., 2018), ethics and entrepreneurship (Wallaster et al., 2019), and innovation and entrepreneurship (Sharma, 2019). Although numerous studies have been conducted on academic entrepreneurship and sustainable entrepreneurship individually, research at the intersection of these two—namely, sustainable academic entrepreneurship—is still limited. The few existing studies in this area primarily focus on the entrepreneurial ecosystem within universities.

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In general, numerous studies have examined the impacts of universities on entrepreneurship and the indicators of academic entrepreneurship. Separately, many investigations have focused on sustainable entrepreneurship, primarily addressing the influence of entrepreneurship on sustainability and vice versa. However, there is currently no comprehensive and integrative model that consolidates valuable insights from previous research and employs a system dynamics approach to design a dynamic model of sustainable academic entrepreneurship tailored specifically for universities. Given that one of the foremost objectives of universities is to foster sustainable entrepreneurship at all educational levels and stages, dynamic modeling combined with simulation is essential and indispensable for university managers and policymakers.

3. Research methodology

This study employs a meta-synthesis approach to comprehensively identify the factors influencing sustainable academic entrepreneurship through a systematic review of existing literature. Meta-synthesis is particularly suitable for integrating findings from multiple qualitative studies, allowing the extraction and operationalization of 25 critical factors that form the basis of our system dynamics model. Meta-synthesis is a qualitative research method that critically examines and integrates findings from related and similar studies to identify new themes, thereby advancing existing knowledge and providing a broader and more comprehensive perspective on the research topic (Sattar et al., 2021). Implementing meta-synthesis involved clearly defined inclusion and exclusion criteria, a systematic search strategy, and independent review by multiple researchers to ensure reliability and minimize bias.

Subsequently, system dynamics methodology was employed for modeling and simulating relevant scenarios, with a specific focus on the interactions among key factors identified from the meta-synthesis. According to system dynamics theory, various variables within a complex system are causally linked through interacting feedback loops, which collectively form the system's structure. This structure determines the behavior of the system .The primary aim of system dynamics is to assist managers in understanding complex systems, enabling them to intervene effectively to align system behaviors with their objectives (Elsawah et al., 2020; Lane, 2023). In this study, system dynamics modeling was tailored to the context of sustainable academic entrepreneurship, providing a practical framework for simulating policy scenarios and evaluating potential outcomes. The modeling and simulation followed the iterative five-step process outlined by Sterman (2000), which has since been refined and applied in diverse socio-technical and sustainability contexts (Elsawah et al., 2020; Lane, 2023).

1. Problem articulation to define the purpose of modeling.
2. Formulation of dynamic hypotheses leading to a conceptual representation of the complex system.
3. Development of a simulation model that translates the conceptual framework into a simulation model with equations defining the relationships among variables.
4. Model testing where simulated flows and stocks were calibrated against existing data, expert expectations, and iterative feedback from academic stakeholders to ensure the validity and credibility of the results.
5. Policy design and evaluation based on scenarios activated by changing parameters or structures to learn about the effects of such changes.

Each stage of this research involves specific methods and data analysis tools tailored to that phase, which are presented in Figure 1.

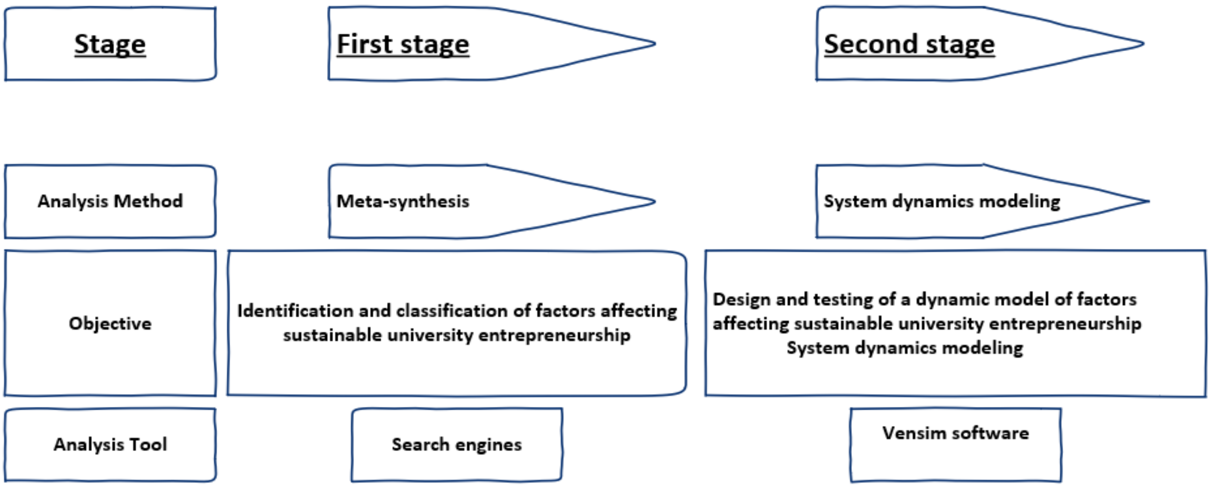

Figure 1. Research stages, objectives, methods, and analytical tools

Stage One: Extraction of Factors Influencing Sustainable University Entrepreneurship. A systematic search was conducted across multiple databases to identify peer-reviewed articles relevant to sustainable academic entrepreneurship. Scopus was the primary database, and keywords were carefully selected to capture economic, social, and environmental aspects of entrepreneurship in higher education. The following keywords were used in the search strategy:

"entrepren***" OR "spin-offs" OR "spin-offs" OR "spin-off" OR "spin off" AND "sustain***" OR "green" OR "ecol***" OR "environmental" OR "social***" AND "univers***" OR "academ***" OR "higher education" OR "educational institutes"

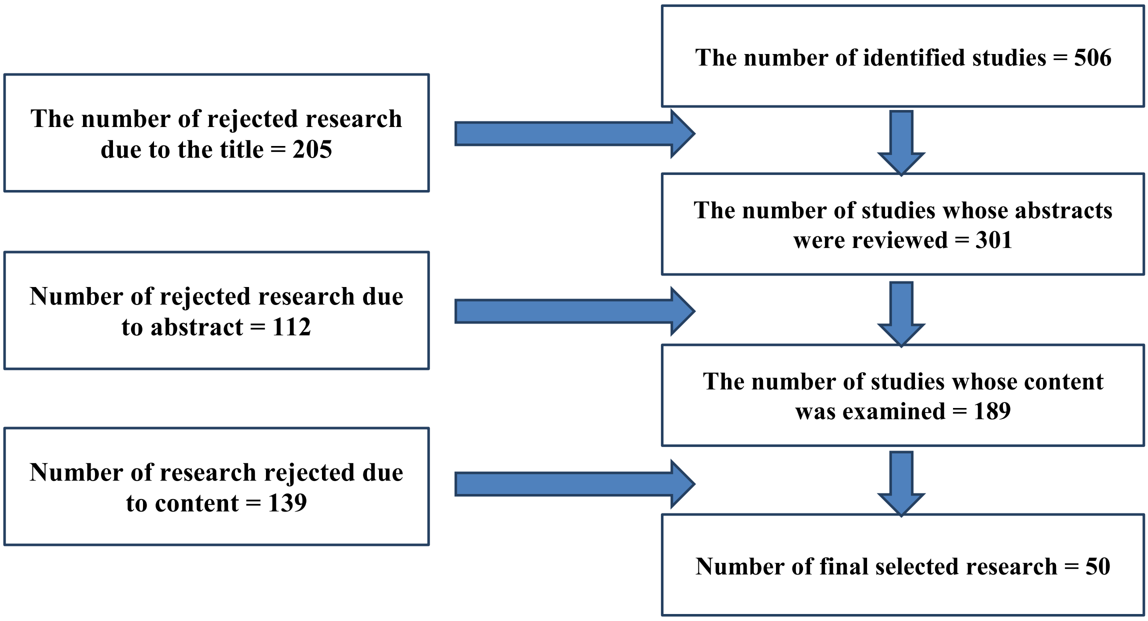

Figure 2. A summary of the search results and selection of appropriate articles

The results obtained from the literature review using the meta-synthesis approach can be seen in Table 1.

Table 1. Extraction of factors affecting sustainable university entrepreneurship development

Row	Coding	Concepts
1	▪ Concentration of decision-making at the macro level and elimination of university participation ▪ Limitations on university authority in managing resources and programs ▪ Hierarchical and inflexible structure in the higher education system ▪ Decreased initiatives and innovations of academic institutions ▪ Severe dependence of universities on central decisions	Centralization in the higher education system
2	▪ Repeated changes in university management levels ▪ Lack of stability in macro policies and long-term programs ▪ Disruption in project implementation due to management instability ▪ Decreased trust of stakeholders in the university management system	Management instability and frequent changes
3	▪ Formulating a strategy for the commercialization of academic research ▪ Supporting the commercialization of students' ideas ▪ Developing new environmentally friendly products in laboratory settings	Commercialization of environmental ideas
4	▪ The level of industry trust in universities ▪ Strengthening the interaction between industry and universities and the external environment ▪ Increasing academic interactions in national and regional spaces ▪ Signing bilateral and multilateral contracts between universities and industry ▪ A dynamic, continuous, and effective connection between universities and the industry and society, and carrying out multiple work contracts ▪ Utilizing the university's brand to attract collaboration ▪ Strategic participation of universities in major economic, environmental, and social projects	Industry-university collaboration and interaction

Row	Coding	Concepts
5	▪ Creating educational platforms for managers and university professors regarding the importance of entrepreneurship ▪ Providing entrepreneurship training programs for newly hired and less experienced professors ▪ Developing an entrepreneurial culture in the university ▪ Institutionalizing an entrepreneurial culture among university staff, faculty members, and students	Entrepreneurship culture in the university
6	▪ Lack of a centralized authority for policy-making in the field of sustainable entrepreneurship ▪ Lack of inter-organizational coordination in the design and implementation of policies ▪ Gap in specialized monitoring of academic entrepreneurial activities ▪ Need for the establishment of an independent and accountable policy-making body	Lack of a specialized policymaking body for sustainable university entrepreneurship.
7	▪ Encouraging the university to use electric vehicles, public transportation, bicycles, etc. ▪ Promoting waste recycling at the university ▪ Raising awareness among professors, students, staff, and university administrators regarding environmental issues ▪ Educating about sustainable development goals. Implementing circular economy principles at the university has positive environmental impacts ▪ Helping the university save energy and resources	Culture of Sustainability in the University
8	▪ The number of business laws related to sustainable development ▪ Making changes to academic regulations to encourage university entrepreneurship ▪ Making changes to educational policies and knowledge development to increase university entrepreneurship ▪ Reviewing existing regulations to facilitate the process of entrepreneurship development	University rules and policies
9	▪ Increase research and development in the field of sustainable entrepreneurship ▪ Establish a research and development unit at the university	Establishment of a research and development unit at the university
10	▪ Creating a curriculum system for teaching innovation and entrepreneurship ▪ Integrating entrepreneurship education with vocational training ▪ Guiding coursework projects in the direction of self-employment and entrepreneurship ▪ Strengthening the teaching capacity of professors in entrepreneurship education ▪ Incorporating entrepreneurship courses as mandatory subjects.	Entrepreneurship education at the university
11	▪ Establishing new structures ▪ Establishing professorships ▪ Creating sustainable or social entrepreneurship centers ▪ Establishing innovation centers	Establishing innovation centers at the university
12	▪ Development of information and communication technology infrastructure at the university ▪ Increasing the university's internet bandwidth ▪ Utilizing digital technology infrastructure at the university ▪ Renovation, equipping, and development of laboratories	Sustainable entrepreneurial infrastructure
13	▪ Cultural resistance to the acceptance of innovation and structural changes ▪ Traditionalism in management and academic teaching methods ▪ Fear of risk-taking and avoidance of entrepreneurial approaches ▪ Challenges in shifting the university members' attitudes towards sustainability	Traditional resistance

Row	Coding	Concepts
14	▪ Inadequate laws to protect the intellectual property of university members ▪ Lack of executive mechanisms for registering patents and trademarks ▪ Challenges in pursuing legal rights for intellectual property violations ▪ Need for a review of existing laws to cover innovations	The weakness of intellectual property protection laws
15	▪ Lack of financial and moral incentives for entrepreneurial activities ▪ Reward systems that do not align with the needs of innovation and sustainability ▪ Neglect of professional motivations in entrepreneurship development ▪ Need for designing multidimensional incentive mechanisms	Inappropriate incentive system
16	▪ Lack of direct interaction between professors and students with industrial projects ▪ Gap between university education and actual industry needs ▪ Weakness in transferring practical experience from industry to the university environment ▪ Need to develop internship programs and joint projects	Industrial experience
17	▪ Complex and time-consuming administrative processes for project implementation ▪ Slowness in approving and executing entrepreneurial plans ▪ Administrative barriers for attracting investment and collaborating with the industry	Bureaucracy in the university
18	▪ The level of financial and non-financial support from institutions for sustainable entrepreneurship in universities ▪ Financial support from institutions for student startup projects ▪ The level of government support for entrepreneurship in the country's universities ▪ Establishing an investment fund to assist newly established university companies ▪ Non-governmental financial resources through enhancing the quality of services and developing university entrepreneurship	University financial support
19	▪ Considering sustainable entrepreneurship in the university's mission statement, vision, and goals ▪ Sustainable development goals should be reflected in the university's vision ▪ The long-term and strategic perspective of university managers towards entrepreneurship and the commercialization of ideas	Sustainable Entrepreneurial Strategic Planning
20	▪ Reforming the system for recruiting and promoting professors based on sustainable entrepreneurship development ▪ Incorporating green and social criteria into recruitment tests and interviews ▪ Assessing sustainable entrepreneurship characteristics in job applicants ▪ Recruiting faculty based on the level of entrepreneurial and environmental initiatives and projects	Appropriate recruitment and hiring system
21	▪ Disconnection between executive, supportive, and supervisory bodies ▪ Lack of alignment between the goals of governmental institutions and the needs of universities ▪ Challenges in the allocation of resources and unified legal support ▪ Interference in the duties and responsibilities of related institutions	Lack of coordination among government agencies
22	▪ Ineffective metrics for assessing entrepreneurial activities ▪ Lack of attention to sustainability criteria in evaluating professors and students ▪ Deficiency in the performance-based reward system for innovation	Weakness in the performance evaluation system
23	▪ Support and commitment of management towards university entrepreneurship ▪ Commitment of senior management ▪ University managers should be supporters and committed to the processes of entrepreneurship and idea creation in the university	Commitment and support of senior management

Row	Coding	Concepts
24	▪ Risk-taking of university managers ▪ Risk-taking ▪ Willingness to take risks among managers	Risk-taking
25	▪ Strengthening financial resources and allocating budget for sustainable entrepreneurship development ▪ Allocating budget for entrepreneurial ideas ▪ Establishing a specific budget line for the development of entrepreneurial activities in the university ▪ Attracting investors to support entrepreneurial ideas	Investment in sustainable university entrepreneurship development

The input variables of the model were derived from a meta-synthesis of25key factors influencing sustainable academic entrepreneurship. The selection process followed clear inclusion and exclusion criteria, predefined keywords, and systematic search strategies to ensure both rigor and comprehensiveness. To further improve the validity of the extracted .factors, the results were reviewed and refined with input from academic experts

3.1. System dynamics approach

The objective of system dynamics modeling is to analyze the dynamic behavior of systems over time, facilitating the design of effective policies and strategies aimed at performance enhancement (Currie et al., 2018), and simulation models offer several advantages over other problem-solving methods, especially when dealing with complex systems. In an analytical solution, it may not be possible for the modeler to formulate the behavioral aspects of the system in the form of analytical equations. However, in a simulation model, virtually any system can be represented based on a set of assumptions.

3.1.1. Dynamic hypotheses

The dynamic hypothesis of this study is developed based on a systematic literature review, expert insights, and a systems thinking perspective. The core assumption is that the development of sustainable academic entrepreneurship in Iranian universities is shaped by a set of interrelated structural, behavioral, and policy-related variables that interact through complex feedback loops. The hypothesis posits that the observed sluggishness and instability in sustainable academic entrepreneurship stem from the dominance of structural barriers over reinforcing mechanisms. These structural constraints include insufficient entrepreneurial education infrastructure, inadequate financial support, limited industrial experience among faculty and students, managerial instability, weak institutional commitment, and the absence of consistent and enabling policies. In contrast, reinforcing loops can be activated by improving entrepreneurship education, enhancing targeted financial support, strengthening university–industry linkages through industrial experience, reducing managerial turnover, fostering high-level commitment, and institutionalizing supportive regulations. These actions are hypothesized to create a reinforcing feedback system that increases idea success rates, encourages the establishment of sustainable innovation centers, and gradually transforms the academic environment into a more entrepreneurial and sustainable ecosystem. For instance, improved entrepreneurship education raises awareness and capabilities, increasing idea success rate and creating a self-reinforcing cycle of innovation. Financial support accelerates commercialization and infrastructure development, while industrial experience bridges the gap between theory and practice. Managerial stability ensures continuity of strategy and trust. Leadership commitment mobilizes resources and embeds a culture of entrepreneurship. Finally, enabling policies reduce bureaucratic frictions and promote coordinated institutional efforts. Together, these interacting variables form the foundation of the system dynamics model and are visualized through a Causal Loop Diagram in the next section.

3.1.2. Causal loop diagram

The Cause-and-Effect Loop Diagram (CLD) is presented in Figure 3, which effectively illustrates the complex causal relationships between the identified variables related to sustainable academic entrepreneurship. This diagram also shows the key reinforcing and balancing cycles in the university ecosystem. The 25 factors extracted through the meta-synthesis were operationalized as input variables in the system dynamics model. To capture both tangible and intangible aspects, each factor was mapped into causal relationships and translated into parameter values. Where empirical data were available, they were used for quantification; in cases where data were unavailable, expert judgment was employed. This approach ensured that qualitative factors—such as institutional support, entrepreneurial culture, and resistance to change—were also adequately represented in the simulation model. To enhance transparency, the assumptions of the model were clearly stated. In cases where empirical data were limited, assumptions were grounded in established findings from the literature and refined through expert consultations. This approach ensured that the model remained both empirically valid and practically feasible, while acknowledging the constraints of data availability.

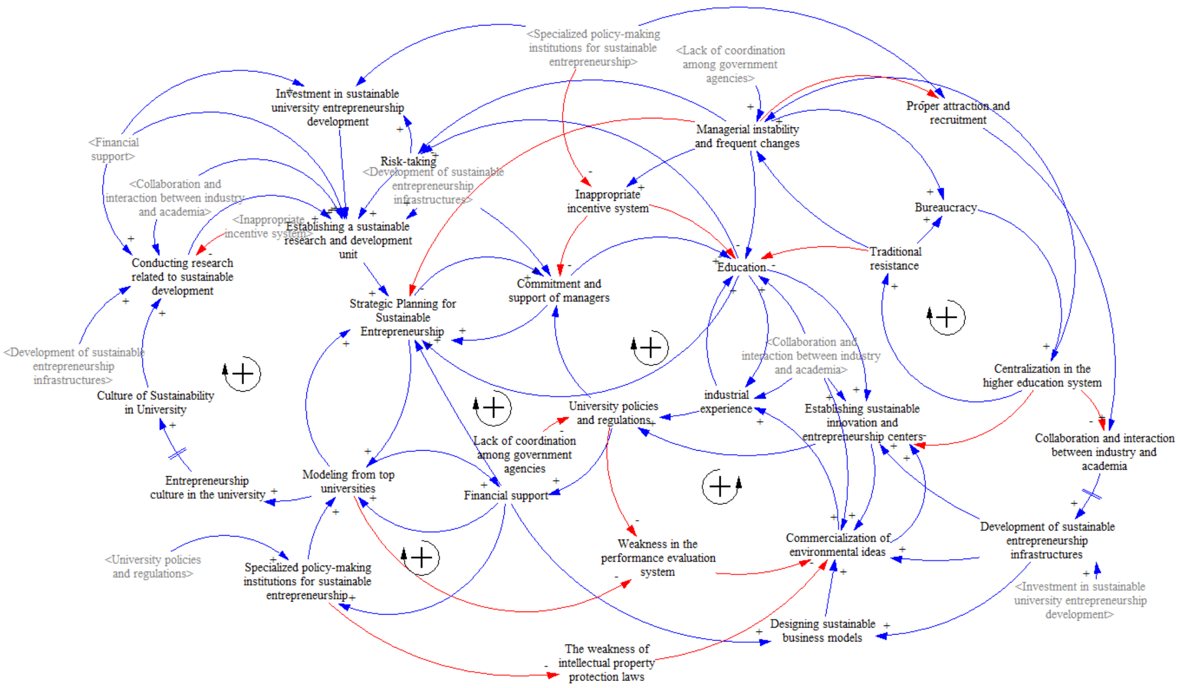

Figure 3. Diagram of the Causal Loop Diagram of sustainable academic entrepreneurship

3.1.3. *Stock and flow diagram*

This diagram illustrates how the variables within a system interact with one another and can serve as a foundation for developing a quantitative model. In drawing a flow diagram, it is essential to understand two key concepts: stock and flow. In any system, the values of certain variables increase or decrease over time. These are referred to as stock variables. The rate at which these variables increase or decrease is called the flow.

A system's flow diagram can be derived using the literature review, expert opinions, and data collected from time-series sampling. During the development of this diagram, quantitative formulas, qualitative relationships, and numerical functions are utilized.

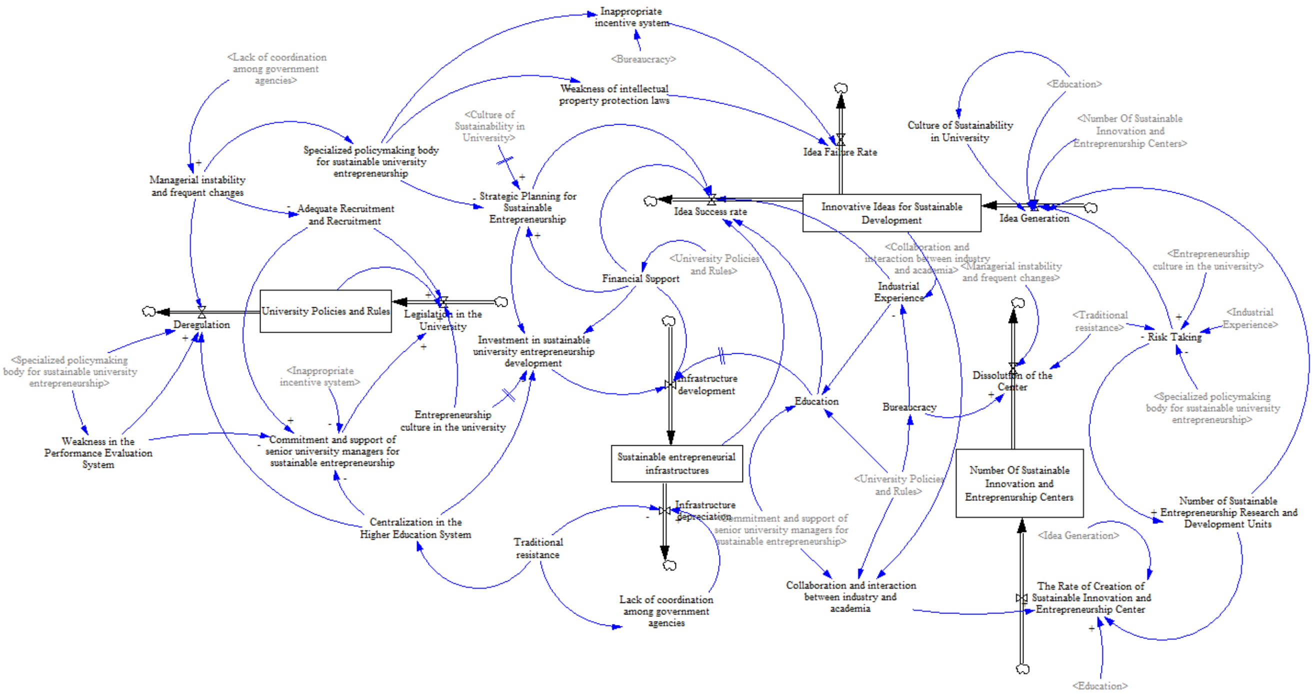

Figure 4. Diagram of the state and flow of sustainable academic entrepreneurship

The stock and flow diagram consists of several important sections. The most significant part of the model is related to the number of innovation and sustainable entrepreneurship centers, which is presented along with the key influencing variables. Another part of the model describes sustainable innovative ideas and the related factors. The most important variable in this regard is idea success rate, which reflects the university's overall performance in achieving sustainable entrepreneurship. Another section of the model addresses variables including managerial instability and frequent changes, weak intellectual property protection regulations, ineffective performance evaluation systems, inappropriate incentive mechanisms, lack of specialized policy-making institutions, bureaucracy, lack of coordination among governmental bodies, and traditional resistance—all of which have a negative impact on sustainable academic entrepreneurship over time. A further section of the model focuses on variables including university laws and policies, commitment and support of senior management, strategic planning, and financial support and investment in the direction of sustainable academic entrepreneurship. These variables have a positive and aligned influence on the development of sustainable academic entrepreneurship.

3.1.4. Model validation

After designing the system dynamics model of the factors influencing the success of sustainable academic entrepreneurship, it is necessary to evaluate its validity prior to simulation. In fact, validating the flow model is a crucial part of the research process that lends credibility to the research findings. Model validation is essential and significant to ensure the model's acceptability by examining its closeness to real-world conditions (Gray and O'Connor, 2018).To strengthen the credibility of the model, several validation procedures were . performed. These included structural verification, extreme condition tests, and comparison of simulated results with patterns reported in the literature. In addition, iterative feedback from academic experts was incorporated to refine assumptions and parameter values, thereby improving the reliability of the simulation outcomes. To ensure the validity of the model's performance, the following tests were conducted.

a) Model Structure Assessment Test:

This test seeks to answer the question: Is the model structure consistent with the existing knowledge of the system? In response, it should be stated that the identification of variables used in designing the system dynamics model of factors influencing the success of sustainable academic entrepreneurship was based on a comprehensive literature review and relevance to the research topic. In this study, with the assistance of experts and professionals in the field of sustainable academic entrepreneurship, the structure of the model was evaluated, and the structural validity of the model was confirmed.

b) Parameter Assessment Test:

This test addresses the question: Are the parameter values in the model consistent with real-world values? Given that the variables used in the model were derived from previous studies, many of the parameter values were extracted from relevant research, making them aligned with actual values. In cases where the literature did not provide specific parameter values, appropriate estimates were assigned based on expert judgment and consultation.

3.1.5. Model simulation and key findings

System dynamics modeling and simulation help researchers see how complex systems act when different policies or feedback are used. Simulation is not just a technical tool; it is a way to learn more about how real-world systems work. Running simulations based on scenarios lets users check how management practices, policies, and support systems might affect sustainable academic entrepreneurship over time. This matches recent studies that stress the value of simulation for policy design and learning (Elsawah et al., 2020; Lane, 2023). In the end, knowing how the model works lets stakeholders better predict what could happen and find good places to intervene in university entrepreneurial environments. Figure 4 shows the simulation results made with Vensim, shown as stock-and-flow diagrams. These results show how key factors for sustainable academic entrepreneurship change over time.

One of the key variables in this analysis is “Education”, which began at a very low initial level and gradually followed an upward trend. However, its final value indicates that progress in entrepreneurial education has been slow, and the potential capacities in this area have not yet been fully realized. This weakness can pose a significant barrier to empowering academic human resources in the transition toward an entrepreneurial university. The variable “Managerial Instability and Frequent Changes” started with a relatively high initial value and gradually decreased, albeit with a very slight slope. This pattern reflects a persistently high level of instability throughout the observed period, which could hinder the effective implementation of entrepreneurial policies .The variable “University Policies and Rules” followed a consistent upward trend without significant fluctuations. However, its overall value remained low during the period, indicating structural weakness and the lack of institutionalized supportive policies for sustainable entrepreneurship within universities. Regarding the variable “Commitment and Support of Senior University Management for Sustainable Entrepreneurship”, a declining trend is observed in the early years, followed by a gradual increase in the middle of the period. Nevertheless, the overall variation was limited, and the value remained low, suggesting a lack of strong and consistent managerial will to support entrepreneurial initiatives .The variable “Industrial Experience of Students and Faculty Members” also showed an increasing trend but remained at a low level. This reflects limited university-industry interaction and scarce opportunities for practical experience in real production and economic environments .The variable “Financial Support”, considered one of the most critical factors for entrepreneurial success, experienced a relatively sharp decline over time. This decrease could directly impact universities' ability to support innovation, build necessary infrastructure, and encourage student participation in entrepreneurial activities .The variable “Idea Success rate”, as an indicator of progress toward sustainable academic entrepreneurship, started at a low level but gradually increased with a modest upward slope. Although the pace of growth is not remarkable, it can be interpreted as a sign of a slow yet steady movement toward strengthening innovation infrastructure and building a university-based entrepreneurial ecosystem .Finally, the variable “Number of Sustainable Innovation and Entrepreneurship Centers” was considered as a structural indicator of entrepreneurial success. This variable remained nearly unchanged throughout the period and maintained a generally low level, indicating limited development of institutional support structures in the domain of academic entrepreneurship.

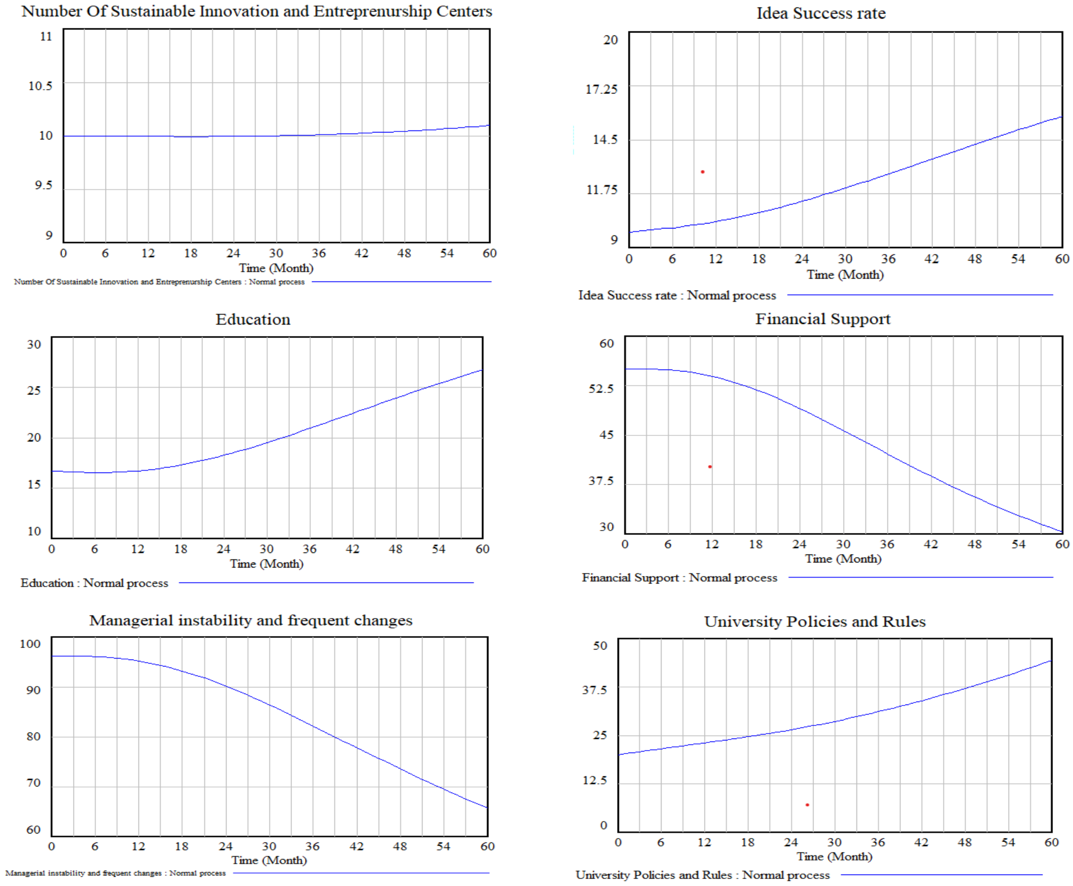

Figure 5. The behavior of the model's key variables during the simulation period

4. Analysis of results (Scenario building and policy evaluation)

One of the most significant capabilities of the system dynamics approach is its ability to incorporate various scenarios and compare their outcomes. Once a valid model with an improved policy structure has been developed, it can be used to design and evaluate alternative future scenarios. At this stage, multiple managerial options can be explored by considering different policy and systemic parameters, and their impacts on the dynamic behavior of the model can be assessed as potential future trajectories. Scenario development involves making different decisions based on the nature of the problem and analyzing their consequences through simulation. The resulting data enable policymakers to evaluate the effectiveness of each strategy and compare its outcomes with one another. In this study, seven policy-oriented scenarios have been developed to analyze and enhance the level of sustainable academic entrepreneurship. In the following sections, each scenario is introduced and discussed in detail.

4.1. Scenario 1: Enhancing the education variable

A significant portion of success in academic entrepreneurship stems from the quality of education provided by universities. In this scenario, the effects of increasing the level of entrepreneurship-related education are examined by analyzing the associated variables. As illustrated in Figure 6, the rate of success for entrepreneurial ideas shows a considerable increase from the beginning of the simulation period. Furthermore, the number of sustainable innovation and entrepreneurship centers begins to rise after a few months, indicating a delayed but positive response to educational improvements (Figure 6).

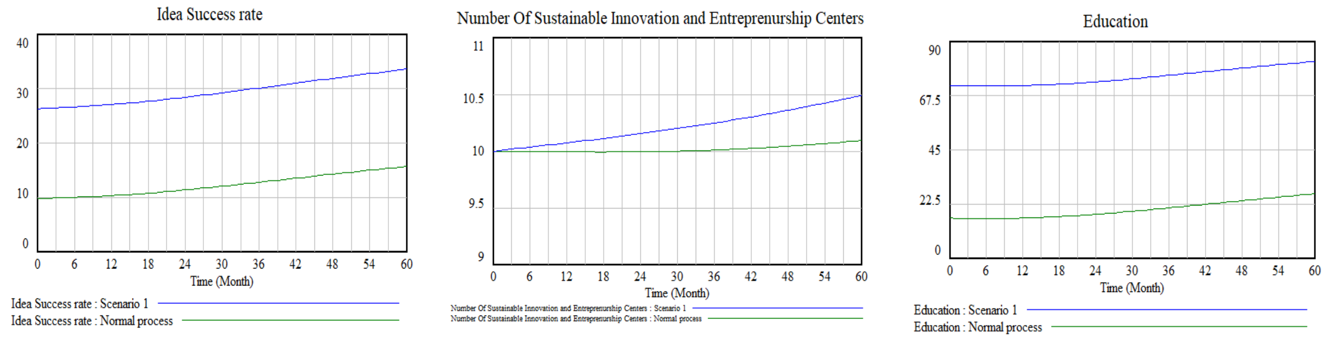

Figure 6. Simulation comparison of key variables under the first scenario and baseline trend

4.2. Scenario 2: Increasing financial support

In this scenario, the level of financial support was enhanced to examine its impact on key variables, including the success rate of entrepreneurial ideas and investment in the development of sustainable academic entrepreneurship. As shown in Figure 7, an increase in financial support leads to a significant rise in both the success rate of entrepreneurial ideas and investment in sustainable academic entrepreneurship (Figure 7).

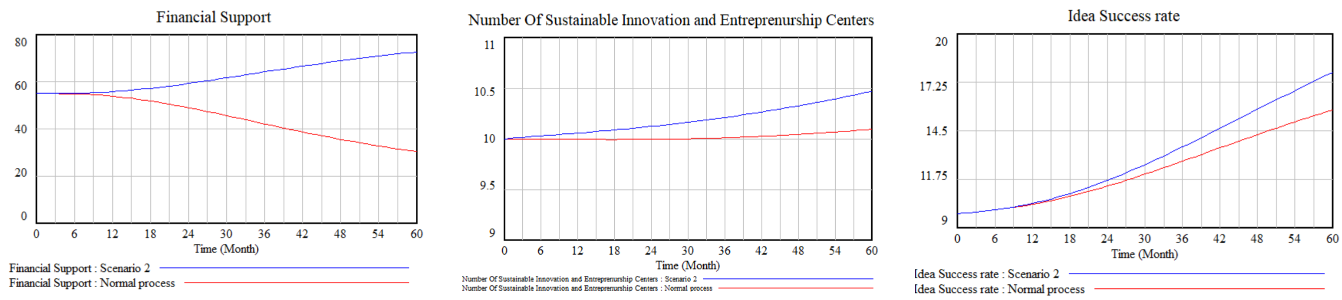

Figure 7. Simulation comparison of key variables under the second scenario and baseline trend

4.3. Scenario 3: Enhancing industrial experience

The third scenario examines the impact of increasing the industrial experience of students and faculty members on the success rate of sustainable entrepreneurial ideas and the establishment of sustainable innovation and entrepreneurship centers over time. According to the results of this scenario, as industrial experience among students and faculty members increases, the necessary foundation is laid for improving both the success rate of entrepreneurial ideas and the number of sustainable innovation and entrepreneurship centers. Once this foundation is established, it subsequently contributes to an improvement in entrepreneurship education at the university level. These factors collectively play a critical role in advancing and ensuring the success of sustainable academic entrepreneurship (Figure 8).

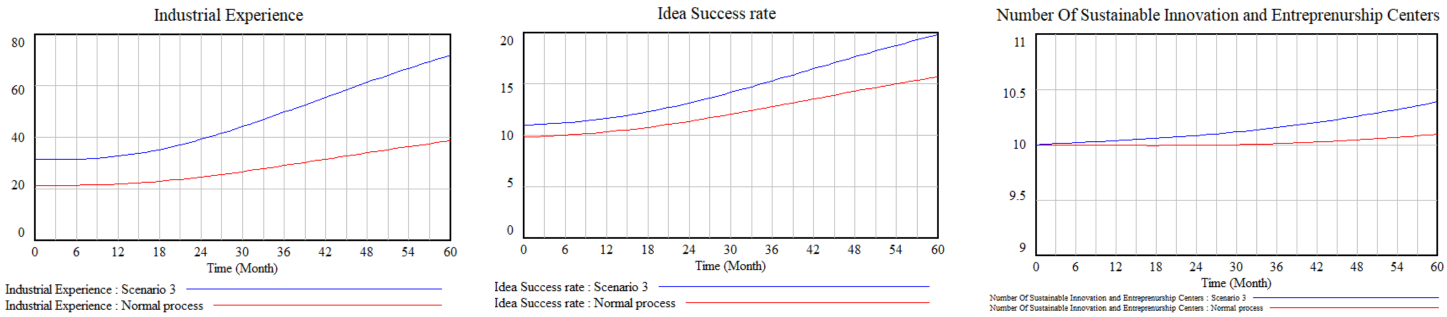

Figure 8. Simulation comparison of key variables under the third scenario and baseline trend

4.4. Scenario 4: Reducing managerial instability and frequent administrative changes

The fourth scenario investigates the impact of managerial instability and frequent administrative changes on the success rate of sustainable entrepreneurial ideas and the establishment rate of sustainable innovation and entrepreneurship centers over time. According to this scenario, reducing managerial instability and minimizing frequent leadership turnover creates the necessary foundation for increasing both the success rate of entrepreneurial ideas and the number of sustainable innovation and entrepreneurship centers. Once such stability is achieved, a more favorable environment emerges for fostering sustainable academic entrepreneurship (Figure 9).

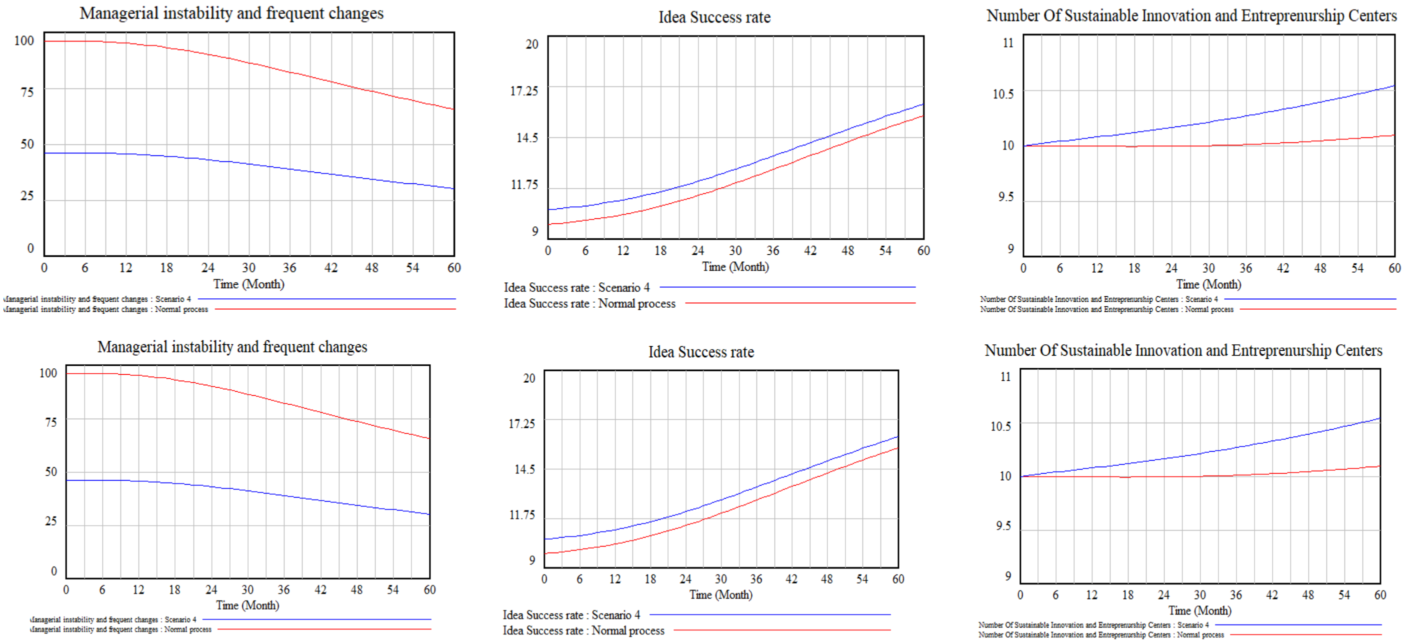

Figure 9. Simulation comparison of key variables in scenario four and normal trend

4.5. *Scenario 5: Increasing commitment and support from senior university managers for sustainable entrepreneurship*

In the fifth scenario, the model examines the impact of enhancing the commitment and support of senior university managers toward sustainable entrepreneurship on key variables. Figure 10 illustrates the effect of increasing this variable on the success rate of entrepreneurial ideas, education, and the establishment rate of sustainable innovation and entrepreneurship centers. As observed, implementing this scenario results in a significant increase in the number of innovation and entrepreneurship centers as well as in educational efforts. Additionally, the success rate of entrepreneurial ideas shows a similar positive effect, doubling by the final year of the simulation period (Figure 10).

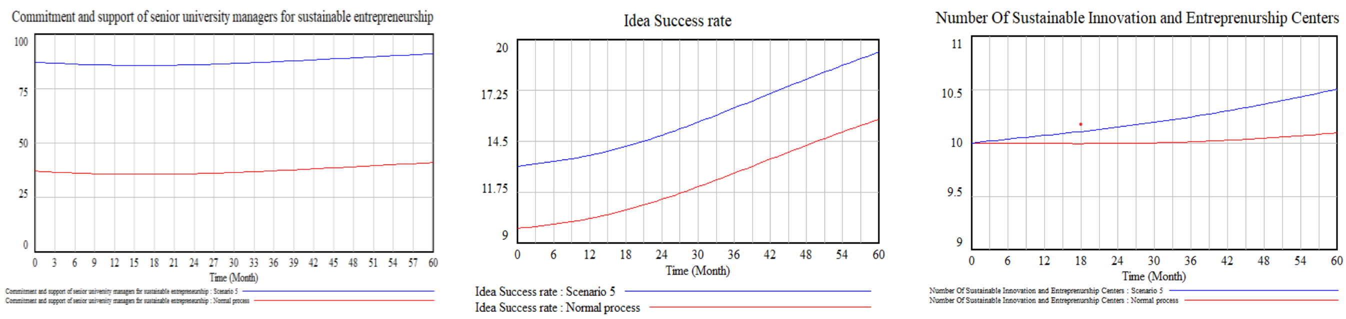

Figure 10. Simulation comparison of key variables in scenario five and normal trend

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4.6. *Scenario 6: Increasing the variable of policies and regulations*

In Scenario 6, the value of the variable policies and regulations was increased, which consequently led to an increase in the variable's idea success rate and the rate of establishment of sustainable innovation and entrepreneurship centers, as shown in Figure 11. The idea success rate exhibited a steep and significant upward trend, while the number of sustainable innovation and entrepreneurship centers also increased considerably.

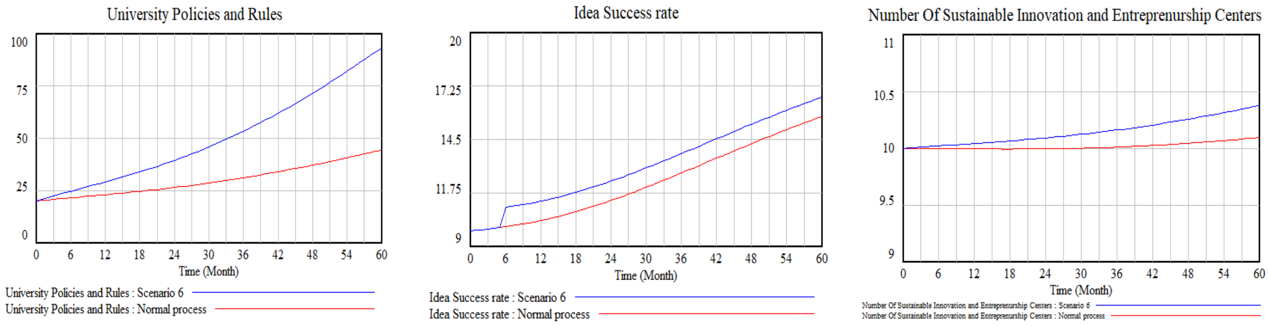

Figure 11. Simulation comparison of key variables in scenario six and normal trend

4.7. *Scenario 7: Simultaneous implementation of scenarios 1–6*

The simultaneous implementation of Scenarios 1 through 6 led to a significant increase in both the idea success rate and the number of sustainable innovation and entrepreneurship centers. The upward trend and substantial improvement in these indicators are illustrated in Figure 12.

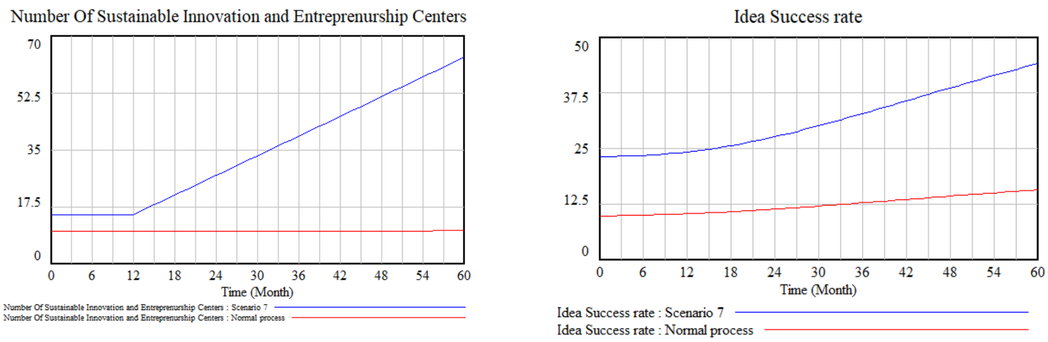

Figure 12. Simulation comparison of key variables in scenario seven and normal trend

5. Conclusion

Sustainable university entrepreneurship is recognized today as a key component of sustainable development within higher education. This study employs system dynamics modeling to analyze the interactive effects of educational, financial, institutional, and managerial interventions on strengthening the entrepreneurial ecosystem within universities. Based on scenario analyses, the following results were obtained:

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Scenario 1, focusing on enhancing entrepreneurship education, demonstrated that structured training leads to an immediate increase in idea success rate. However, its impact on the establishment of sustainable institutions exhibited a time lag, indicating that educational interventions require longer-term reinforcement to influence institutional structures. This finding aligns with Etzkowitz (2023), who emphasizes the role of education in enhancing entrepreneurial skills. Scenario 2 regarding financial support revealed that funding has limited short-term effectiveness, and its impact depends on the capacity for institutional absorption and learning. These results are consistent with Sterman (2000) and Guerrero and Marozau, (2023). Scenario 3, examining the increase in industrial experience among members, highlighted its crucial role in strengthening experiential learning and facilitating knowledge transfer into products, reinforcing the importance of industry-academia collaboration (Guerrero and Marozau, 2023). Scenario 4, addressing managerial stability, showed that structural stability and long-term decision-making enhance internal trust and strategic sustainability within the entrepreneurial ecosystem, echoing the findings of Etzkowitz and Zhou (2018). Scenario 5, increasing senior managers' commitment, revealed that leadership support significantly influences all model variables, confirming that committed leadership is fundamental for entrepreneurial transformation (Mousavi et al., 2023; Rasmussen and Wright, 2015). Scenario 6, focusing on policies and regulations, emphasized the pivotal role of clear laws, supportive frameworks, and soft infrastructures in institutionalizing entrepreneurship, consistent with Naderi and Amiri (2021) and Klofsten et al. (2019). Scenario 7, involving the simultaneous implementation of all interventions, showed the highest effectiveness, resulting in systemic and sustainable transformation within universities. This confirms that integrated, multilayered, and synergistic interventions are most effective in developing entrepreneurial ecosystems (Etzkowitz, 2008; Guerrero and Urbano, 2012).

Overall, these findings indicate that sustainable university entrepreneurship cannot be achieved through isolated interventions alone. A systemic, long-term, synergistic, and institutionalized approach is required. Universities that effectively integrate human, structural, and cultural elements are better positioned to contribute actively to national sustainable development.

Limitations and implications: It should be noted that the simulation results are contingent on the selected variables and assumptions, and real-world implementation may vary due to contextual differences. Future research could extend the model by incorporating additional factors such as digital infrastructure, external partnerships, and policy shifts.

Practical recommendations: Universities should prioritize simultaneous interventions in education, finance, management, and policy, ensure leadership commitment, and foster industry-academia collaboration. Policy-makers are advised to support systemic strategies rather than isolated programs, emphasizing long-term and integrated development of entrepreneurial ecosystems.

Disclosure statement

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

References

Alden, M., Smith, K., and Johansson, L., 2017. Social entrepreneurship and community development: An integrated approach to solving social problems. *Journal of Social Innovation*, *12*(3), pp.201–215.

Abreu, M., Demirel, P., Grinevich, V. and Karataş-Özkan, M., 2016. Entrepreneurial practices in research-intensive and teaching-led universities. *Small business economics*, *47*(3), pp.695-717. https://doi.org/10.1007/s11187-016-9754-5.

Breznitz, S.M. and Etzkowitz, H., 2014. *University Technology Transfer : The globalization of academic innovation*. Routledge.

Burzyńska, D., Bartoszczuk, P., & Gawlik, A., 2018. Sustainable entrepreneurship in practice: A review of existing literature. *Sustainability*, *10*(12), 4321. https://doi.org/10.3390/su10124321

Currie, D.J., Smith, C. and Jagals, P., 2018. The application of system dynamics modelling to environmental health decision-making and policy-a scoping review. *BMC public health*, *18*(1), p.402. https://doi.org/10.1186/s12889-018-5318-8.

Dionisio, P., 2019. Social entrepreneurship: An emerging field and its role in addressing societal challenges. *Journal of Social Entrepreneurship, 14*(2), pp.85-102.

Elsawah, S., Filatova, T., Jakeman, A.J., Kettner, A.J., Zellner, M.L., Athanasiadis, I.N., Hamilton, S.H., Axtell, R.L., Brown, D.G., Gilligan, J.M. and Janssen, M.A., 2020. Eight grand challenges in socio-environmental systems modeling. *Socio-Environmental Systems Modelling*, *2*, p.16226. https://doi.org/10.18174/sesmo.2020a16226.

Etzkowitz, H., 2008. *The triple helix: University-industry-government innovation in action*. Routledge.

Etzkowitz, H., 2023. The impact of structured training on entrepreneurship education: A long-term view on sustainability. *Journal of Entrepreneurship and Education, 29*(2), pp.112-130.

Etzkowitz, H., and Zhou, C., 2018. Addressing managerial instability: The role of structural stability and long-term decision-making in fostering internal trust and strategic sustainability in entrepreneurial ecosystems. *Journal of Innovation and Entrepreneurship, 12*(3), pp.221-239.

Fayolle, A. and Redford, D.T., 2014. *Handbook on the entrepreneurial university*. Edward Elgar Publishing.

Guerrero, M., Urbano, D., Fayolle, A., Klofsten, M. and Mian, S., 2016. Entrepreneurial universities:

emerging models in the new social and economic landscape. *Small business economics*, *47*(3), pp.551-563. https://doi.org/10.1007/s11187-016-9755-4.

Guerrero, M. and Urbano, D., 2012. The development of an entrepreneurial university. *The journal of technology transfer*, *37*(1), pp.43-74. https://doi.org/10.1007/s10961-010-9171-x.

Guerrero, M. and Marozau, R., 2023. Assessing the influence of institutions on students' entrepreneurial dynamics: evidence from European post-socialist and market-oriented economies. *Small Business Economics*, *60*(2), pp.503-519.

Goddard, J., Kempton, L. and Vallance, P., 2012. The civic university: Connecting the global and the local. In *Universities, cities and regions* (pp. 43-63). Routledge. URL: http://www.routledge.com/books/details/9780415631082/.

Gupta, S.M., 2020. Towards an integrative definition of scaling social impact in social enterprises. *Journal of Business Venturing Insights*, *13*, p.e00164. https://doi.org/10.1016/j.jbvi.2020.e00164.

Gray, D. L., and O'Connor, R. V., 2018. An insight into validation and verification approaches in simulation modelling research. *International Journal of Simulation and Process Modelling*, *13*(5–6), pp.527–548. https://doi.org/10.1504/IJSPM.2018.095927.

Jolink, A., and Niesten, E., 2015. Sustainable development and business models of entrepreneurs in the organic food industry. *Business Strategy and the Environment*, *24*(6), pp.386–401. https://doi.org/10.1002/bse.1826.

Klofsten, M., Fayolle, A., Guerrero, M., Mian, S., Urbano, D. and Wright, M., 2019. The entrepreneurial university as driver for economic growth and social change-Key strategic challenges. *Technological Forecasting and Social Change*, *141*, pp.149-158. https://doi.org/10.1016/j.techfore.2018.12.004.

Kaplaperis, P., Stathopoulou, A., and Giannarakis, G., 2020. Social entrepreneurship as a vehicle for addressing poverty and inequality. *International Journal of Entrepreneurship and Small Business*, *41*(1), pp.42–60.

Lane, D. C., 2023. The power of system dynamics: addressing grand challenges in complex systems. System Dynamics Review, *39*(1-2), 5–28.

Mousavi, M. S., Rezaeifar, H., Mohammadi, M., and Yaghoubi, N., 2023. Investigating the increase in senior managers' commitment: The influence of leadership support on model variables. *Journal of Management Studies, 45*(7), pp.456-472. https://doi.org/10.48308/jpap.2023.103571.

López, A., Kundu, S. K., and Ciravegna, L. 2016. Entrepreneurship in family firms: A systematic review and future research agenda. *Journal of Family Business, 15*(3), pp.217-232. https://doi.org/10.1016/j.jfbs.2016.07.002

Naderi, M., N., and Amiri, S. 2021. Strengthening university policies and regulations: The role of clear laws, supportive frameworks, and soft infrastructures in institutionalizing entrepreneurship. *Journal of Entrepreneurship Education, 24*(5), pp.142-158. https://doi.org/10.22092/jaear.2018.123467.1552.

Rasmussen, E., and Wright, M., 2015. Investigating senior managers' commitment: The influence of leadership support on organizational outcomes. *Journal of Management and Organizational Behavior, 38*(6), pp.1345-1362.

Rey-Martí, A., Ribeiro-Soriano, D. and Palacios-Marqués, D., 2016. A bibliometric analysis of social entrepreneurship. *Journal of business research*, *69*(5), pp.1651-1655. https://doi.org/10.1016/j.jbusres.2015.10.03.

Rybnicek, R. and Königsgruber, R., 2019. What makes industry–university collaboration succeed? A systematic review of the literature. *Journal of business economics*, *89*(2), pp.221-250. https://doi.org/10.1007/s11573-018-0916-6.

Roslan, S., Mohd Nor, M. Z., and Yusof, S. N., 2020. Fostering social entrepreneurship through higher education: A Malaysian perspective. *International Journal of Academic Research in Business and Social Sciences*, *10*(2), pp.123–134. https://doi.org/10.6007/IJARBSS/v10-i2/6926

Sassetti, S., Marzi, G., Cavaliere, V. and Ciappei, C., 2018. Entrepreneurial cognition and socially situated approach: A systematic and bibliometric analysis. *Scientometrics*, *116*(3), pp.1675-1718.

Sattar, R., Lawton, R., Panagioti, M. and Johnson, J., 2021. Meta-ethnography in healthcare research: a guide to using a meta-ethnographic approach for literature synthesis. *BMC health services research*, *21*(1), p.50. https://doi.org/10.1186/s12913-020-06049-w.

Şener, Ş., Karabacak, K., and Yıldırım, M., 2018. Green entrepreneurship in universities: A pathway to sustainable development. *Journal of Cleaner Production*, 172, pp.4390–4402.

Sharma, P., 2019. Innovation and entrepreneurship: Key drivers of economic growth and societal development. *Journal of Innovation and Entrepreneurship, 17*(2), pp.150-167.

Sterman, J. D. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. McGraw-Hill.

Trippl, M., Sinozic, T. and Lawton Smith, H., 2015. The role of universities in regional development: Conceptual models and policy institutions in the UK, Sweden and Austria. *European Planning Studies*, *23*(9), pp.1722-1740.. https://doi.org/10.1080/09654313.2015.1052782.

Wallaster, C., Kraus, S., Merigó Lindahl, J. M., & Nielsen, A., 2019. Ethics and entrepreneurship: A framework for sustainable business practices. *Journal of Business Ethics, 58*(3), pp.245-263. https://doi.org/10.1016/j.jbusres.2019.02.050.

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Systems Thinking in the Age of Environmental Complexity: A Practical Urban Problem-Solving Framework

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ABSTRACT

Urban environments are becoming increasingly complex, so urban planning requires new and innovative approaches to address these challenges. This study explores a detailed framework to address these challenges by combining different problem-solving techniques across three key stages: identifying the problem (What), analysing the problem (Why), and developing solutions (How). The research employs various tools, including SWOT analysis, Fishbone diagrams, World Café, and Causal Loop diagrams. Also, it evaluates the effectiveness of their usage by combining various methods, including questionnaires with urban planning students and real-world case studies. The findings underscore the importance of integrating qualitative and quantitative techniques to promote collaboration and informed decision-making. For example, tools like Discovery & action dialogue (DAD) help create inclusive engagement, while data-driven approaches like GIS mapping provide actionable insights. The study also highlights patterns in how these techniques perform at different stages. The proposed framework addresses a wide range of challenges, from simple to complex, such as ill-defined, ethical, and wicked problems. It highlights the importance of adaptability and learning through iterative processes. This research offers a comprehensive, structured, and integrative framework for urban settings. This framework is designed to help urban practitioners, policymakers, and educators navigate the complexities of urban systems while improving decision-making, and it can be adapted to different contexts.

Keywords

Urban problem-solving, Problem-solving techniques, System thinking, Case analysis, Integrated methodology.

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1. Introduction

Problem-solving is one of the most essential elements of a system. The growing complexity of modern urban planning challenges conventional planning and design approaches to their limits (Koenig et al., 2020). In academic settings, educators train urban planning students to apply scientific and technical knowledge to well-defined problems. However, graduates must also be prepared to tackle complex, open-ended urban challenges involving economic, environmental, social, political, ethical, and sustainability constraints (Ruby et al., 2013). Problem-solving is a core skill that combines critical and creative thinking. It improves deep cognitive processing and requires mastery of analytical and evaluative tools (Gusau et al., 2020). The process of problem-solving enables people to use both critical and creative thinking to solve common issues. By avoiding a tendency to approach problems randomly, creative problem-solving prevents surprises and dissatisfaction with the outcome (Treffinger et al., 2023).

Additionally, this process fosters higher-order skills and is recognized as one of the essential competencies in the field (Guaman-Quintanilla et al., 2023). This study proposes a structured framework to address these challenges by focusing on three key questions: What are the issues? Why do they exist? How can they be solved? Through a systematic literature review, case study analysis, and a questionnaire collecting student feedback, the research evaluates the effectiveness of problem-solving techniques. It introduces a novel framework tailored to urban contexts.

2. Literature review

This section studies problems and problem-solving concepts. The section also examines problem-solving frameworks and techniques while reviewing and evaluating related case studies.

2.1. Problem and problem-solving concepts specifically in urban areas

Problems are general terms that carry both positive and negative meanings, exist in varying degrees, and have multiple levels. Getzels (1982) distinguished between two definitions: a problem happens when a desired action is blocked, and a problem occurs in unfavourable circumstances with clearly defined issues (Abdulla and Cramond, 2018). Any unanticipated, undesirable incident or circumstance that must be addressed and managed before it becomes overly complicated is a problem in any project or assignment. Another way to describe a problem is the difference between what should happen and what occurs (Pal and Poyen, 2017).

2.1.1. Urban problem

To gain a deeper understanding of urban problems, a bibliometric analysis was conducted using Vos Viewer software, focusing on the keywords "problem" and "urban studies". This analysis identified the most frequently addressed urban challenges in the academic literature over the past few years. The software output divided the keywords into twelve clusters. Each node symbolizes a keyword, and its size is related to its value and importance. Additionally, the keywords clustered together were strongly related and found in similar documents. Furthermore, in monitoring the years of publication, papers utilized keywords such as mental health, Transportation, climate change, urbanization, and behavioural problems, which reflect the challenging and complex nature of urban problems. For instance, mental health is often linked with keywords such as stress and depression in urban studies. Moreover, Transportation is another key issue related to cost reduction, efficiency, and environmental impact mitigation. The primary objective of using this bibliometric analysis was to highlight the complexity and interconnectedness of urban challenges, demonstrating that these problems rarely occur in isolation. The Co-occurrence analysis (Figure 1) revealed the need for a structured and adaptable problem-solving framework capable of navigating the multidimensional nature of urban planning. These findings support the study's goal of identifying and refining a practical framework suitable for the complex and evolving demands of urban planning practice and education.

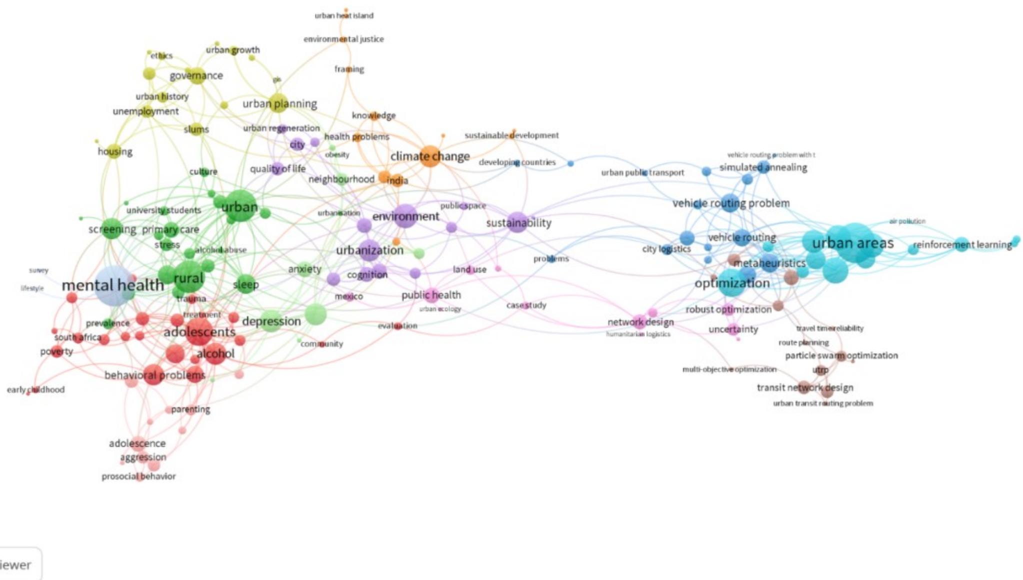

Figure 1. Co-occurrence analysis by keyword in the Network visualization (Vos viewer)

It is essential to understand the various types of problems and their importance, including wicked problems, which are particularly relevant to urban challenges due to their complexity. Therefore, Table 1 demonstrates the problem and the wicked problem.

Table 1. Exploring the concept of the problem and the wicked problem (Ruhl and Salzman, 2020)

Type		Definition	Example
Simple or well-defined problems		Clear, straightforward, have solutions, easy to identify and implement	The problem of streetlights is easy to identify and solve; it can be quickly repaired or replaced to ensure public safety and visibility.
Complex problems		More complicated, involving multiple factors, still solvable, requiring a more profound understanding	Traffic congestion involves numerous factors and requires a detailed analysis, but it can still be effectively managed through targeted strategies.
Ill-defined problems		Harder to articulate clearly, difficult to determine the best path, unclear objectives, incomplete data, and uncertainty about the proper method.	Urban water supply management is a complex task that requires balancing the demands of residential, industrial, and agricultural sectors.
Social problems		Impact large groups of people; more complex than technical problems, they involve human behavior, values, and varying perspectives.	Cities face challenges integrating migrants and refugees, resulting in social tensions, housing shortages, and public service pressure.
Ethical or moral problems		Concerns and dilemmas that involve right and wrong, often with no clear or universally accepted solutions, require subjective judgments and may lead to different solutions.	Cities are integrating surveillance technologies for traffic management, public safety, and urban planning, which raises ethical concerns about privacy. Balancing efficiency, security, and individual rights is crucial.
Wicked problem	No definitive problem definition	Wicked problems resist simple and definitive understanding or framing.	Cities face diverse and evolving impacts of climate change, making it difficult to define the exact nature of the problem or find a one-size-fits-all approach.
	No stopping rule	Wicked problems evolve continually, making it impossible to declare any solution truly “complete.	Air pollution control is an ongoing process with no clear endpoint.
	Solutions are not true-or-false but better-or-worse	The complexity of wicked problems means that solutions cannot be neatly categorized as correct or incorrect.	Expanding public transit doesn’t have a single “right” answer, but options must be weighed in terms of cost, coverage, and efficiency, considering their varying impacts on different groups.
	No immediate test of a solution	Solutions to wicked problems can take years or even decades to fully manifest.	The effects of redevelopment, such as economic revitalization or displacement, may take years or challenging to assess success even after several decades.
	One-shot operations	Every attempt to solve a wicked problem has lasting consequences.	Large infrastructure projects (such as building a bridge or tunnel) are costly and difficult to reverse, so each decision has long-term, irreversible consequences.
	Unique nature	Every wicked problem has its own unique set of characteristics, based on its specific context.	Each city faces unique risks from natural disasters, necessitating tailored solutions that are specific to its geography, infrastructure, and population needs.
	Interconnectedness	Wicked problems are often interconnected. Addressing one issue may lead to unintended consequences in another area.	Affordable housing projects are often linked to transportation access, so improving housing far from urban centers can increase commute times and create new challenges, such as traffic congestion.
	No exhaustive set of solutions	Wicked problems don’t have a finite or exhaustively known set of possible solutions, and there’s no guarantee that the “best” solution exists.	Urban waste management must strike a balance among various approaches, including recycling, landfills, and composting. No single solution fits every city’s needs and resources.
	Symptom of another problem	Wicked problems are a symptom of a larger, more complex issue. For instance, urban poverty may be a symptom of broader issues such as economic inequality.	Poverty in cities often results from broader economic issues such as unemployment, inadequate education, or systemic inequality, making it a symptom of larger problems.
	The planner has no right to be wrong.	Mistakes can have severe, long-term consequences, and there is little room for learning through failure.	Mistakes in designing flood defenses can lead to catastrophic outcomes, such as property damage or loss of life, so planning must be highly accurate and risk-averse.

2.2. *Problem-solving frameworks*

Finding new solutions to address a problem is a key aspect of problem-solving (Almulla, 2023). The problem-solving steps and their evolution over the past century are demonstrated in Table 2. Each framework breaks down into distinct stages, including problem identification, problem analysis, solution application, and evaluation.

Table 2. Exploring the problem-solving frameworks

Authors	**Stages**		
	What?	**Why?**	**How?**
Polya, 1945	Understanding the problem	Devising a plan	Carrying out the plan Looking back
Parnes, 1967	Fact-finding	Problem finding	Idea finding Solution finding Acceptance finding
Branford and Stein, 1993	Identify problems and opportunities	Define the Problems, develop and understand the goals	Explore possible strategies Anticipate potential effects before applying Look back and learn
Woods, 2000	Engage Define the stated problem	Explore: create the internal notion of the problem	Plan a solution Do it: carry out the plan Evaluate: check and look back
Lau et al, 2006	Define the problem	Analyze the problem	Develop hypotheses and determine interventions Monitor progress and evaluate effectiveness Repeat as necessary
Marksberry et al., 2011	Clarify the problem	Break down the problem Target setting Root cause analysis	Develop countermeasures Monitor both results and processes Standardize successful processes
Singer and Voica, 2013	Decoding representing	Processing	Implementing
Basadur et al., 2014	Generating	Conceptualization	Optimization Implementation
Payne, 2016	Data collection and observation	Problem definition analysis and categorization	Stakeholder involvement Continuous assessment
Koenig, 2020	Problem representation	Objective definition	Optimization using evolutionary algorithms Iterative evaluation and selection Visual analysis and stakeholder engagement
Choi, 2021	Field Research	Define Problems	Establish alternatives Evaluate alternatives Apply the solution Validation
Fraser, 2023	Defining the problem Appreciative inquiry	Considering multiple solutions Exploring multiple approaches	Seven decision-making styles Overcoming common mistakes
Kondić et al, 2024	Preparation	Resolution	Resolution &improvement of solutions
Proposed process	Problem identification	Problem analysis	Solution development Evaluation and feedback

Regardless of variations in terminology and focus, these models collectively emphasize the importance of iterative learning, stakeholder involvement, and flexibility in problem-solving and decision-making processes. According to the studies, these frameworks can be categorized into three periods.

1. Early foundations (1950-2000): Frameworks, such as Polya (1945), introduced their ideas based on systematic stages. Polya's widely cited model follows a linear concept, encompassing understanding the problem, devising a plan, carrying out the plan, and reflecting on the outcome. Parnes (1967) also recommended "fact-finding" and "idea-finding" stages to improve active brainstorming.
2. Integrative Models (2000-2012): Models such as Woods (2000) and Lau et al. (2006) began to emphasize motivation and metacognition ("engage: I want to, and I can"), as well as cyclic analysis and repeated interventions. Marksberry et al. (2011) introduced more detailed tools like root cause analysis, countermeasure development, and process standardization. These frameworks reflect a shift toward regular learning and the integration of quality and systems thinking principles.
3. Contemporary models (2012-present): The most recent models, including Basadur et al. (2014), Payne (2016), Koenig (2020), Choi (2021), Fraser (2023), and Kondić et al. (2024), reflect the increasingly complex nature of modern challenges. These approaches stress optimization, continuous assessment, evaluation, and stakeholder involvement. For example, Payne (2016) and Koenig (2020) emphasized stakeholder engagement and advanced analytical tools (e.g., evolutionary algorithms, visual analysis), whereas Choi (2021) and Fraser (2023) integrate validation, a variety of decision-making styles, and appreciative or collective inquiry. Kondić et al. (2024) exemplify the evolution toward ongoing improvement for modern urban and organizational problem-solving.

2.2.1. Comparative analysis

A comparative analysis of models from different periods reveals problem identification terms. Although the terminologies mentioned by the authors differ, they all emphasize the importance of having a clear and collective understanding of the problem. In the early stages, the concept of the problem is a challenge that needs to be solved. On the other hand, in the late periods, Iterative Evaluation and Selection, Evaluating, Refining, and Repeating are central to most contemporary approaches. In summary, every framework adjusts to various situations. Previous models are appropriate for organizing individual problem-solving, whereas subsequent models concentrated on collaborative and dynamic activities .Accordingly, the proposed process combines the strengths of approaches and explicitly incorporates iterative feedback at each stage.

2.3. Exploration of techniques

This section outlines various problem-solving and strategic planning techniques, detailing the steps and providing examples of urban challenges. Table 4 provides a comprehensive resource for addressing challenges and generating actionable solutions. The 12 problem-solving techniques were selected based on their widespread application in urban planning education and practice, as evidenced by their application in analysing complex urban issues. These techniques were selected for their simplicity, accessibility, and alignment with the three stages of problem-solving, as observed in an urban planning studio over several months. Techniques are categorized into three groups based on their purposes and nature: what, why, and how. Every technique offers a unique perspective for identifying problems, analyzing them, or finding solutions through creative steps. More complex tools were excluded due to their specialized training requirements and limited use in the educational context of this study. Importantly, the techniques were also selected for their adaptability to various urban planning contexts, from highly institutionalized systems in developed cities to informal or resource-limited environments. Tools like “Mind mapping”, “SWOT”, “Problem tree”, and the “Five whys” require minimal resources and facilitation, making them ideal for grassroots applications. Others, such as the “Causal loop diagram” or “Agreement certainty matrix”, can be scaled in complexity based on participants' expertise. Participatory techniques like “World café” and “Discovery & action dialogue” were chosen for their flexibility, cultural neutrality, and ability to engage diverse stakeholders across different settings.

1. WHAT: This category includes techniques like “SWOT”, “Mind maps”, and “Journalists”. SWOT analysis is a strategic approach to problem-solving and decision-making. It provides valuable insights for identifying essential internal and external factors that contribute to achieving the specified objective (Cui et al., 2019).
2. Why: Techniques like the “Five whys”, “Problem tree”, “Fishbone analysis”, and “Causal loop diagram” are presented in this category. For instance, the “Problem tree” (visual tool) or the “5 whys” techniques explore deeply to pinpoint the essential reasons behind issues. It ensures that solutions are extracted from the fundamental problems, rather than the symptoms.
3. How: Techniques like the “Agreement certainty matrix”, “World café”, “Discovery & Action dialogue (DAD)”, “Goal tree”, and “The Impact and effort matrix” are presented in this category. For instance, the “Impact and effort matrix” can guide teams in exploring unique and feasible ideas, as well as prioritize and plan for development.

Table 3 outlines urban environment techniques focusing on collaboration, inclusivity, and visualization for clarity. Collaboration and inclusivity are essential concepts for achieving optimal performance. Additionally, visualization for clarity is another aspect that offers explicit visual representations of relationships and focus areas. Structured problem-solving also helps to use these techniques step by step, providing a comprehensive view of problems and efficiently creating practical solutions.

Table 3. Exploration of problem-solving techniques

Categorization	Technique	Definition	Details	Source
What	SWOT	A SWOT analysis is a strategic planning tool. It identifies both external and internal elements needed to achieve a goal.	Steps Create a quadrant with "Strengths" and "Weaknesses" on the top left, "Opportunities" on the top right, and "Threats" on the bottom right. Generate ideas, sort, and create clusters. Start a group conversation to create broad categories for each cluster. Dot votes next to relevant categories, highlighting the most votes. Summarize the findings and engage the group in a creative exercise to evaluate weaknesses and threats in a positive light.	Cui et al, 2019 SessionLab,n.d.a
	Journalists	Journalists help groups avoid getting stuck in problem identification by allowing them to draft a fictional newspaper front page and determine stories' covers and headlines.	Steps Collecting potential stories for the first page. Choosing the most important story for thelead article. Write headlines for each article. Getting to the point in the first paragraph. Collecting essential facts for the second paragraph. Designing the entire page, if time allows	Smart, 2024
	Mind map	Mind mapping is a nonlinear learning technique that helps users explore the context through visual-spatial links that flow from a central theme to outer branches that may be interconnected.	Steps Pinpoint the central idea: choose a main idea for the environment, let it develop, and keep it straightforward. Provide branches for the categories, creating main branches for major concepts that represent specific knowledge or ideas. Expanding the sub-branches: generate sub-branches from main branches to investigate specific elements of each category, simplifying complex concepts into easily understood sections Using visuals: adding visual components to mind maps, such as colors, icons, or drawings, to make the content more interesting and memorable. Refine and review: step back and evaluate the effectiveness of the mind map.	Atlassian,n.d Rai and Kaur, 2025
Why	Fishbone analysis	Fishbone diagrams show cause-and-effect relationships in productivity and management. It reveals the main factors.	Steps Define the problem: clearly state the issue. Identify the main causes and determine the major categories. Brainstorm sub-causes: break down each category into specific factors. Analyze the diagram: examine relationships and prioritize potential causes for investigation.	Sakdiyah et al, 2022 SessionLab,n.d.b
	The 5 Whys	The Five Whys is a method for identifying the root cause of organizational issues, enabling a group to develop effective strategies. It involves creating and refining a problem statement through five	Stages — Examples by authors: air quality challenges Why? — Why is the urban area's air quality relatively poor? Because the region has a significant concentration of vehicle emissions. Why? — What causes the high car emissions in the urban area? Because a large number of individuals commute to work by car, which results in high pollution levels and frequent traffic congestion.	Smart, 2024

Categorization	Technique	Definition	Details		Source
		stages, providing a comprehensive approach to identifying and resolving problems.	Why? Why? Why?	Why do so many people drive to work instead of using public transportation? Because there aren't enough convenient or efficient options. Why aren't there more convenient options for public transportation? The city's limited budget for public transportation investments. Why hasn't the expansion of transit infrastructure been given priority? The city's development and planning regulations have traditionally prioritized car capacity.	
	Problem tree	The problem tree involves groups brainstorming and organizing problems into a hierarchy, ranging from most important to least important or abstract to practical.	Steps Define the core problem: identify and state the main issue. Identify causes: determine the underlying factors contributing to the problem (these are the roots). Identify effects: note the consequences of the problem (placed as branches). Analyze relationships: examine how causes and effects interact and influence each other.		Smart, 2024
	Causal loop diagram	A Causal loop diagram (CLD) is a systems thinking tool that uses variables and arrows to represent and analyse a system's feedback structures.	Steps Problem articulation: identify research problems, identify stakeholders based on role and impact, and gather variables through literature reviews. Formulating a dynamic hypothesis: classifying variables, defining relationships, and developing a preliminary CLD diagram. Refinement and validation: Refine relationships and identify and add any overlooked variables.		Dhirasasna and Sahin, 2019.
How	World café	The World café is a methodical discourse technique used in community or organizational settings for teamwork, information exchange, strategic planning, problem-solving, and brainstorming, fostering a shared understanding and robust discussions.	Steps Set the Context Form small groups Share insights Connect ideas Synthesize results	Examples by authors: homelessness in the city Community members, nonprofits, and city officials are collaborating to discuss strategies for reducing homelessness, including improving access to living spaces and implementing local services to prevent homelessness. Attendees break into small groups to discuss each question. Each group records ideas, such as increasing affordable housing or expanding mental health services. Participants rotate and add to prior groups' discussions. Collective insights are shared, forming actionable strategies to address homelessness collaboratively.	Smart, 2024 SessionLab,n, d.c
	Discovery & action dialogue (DAD)	Creating a safe space for a group to share and discover practices and behaviours can help them find solutions. DAD helps groups choose their problems and approaches, removing resistance to change and gaining buy-in at all levels. This process of enabling frontline ownership ensures follow-through	Steps Identify Participants Set the problem context. Ask guiding questions Identify Positive Deviants	Examples by authors: enhancing urban green spaces Gather city planners, residents, environmental groups, urban planners, and landscape architects. Frame the issue around a lack of accessible green spaces, and mention neighbourhoods with effective park use. Use questions like, "What do people love about green spaces in other areas?" Identify neighbourhoods where green spaces thrive and are well-used.	SessionLab,n. d,d Smart,2024

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Categorization	Technique	Definition	Details		Source
		and is a valuable tool for facilitators to have in their toolbox.	Discuss Barriers and Opportunities	Recognize funding, space, or accessibility challenges while brainstorming applicable successes.	
			Create an Action Plan	Define steps like improving park access, landscaping, or organizing community events.	
	The impact and effort matrix	The "Impact and effort matrix" is a problem-solving technique that encourages critical thinking by categorizing ideas into a 2x2 matrix, guiding participants from ideas to evaluating potential solutions.	Steps Idea generation: Collect potential projects or tasks that align with a specific goal. Plot on matrix: assess each idea by plotting it on a 2x2 grid: high impact, low effort: quick wins (top priority), high impact, high effort: consider, if resources allow, low impact, low effort: fill-ins, for available time, and low impact, high effort: Often discard. Prioritize and plan: Focus on high-impact, feasible tasks first.		Smart,2024
	The goal tree	A goal tree is a hierarchical tool that breaks down high-level objectives into smaller, more manageable objectives and functional activities.	Steps Identify high-level goals: the project should have suitable and sufficient goals that align with the strategic objectives. Decompose into sub-goals: breaking down high-level goals into sub-goals that serve as intermediate achievements. Define operational tasks: the task should be actionable and assignable for each sub-goal, outlining the specific tasks, actions, or requirements. Establish traceability links: establish clear connections between high-level goals, sub-goals, and operational tasks. Analyze and validate the goal tree by reviewing it for alignment, consistency, and completeness.		Van Lamsweerde, 2001 Lukyanova, 2024
	Agreement certainty matrix	The "Agreement and certainty matrix" is a tool that categorizes issues into technical and adaptive challenges. Technical challenges have clear, agreed-upon solutions, while adaptive challenges are complex and lack agreement on causes or solutions. The matrix facilitates understanding of problem types and exploring suitable solutions.	Steps Identify the problem and root causes. Plot root causes: draw a matrix and use sticky notes to represent each root cause, arranging them based on team members' certainty and agreement levels. Evaluate agreement and certainty: Discuss the team's agreement and certainty for each root cause to determine whether the problem is technical, complicated, or adaptive. Choose solution approaches: based on where each root cause falls on the matrix, find suitable approaches for addressing the problem (e.g., direct action, changing processes, or examining patterns). Brainstorm solutions: Utilize the chosen approach to develop targeted solutions for each identified root cause. Prioritize solutions: Use a prioritization matrix to decide which solutions to implement first.		Zimmerman, 2001 RHNTC, 2019

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2.4. Reviewing and evaluating problem-solving case studies

This section examines how problems are identified in case studies, using selected projects as examples. These case studies represent a range of urban contexts and planning conditions, thereby supporting the methodological triangulation employed in this study. These projects were analysed at micro, meso, and macro levels, and the actions have been classified into three categories: what, why, and how. Table 4 provides a detailed breakdown of each case study.

2.4.1. What – Problem identification

Micro-scale case studies use public input, site observations, and historical data reviews to address local issues effectively. However, it may lack structured techniques and rely on quantitative data. Meso-scale cases, such as field observations and surveys, may not engage diverse stakeholders or address urban challenges. Macro-scale cases, such as context analysis and consultations, provide a broader understanding but may lack local sensitivity and community involvement.

2.4.2. Why – Problem analysis

micro-scale case studies methods like interviews, workshops, and “SWOT” analysis provide detailed insights into underlying causes, relying on qualitative approaches. Meso-scale cases involve consultation, “SWOT” analysis, and contextual reviews, but may lack local engagement. Macro-scale cases often utilize high-level stakeholder engagement and data analytics, but may overlook broader social or cultural impacts, focusing instead on quantifiable data.

2.4.3. How – Developing solutions

micro-scale case studies solutions focus on flexible programming and phased implementation, lacking long-term monitoring and institutional support. Meso-scale ones use integrated zoning, expert input, and participatory approaches, but may face affordability and timeline delays. Macro-scale cases employ long-term, systemic strategies with comprehensive goals, but may lack detailed implementation strategies and measurable progress indicators.

Table 4. Reviewing and evaluating problem-solving case studies

Scale	City	Problem-solving steps What? Problem Identification	Why? Problem Analyzation	How? Problem Resolution	Evaluation What?	Why?	How?
Micro-Scale	Town Square Park, Anchorage, Alaska (Municipality of Anchorage Parks and Recreation Department, 2019)	By public input (online surveys to gather perceptions about the park), observation (site analysis) method, and historical data review. The park faces challenges related to public safety, lack of identity, and underutilization.	By stakeholder engagement (interviews and roundtable meetings), workshops, and data analysis (survey results). Illegal activity in urban areas, poor infrastructure, outdated amenities, limited connectivity and interaction, and lack of consistent programming	By collaborative workshops, best practices case studies, and community-driven design (integration of public preferences and use of advisory groups) • Design solutions modify landscaping, introduce flexible-use areas, and update hardscape • Programming enhancements Expand year-round activities and family-friendly and inclusive programming • Management strategies adopt a sustainable management model involving public and private partnerships. • Community involvement Engage stakeholders and residents through workshops and surveys • Implementation phase-based execution with regular monitoring	Strengths: Important issues are supported by statistics and public participation. Weaknesses: insufficient comparative context with other urban park issues to offer a more comprehensive viewpoint.	Strengths: effectively identifies underlying reasons Weaknesses: relies heavily on qualitative feedback; limited quantitative analysis, and insufficient exploration of the long-term impacts.	Strengths: proposes actionable and comprehensive solutions Weaknesses: Some strategies may be too ambitious without assurance of long-term support
	Gharani &HorAmeli Street, Mashhad, Iran (Ministry of Roads and Urban Development, 2020)	By initial observations or context analysis, quantitative data disorganized land use, traffic congestion, and poor access, insufficient pedestrian and green spaces.	By data analysis, SWOT analysis, and GIS-based mapping	By the development of proposed solutions and the creation of an implementation framework • Define vision, objectives, and goals. Enhance zoning regulations, improve pedestrian pathways, reduce traffic congestion, and preserve historical and cultural landmarks. • Define policies • Alternative solutions and evaluation Redesigning zoning for different spaces, improving public transportation, and revitalizing underutilized buildings. • Implementation plan	Strengths: clearly defines the main challenges Weaknesses: Some issues are mentioned without adequate supporting quantitative data	Strengths: The document employs tools like SWOT Weaknesses: The analysis does not fully explore the main problem	Strengths: proposed solutions are actionable and align with identified problems Weaknesses: detailed plans for monitoring and evaluating the impact of the solutions are missing

Scale	City	Problem-solving steps: What? Problem Identification	Why? Problem Analyzation	How? Problem Resolution	Evaluation: What?	Why?	How?
Meso-Scale	Hammarby Sjostad district, Stockholm, Sweden (Gaffney et al., 2007)	By initial site analysis and policy review. Environmental pollution from industrial use, rising urban housing demand, and lack of infrastructure integration	Through stakeholder consultation and historical research, policy impact analysis. Inefficient land use and pollution were the results of historical industrialization.	By public engagement and integrated planning • Design approach Create a sustainable, low-impact urban environment • Social and environmental goals Equity, sustainability, and social interaction • Stakeholder collaboration Partnership among municipal, private, and national actors • Implementation process Detailed description of the planning phases • Specific design approaches Compact urbanism, green infrastructure, and water-sensitive design	Strengths: comprehensive site analysis, focus on urban housing needs, strategic urban positioning Weaknesses: Various urban challenges heavily influenced the problem identification	Strengths: detailed research into historical and policy context Weaknesses: Lack of practical methods and techniques, limited resident engagement	Strengths: successfully implemented a Hammarby model and phased development Weaknesses: Implementation delays and affordability goals not met
	The District Surrounding the Holy Shrine of Imam Reza, Mashhad, Iran (Ministry of Roads and Urban	By Field observations, site visits, surveys, and feedback from stakeholders, zoning, transportation, and land use concerns near Imam Reza's holy shrine.	By using focus groups, collaboration, interviews, consultations, and SWOT analysis.	By stakeholder workshops and meetings, scenario modeling, and the use of goal-setting frameworks • Define objectives and goals Develop a balanced urban system • Alternative solutions and evaluation Enhancing public transit options and pedestrian pathways • Implementation plan Create phased and zoning plans to guarantee that solutions are implemented gradually.	Strengths: identifies urban challenges clearly by using different methods and documents	Strengths: Analyse problems by using different methods and opinions. Comprehensive analysis Weaknesses: Lack of practical methods to enhance engagement	Strengths: Actionable strategies and an implementation plan Weaknesses: lacks detailed mechanisms for tracking progress or assessing the success of implementation
Macro-Scale	Charlotte, North Carolina, USA (City of	By data analysis, geospatial mapping, and stakeholder feedback Charlotte faces a significant public	By data analysis, stakeholder engagement, and community input human error (speeding, distracted driving,	By phased implementation planning, collaborative engagement, and educational campaigns • Proposed solutions: -Engineering: Redesigning streets to improve safety -Education: creating community ambassador programs	Strengths: Clearly defines the problem of traffic-related fatalities and injuries and focuses on vulnerable road users	Strengths: Identifies root causes and uses stakeholder engagement	Strengths: proposes comprehensive solutions and focuses on systemic change

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Scale	City	Problem-solving steps: What? Problem Identification	Problem-solving steps: Why? Problem Analyzation	Problem-solving steps: How? Problem Resolution	Evaluation: What?	Evaluation: Why?	Evaluation: How?
		safety issue due to traffic-related fatalities and serious injuries.	and failure to yield), infrastructure issues, and equity concerns (vulnerable populations)	-Enforcement: data-driven enforcement targeting high-risk areas -Engagement and equity: continued involvement of the community • Implementation plan: -Regular updates to the action plan based on data and progress. -Multi-year benchmarks from 2020 to 2030 to track progress in sidewalk construction, bike lane improvements, and policy updates.	Weaknesses: lacks comparison with national or global trends, and insufficient exploration	Weaknesses: Limited examination and insufficient detail	Weaknesses: lacks detailed funding strategies
	Ludwigsburg, Germany (Kuhla von Bergmann and Dieterle, 2019)	By observations and context analysis. Identified key urban challenges such as rising temperatures, air pollution, and housing shortages.	By data collection and analysis, stakeholder engagement, SWOT analysis, and comparative research car-centric planning, pollution, and reduced urban efficiency, while high land and construction costs limit housing development	By using the SMAC framework and scenario development • Define objectives and measurable goals sustainable mobility, enhanced housing, and increased green spaces • Generate and evaluate alternative solutions • Engage stakeholders for validation Used co-creation workshops to ensure solutions are inclusive and adaptable • Create an implementation plan Involves the phased execution of a dynamic master plan, incorporating pilot projects and real-time feedback, and utilizing monitoring frameworks to track progress and adjust solutions as needed.	Strengths: Comprehensive data collection and clear articulation of symptoms and their interconnections. Weaknesses: limited emphasis on specific demographic impacts and geographic focus on central Ludwigsburg	Strengths: Effective use of stakeholder consultations and robust systemic analysis Weaknesses: Lack of deep exploration of social parameters and limited discussion on governance or policy barriers	Strengths: Practical solution, useful framework (SMAC), and long-term adaptability in scenarios Weaknesses: Limited metrics or KPIs for tracking the success of interventions, and limited funding

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3. Methodology

This study employs a comprehensive three-phase methodological approach to identify urban problem-solving frameworks, utilizing both qualitative and quantitative research methods (Figure 2). The research methodology follows a systematic process to develop the urban problem-solving framework.

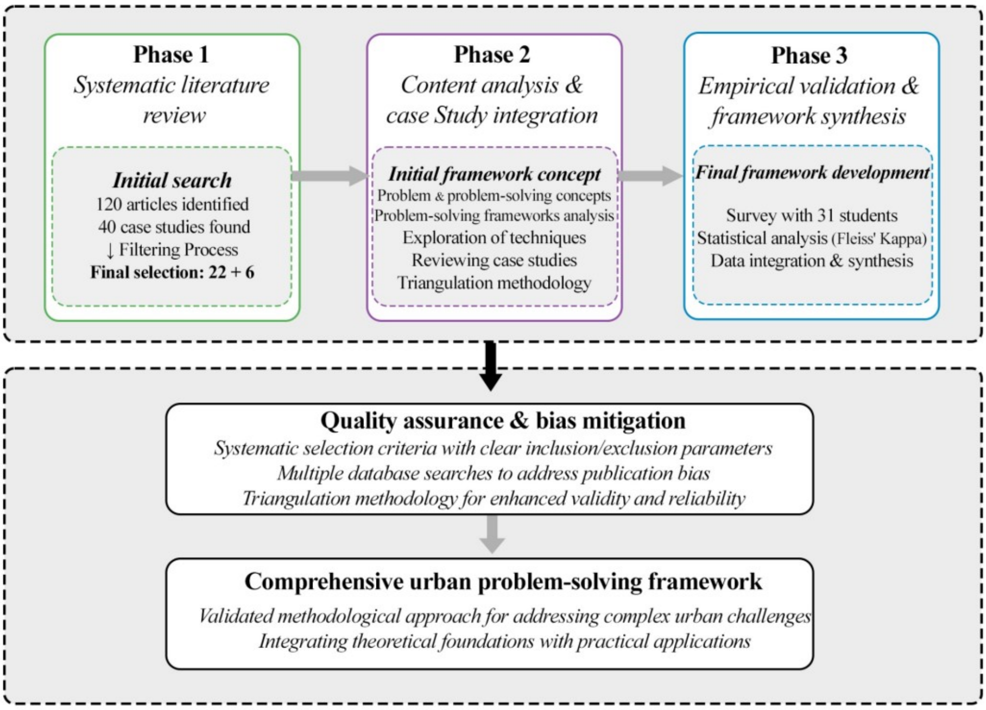

Figure 2.Methodological framework for urban problem-solving analysis

3.1. Phase 1: Systematic literature review

A systematic literature review was conducted using Google Scholar, Web of Science, and Scopus. The methodological review is based on Sandelowski and Barroso's (2007) meta-analysis approach ,which systematically synthesizes existing research. One hundred twenty articles and forty case studies were identified from databases. The list was eliminated based on inclusion and exclusion criteria. The inclusion criteria included studies of urban problem-solving, planning tools, clear goals, conceptual or methodological frameworks, published in adequate journals, and real-world application of techniques in urban planning. Exclusion criteria included unrelated titles, studies lacking methodological transparency or academic quality, indicators without established frameworks, or publications outside the scope of the study. Finally, 22 peer-reviewed articles and six relevant case studies were selected for final analysis. The systematic selection of articles and case studies was accurate; however, potential biases, such as publication bias favoring certain journals, the exclusion of non-English sources, and subjective judgments, were addressed (Figure 3).

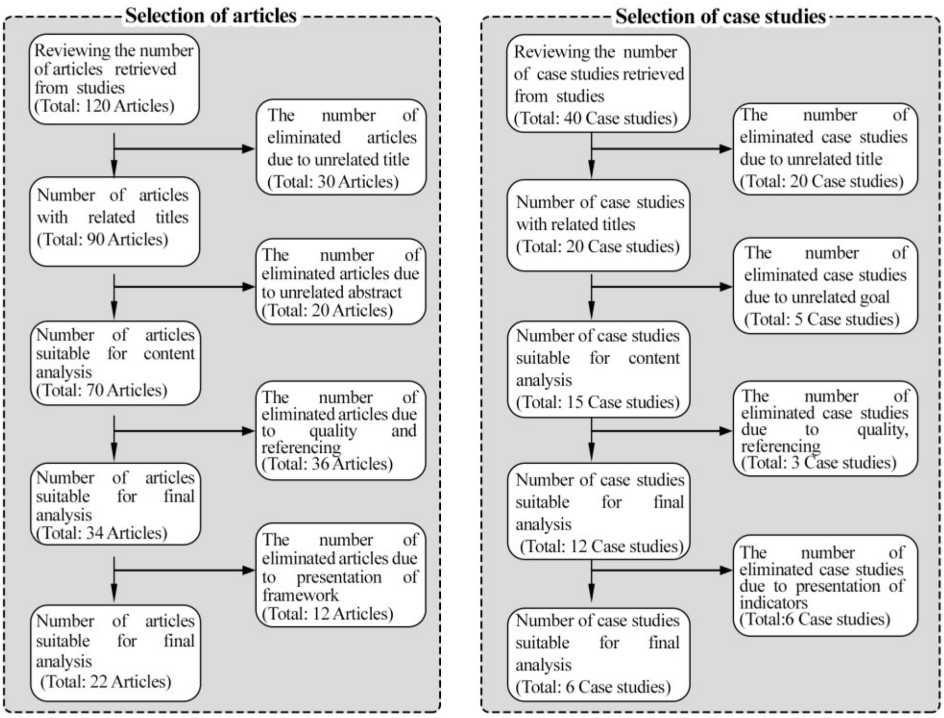

Figure 3. Selection process of sources

3.2. Phase 2: Content analysis and case study integration

Following this, a systematic review was conducted to analyze the structure and content of the literature, extracting key information. This phase systematically reviewed four key areas: (1) problem and problem-solving concepts specifically in urban contexts, (2) existing problem-solving frameworks and their theoretical foundations, (3) exploration and categorization of various problem-solving techniques, and (4) reviewing and evaluating real-world case studies to understand practical applications. The study included diverse case studies from different geographical, cultural, and planning contexts to support the triangulation methodology. Triangulation is a methodological approach that uses multiple data sources to improve the credibility and validity of research findings. It is particularly helpful in qualitative studies, which aim to understand complex social phenomena and multicultural environments. By embracing diverse perspectives, researchers can verify and validate their findings, leading to more comprehensive and reliable conclusions (Meydan and Akkaş, 2024). The findings from this phase provided the foundation for developing a structured urban problem-solving framework that would be empirically validated in the next phase.

3.3. Phase 3: Empirical validation and framework synthesis

Likewise, A questionnaire, designed with structured and semi-structured questions, was administered to 31 urban planning students to evaluate the practical effectiveness of problem-solving techniques. These participants were deliberately chosen due to their extensive practical experience, having actively applied problem-solving techniques over several months in an urban planning studio. This hands-on engagement provided deep insights into the applicability and efficacy of these methods in addressing urban challenges. In contrast, urban policymakers and practitioners, who prioritize practical outcomes over structured problem-solving frameworks in real-world settings, often lack direct experience with these specific techniques, making students a more suitable sample for this study. Fleiss' Kappa coefficient was calculated to assess the reliability of binary-response items, and descriptive statistics were used to evaluate the effectiveness of techniques across three stages: problem identification, analysis, and solution development. Thematic analysis of open-ended responses identified key themes and student perceptions, further enriching the findings. Findings from all data sources were synthesized to propose a structured urban problem-solving framework that integrates insights from the literature, case study applications, and empirical validation results.

4. Results

In this section, the questionnaire was designed to evaluate problem-solving techniques based on the opinions of 31 students. The participants were selected based on their expertise in using these techniques during their projects. The primary purpose was to gather students' insights into the applicability and effectiveness of these techniques in addressing urban challenges. The questionnaire consisted of two main sections.

4.1. Structured questions

In Structured Questions, respondents evaluated the effectiveness of 12 techniques across the three stages of problem-solving using a binary scale ("Yes" or "No"). Table 5 demonstrates a quantitative evaluation of techniques across the three stages of what, why, and how. The overall status shows that the average proportion of agreement (Pi) for all techniques is 0.89, indicating high response consistency. Moreover, the average proportion of 'yes' responses is 0.37, and 'no' responses are 0.63, indicating limited endorsement of the techniques at certain stages.

Analyze techniques based on their effectiveness:

- High effectiveness (80%-100% of yes): Five Whys (Why), Journalists (What), Discovery and action dialogue (How), Agreement certainty matrix (what), Mind map (What), Goal tree (How), Impact and effort matrix (How) and Causal loop diagram (Why), Problem tree (Why), World café(How), SWOT analysis (What), World café(What).
- Moderate effectiveness (50%-80% of yes): Fishbone analysis (Why), and Problem Tree (What).

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Fleiss' Kappa is a statistical measure that assesses the agreement among more than two respondents, particularly in studies where responses are categorized, such as "Yes" or "No." The Kappa value of 0.77 indicates substantial agreement (Table 5) among participants regarding the effectiveness of different problem-solving techniques in urban studies. This agreement regarding their responses provides assurances of the dependability and validity of the collated data.

Table 5. Analysis of structured questions

Technique	Stage	Yes	No	Proportion Yes	Proportion No	Pi (Agreement) (Proportion Yes)^2 +(Proportion No)^2
The 5 Whys	What	0	31	0.00	1.00	1.00
	Why	31	0	1.00	0.00	1.00
	How	0	31	0.00	1.00	1.00
Fishbone analysis	What	5	26	0.16	0.84	0.73
	Why	24	7	0.77	0.23	0.65
	How	0	31	0.00	1.00	1.00
SWOT analysis	What	25	6	0.81	0.19	0.69
	Why	3	28	0.10	0.90	0.83
	How	3	28	0.10	0.90	0.83
Journalists	What	31	0	1.00	0.00	1.00
	Why	0	31	0.00	1.00	1.00
	How	0	31	0.00	1.00	1.00
Problem tree	What	24	7	0.77	0.23	0.65
	Why	26	5	0.84	0.16	0.73
	How	0	31	0.00	1.00	1.00
Goal tree	What	1	30	0.03	0.97	0.94
	Why	0	31	0.00	1.00	1.00
	How	29	2	0.94	0.06	0.88
World café	What	25	6	0.81	0.19	0.69
	Why	0	31	0.00	1.00	1.00
	How	26	5	0.84	0.16	0.73
Discovery & action dialogue	What	2	29	0.06	0.94	0.88
	Why	1	30	0.03	0.97	0.94
	How	30	1	0.97	0.03	0.94
The Impact and effort matrix	What	0	31	0.00	1.00	1.00
	Why	3	28	0.10	0.90	0.83
	How	29	2	0.94	0.06	0.88
Agreement certainty matrix	What	30	1	0.97	0.03	0.94
	Why	0	31	0.00	1.00	1.00
	How	1	30	0.03	0.97	0.94
Causal loop diagram	What	2	29	0.06	0.94	0.88
	Why	29	2	0.94	0.06	0.88
	How	1	30	0.03	0.97	0.94
Mind map	What	30	1	0.97	0.03	0.94
	Why	2	29	0.06	0.94	0.88
	How	1	30	0.03	0.97	0.94
Average				0.37	0.63	0.89
Po (observed agreement) = average (Pi Column)						0.89
Pe (expected agreement) = (average proportion yes)^2+(average proportion no)^2						0.53
Fleiss' Kappa = (Po−Pe) ÷ (Pe -1)						0.77

4.2. Semi-Structured questions

This section presents participant insights and suggestions for improvement. Based on Table 6, the semi-structured questions provide a qualitative evaluation of problem-solving techniques in urban projects. According to the findings, most respondents reported significant improvements in their ability to solve problems, particularly in reducing complexity and enhancing the quality of their decisions.

Table 6. Analysis of semi-structured questions

Semi-structured questions	Summary of results
Impact of techniques in the problem-solving process	Yes: 23 people (74%) Somewhat: 8 people (26%)
Impact of techniques on reducing complexity	Yes: 21 people (68%) Somewhat: 7 people (23%) No: 3 people (9%)
Most effective techniques in urban projects	SWOT analysis (21 mentions), 5 Whys (21 mentions), Mind map (12 mentions)
Combination of techniques for greater effectiveness	Suggested combinations: 5 Whys + SWOT analysis (12 times) 5 Whys + Goal tree + SWOT analysis (11 times) 5 Whys + Problem tree + Mind map (10 times)
Techniques for teaching students	SWOT analysis (18 times), 5 Whys (17 times), Mind map (10 times), Problem tree (9 times), World café(8 times)

The finding indicates that problem-solving techniques are effective in solving urban challenges. The five whys are identified for their ability to enhance decision-making. The agreement in participant responses (Kappa value: 0.77) supports the reliability of the findings. These results support an integrated, adaptable approach to urban problem-solving.

5. Discussion

Based on the data extracted from the results, Table 7, "Urban problem-solving framework," outlines a structured approach to addressing urban challenges. It organizes the problem-solving process into four stages: problem identification, problem analysis, solution development, and evaluation and feedback. Each stage emphasizes objectives, tools, techniques, and expected outcomes. For example, tools like SWOT analysis and GIS-based mapping are suggested to ensure comprehensive problem definitions and analyses. This structured methodology balances quantitative methods (e.g., data analytics) and qualitative approaches (e.g., stakeholder engagement).

Table 7. Urban problem-solving framework

Problem-solving process	What? Problem identification	Why? Problem analysis	How? Solution development	Evaluation and feedback
Objective	Define comprehensive, clear problems by considering different perspectives and contexts.	Investigate root causes and system interconnections to understand why the problem exists.	Generate inclusive solutions that consider creative approaches, feasibility, phased implementation, and stakeholder impact.	Develop pilot programs to evaluate the effectiveness of proposed solutions.
Tools, Techniques	SWOT, Journalists, Mind map, World café, Agreement Certainty matrix	The 5 Whys, Problem tree, Fishbone analysis, Causal loop diagram	World café, Discovery & action dialogue (DAD), The Impact and effort matrix, The Goal tree, Agreement certainty matrix	
	Using stakeholder and public input, GIS analysis, and spatial data analysis	Integrate quantitative methods (such as data analytics and GIS-based mapping) with qualitative approaches.	Scenario modelling for predictive analysis conducts regular public and stakeholder engagement, community consultations, and educational campaigns.	
Outcomes	A complete and accurate problem definition that considers stakeholder concerns and the spatial context into account	A comprehensive recognition of the problem, root causes, and interdependencies	Their effectiveness and practicality sort out a varied collection of possible solutions.	Validated and evaluated solutions using data-driven analysis regarding their potential for success.

Table 8, "Problem types and solution techniques framework," examines techniques and methods for addressing various types of problems, including simple, complex, ill-defined, social, ethical, and wicked problems. Each category encompasses "What" (problem identification), "Why" (problem analysis), and "How" (solution development), with specific techniques tailored to the complexity and nature of the issue. This part employs cognitive epistemic purposes (e.g., description, explanation, understanding, and change) in conjunction with structured problem-solving stages (what, why, how) to align specific techniques with urban problem types, utilizing questionnaire data, case study analysis, and theoretical literature.

Table 8. Problem types and solution techniques framework

Type of problem	What (epistemic purpose + technique	Why (epistemic purpose + technique)	How (epistemic purpose + technique)
Simple or well-defined problems	Description: Mind map (83% agreement): organizes problem components visually, particularly in micro-scale projects.	Explanation 5 Whys (100% agreement): identifies root causes and is highly effective in the Micro-scale studies.	Evaluation Impact-Effort matrix (88% agreement): Prioritizes feasible solutions efficiently.
Complex problems	Description & exploration: Mind map + SWOT analysis (70% agreement): Explores systemic factors, especially in a micro-scale project	Explanation 5 Whys+ Problem tree (73% agreement): Identifies hierarchies of causes and effects for better clarity, especially in a micro-scale project	Evaluation & change Impact-effort matrix+ Goal tree (88% agreement): Breaks complex objectives into actionable steps. Collaborative idea generation and exploration

Type of problem	What (epistemic purpose + technique	Why (epistemic purpose + technique)	How (epistemic purpose + technique)
Ill-defined problems	Description & exploration: Mind map+ SWOT analysis+ Journalists (100% Agreement): Frames unclear problems with structured narratives, especially in a micro/meso-scale project	Explanation & understanding 5 Whys+ Problem tree+ Fishbone analysis (65% agreement): analyzes indirect causes, especially in micro- and meso-scale studies.	Evaluation& Change Impact-effort matrix+ Goal tree+ Discovery & action dialogue (94% agreement): Encourages participatory resolution of ethical challenges. Highly effective in micro/meso-scale studies.
Social problems	Description & Exploration& prediction: Mind Map+ SWOT analysis+ Journalists+ Stakeholder engagement: Identifies the problem through collaborative input, highly effective (Table 4). Meso-scale	Explanation& understanding 5 Whys+ Problem tree+ Fishbone analysis Causal loop diagram (88% agreement): Examines policy and social interconnections	Evaluation& Change Impact-effort matrix+ Goal tree+ Discovery & action dialogue+ World café (73% agreement): Generates inclusive strategies with broad stakeholder input.
Ethical or moral problems	Description, exploration & prediction: Mind map+ SWOT analysis+ Journalists	Explanation& understanding 5 Whys+ Problem tree+ Fishbone analysis Causal loop diagram	Evaluation& Change Impact-effort matrix+ Goal tree+ Discovery & action dialogue+ World Café
Wicked problem	Description & exploration& prediction Mind map+ swot analysis+ journalists+ World café(70% agreement): fosters understanding of stakeholder priorities Agreement certainty matrix (94% agreement): balances technical and adaptive approaches. Problem tree (65% agreement): maps complex issues Stakeholder engagement: Identify problems from a wide perspective. Visualization tools and techniques (e.g., system diagrams): illustrate relationships	Explanation& understanding& evaluation 5 whys+ Problem tree+ Fishbone analysis Causal loop diagram	Evaluation & change & impact assessment Impact-effort matrix+ Goal tree+ Discovery & action dialogue+ World café+ Scenario modelling: develops dynamic, long-term strategies.

6. Conclusion

Urban environments show complex challenges that require creative and multidimensional problem-solving approaches. This research highlights the importance of structured problem-solving processes, encompassing the entire spectrum from problem identification to solution implementation and evaluation. The results emphasize that effective urban problem-solving should use balanced technical accuracy. The framework developed in this study is based on a systematic literature review, case study analysis, and data from students with hands-on experience in planning studios. The analysis of case studies, ranging from micro-scale, showed that projects employed creative strategies; however, the use of problem-solving techniques remained limited, uncreative, and often unstructured. Many interventions relied on singular methods without a clear connection between the problem types and the selected tools. This gap highlights the need to develop a framework that categorizes problems and aligns them with epistemic purposes and appropriate techniques, informed by data from questionnaires and case analysis. SWOT analysis, Fishbone diagrams, Mind mapping, and World café were selected based on their effectiveness scores and flexibility across urban contexts. These techniques help to have a better understanding, enhance creativity, and provide suitable solutions. Notably, the use of both qualitative and quantitative methods is essential. Tools and techniques, such as GIS mapping and scenario modeling, are combined with stakeholder workshops and public engagement to enhance the acceptance and adoption of these approaches. In conclusion, the problem-solving framework enhances understanding and serves as a practical tool for tackling urban challenges. While the suggested urban problem-solving framework could be useful, cities with different governance systems, varying resource availability, and distinct contexts require sensitivity to their unique contexts. Other administrative or stakeholder engagement strategies could impact the effectiveness of the framework. As a result, a successful application depends on contextual adaptation and awareness of local conditions. Future studies should examine specific adjustments and approaches to identify these obstacles, guaranteeing the framework's adaptability and applicability in urban contexts.

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References

Abdulla, A.M. and Cramond, B., 2018. The creative problem finding hierarchy: A suggested model for understanding problem finding. *Creativity. Theories-Research-Applications*, *5*(2), pp.197-229. https://doi.org/10.1515/ctra-2018-0019.

Atlassian, n.d. Mind mapping in project management. Available at: https://www.atlassian.com/work-management/project-management/mind-mapping [Accessed 16 January 2025].

Almulla, M.A., 2023. Constructivism learning theory: A paradigm for students' critical thinking, creativity, and problem solving to affect academic performance in higher education. *Cogent Education*, *10*(1), p.2172929. https://doi.org/10.1080/2331186X.2023.2172929.

Basadur, M., Gelade, G. and Basadur, T., 2014. Creative problem-solving process styles, cognitive work demands, and organizational adaptability. *The journal of applied behavioral science*, *50*(1), pp.80-115. https://doi.org/10.1177/0021886313508433.

Branford, J.D. and Stein, B.S., 1993. The IDEAL problem solver: A guide for improving thinking, learning, and creativity.

Choi, C., Yang, S., Choi, S.H. and Jang, S., 2021. Modeling & Simulation-Based Problem Solving Process in Sustainable Living Lab. *Sustainability*, *13*(7), p.3690. https://doi.org/10.3390/su13073690.

City of Charlotte, 2019. C*harlotte's Road to Vision Zero: Safer streets for Charlotte. Charlotte*, NC: City of Charlotte. vision-zero-action-plan.pdf

Cui, J., Allan, A. and Lin, D., 2019. SWOT analysis and development strategies for underground pedestrian systems. *Tunnelling and Underground Space Technology*, *87*, pp.127-133. https://doi.org/10.1016/j.tust.2018.12.023.

Dhirasasna, N. and Sahin, O., 2019. A multi-methodology approach to creating a causal loop diagram. *Systems*, *7*(3), p.42. https://doi.org/10.3390/systems7030042.

Fraser, M.R., 2023. *Problem-Solving and Decision-Making Skills for*. *Building Strategic Skills for Better Health: A Primer for Public Health Professionals*, Oxford: Oxford University Press, pp.122-136.

Gaffney, A., Huang, V. et al., 2007. *Hammarby Sjöstad: A case stud*y. CP 249 Urban Design in Planning, Fall 2007. Available at: Harvard University.

Getzels, J.W., 1982. The problem of the problem. *New directions for methodology of social and behavioral science: Question framing and response consistency*, *11*, pp.37-49.

Guaman-Quintanilla, S., Everaert, P., Chiluiza, K. and Valcke, M., 2023. Impact of design thinking in higher education: a multi-actor perspective on problem solving and creativity. *International Journal of Technology and Design Education*, *33*(1), pp.217-240. https://doi.org/10.1007/s10798-021-09724-z.

Gusau, N.M.B. and Mohamad, M.M., 2020. Problem solving skills based on IDEAL model in implementing undergraduate final year project. *Journal of Technology and Humanities*, *1*(1), pp.26-33. https://doi.org/10.53797/jthkkss.v1i1.4.2020 .

Koenig, R., Miao, Y., Aichinger, A., Knecht, K. and Konieva, K., 2020. Integrating urban analysis, generative design, and evolutionary optimization for solving urban design problems. *Environment and Planning B: Urban Analytics and City Science*, *47*(6), pp.997-1013. https://doi.org/10.1177/2399808319894986

Kondić, V., Knok, Ž., Horvat, M. and Hegeduš, I., 2024. Building Models for a Scientific Approach to Problem Solving in Production Systems. *Tehnički glasnik*, *18*(2), pp.331-336. https://doi.org/10.31803/tg-20230705204106.

Kuhla von Bergmann, N. and Dieterle, R., 2019. *Case study project: Smart city Ludwigsburg*. International Master's Program: Smart City Solutions. Stuttgart: HFT Stuttgart.

Lau, M.Y., Sieler, J.D., Muyskens, P., Canter, A., VanKeuren, B. and Marston, D., 2006. Perspectives on the use of the problem-solving model from the viewpoint of a school psychologist, administrator, and teacher from a large midwest urban school district. *Psychology in the Schools*, *43*(1), pp.117-127. https://doi.org/10.1002/pits.20135.

Lukyanova, S., 2024. *Project goal tree: A method for achieving project success*. Available at: https://weeek.net/blog/project-goal-tree [Accessed 16 January 2025].

Marksberry, P., Bustle, J. and Clevinger, J., 2011. Problem solving for managers: a mathematical investigation of Toyota's 8-step process. *Journal of Manufacturing Technology Management*, *22*(7), pp.837-852. https://doi.org/10.1108/17410381111160924.

Mashhad Municipality, 2014. *Thematic plan of Qarani and Har Ameli streets with an urban design approach (First edition)*. Urban Development and Architecture Department, Mashhad Municipality. [in Persian].

Meydan, C.H. and Akkaş, H., 2024. The role of triangulation in qualitative research: Converging perspectives. In *Principles of conducting qualitative research in multicultural settings* (pp. 98-129). IGI Global. https://doi.org/10.4018/979-8-3693-3306-8.ch006.

Ministry of Roads and Urban Development, 2020. *Detailed plan of the Holy Shrine District of Imam Reza (AS): Summary of studies and final plan documents* (Second edition). Mashhad, Iran: Urban Development and Architecture Department. [in Persian].

Municipality of Anchorage Parks and Recreation Department, 2019. *Town Square Park Master Plan: Public hearing draft*. Anchorage, AK: Municipality of Anchorage. [in Persian].

Pal, A. and Poyen, E.F.B., 2017. Problem solving approach. *International Journal of Advanced Engineering Research and Science*, *4*(5), pp.184-189.

Parnes, S.J., 1967. *Creative behavior guidebook (CBG).* Nueva York: Scribners.

Payne, T.C. and Reinhard, D., 2016. The complexity of problem-solving in urban parks: A case study. *International criminal justice review*, *26*(2), pp.134-149. https://doi.org/10.1177/1057567716638903.

Polya, G., 1945. *How to solve it: A new aspect of mathematical method*. Princeton university press.

Rai, M. and Kaur, N., 2025. Mind Mapping as an Innovative Teaching Learning Tool in Education. In *Innovative Educational Frameworks for Future Skills and Competencies* (pp. 63-80). IGI Global Scientific Publishing. https://doi.org/10.4018/979-8-3693-7555-6.ch003.

Rhntc, 2019. *Agreement certification matrix*. Available at: https://rhntc.org/resources.pdf [Accessed 16 January 2025].

Ruby, F.J., Smallwood, J., Sackur, J. and Singer, T., 2013. Is self-generated thought a means of social problem solving?. *Frontiers in psychology*, *4*, p.962. https://doi.org/10.3389/fpsyg.2013.00962

Ruhl, J.B. and Salzman, J., 2020. Introduction: Governing wicked problems. URL: http://hdl.handle.net/1803/17320

Sakdiyah, S.H., Eltivia, N., and Afandi, A., 2022. Root cause analysis using fishbone diagram: company management decision making. *Journal of Applied Business, Taxation and Economics Research*, *1*(6), pp.566-576.

Sandelowski, M. and Barroso, J. 2007. Handbook for Synthesizing Qualitative Research. Springer Publishing Company, New York.

SessionLab, n.d.a. *SWOT analysis*. Available at: https://www.sessionlab.com/methods/swot-analysis.

SessionLab, n.d.b. *Fishbone analysis* [Online]. Available at: https://www.sessionlab.com/methods/fishbone-analysis.

SessionLab, n.d.c. *World café*. Available at: https://www.sessionlab.com/methods/world-cafe.

SessionLab, n.d.d. *Discovery & action dialogue (DAD)* [Online]. Available at: https://www.sessionlab.com/methods/discovery-action-dialogue-dad.

Singer, F.M. and Voica, C., 2013. A problem-solving conceptual framework and its implications in designing problem-posing tasks. *Educational studies in mathematics*, *83*(1), pp.9-26. https://doi.org/10.1007/s10649-012-9422-x.

Smart, J., 2024. *49 problem-solving techniques: The big list*. Available at: https://www.sessionlab.com/blog/problem-solving-techniques/#Six_Thinking_Hats.

Treffinger, D.J., Isaksen, S.G. and Stead-Dorval, K.B., 2023. *Creative problem solving: An introduction*. Routledge. https://doi.org/10.4324/9781003419327 .

Van Lamsweerde, A., 2001, August. Goal-oriented requirements engineering: A guided tour. In Proceedings fifth ieee international symposium on requirements engineering (pp. 249-262). IEEE.

Woods, D.R., 2000. An evidence-based strategy for problem solving. *Journal of Engineering Education*, *89*(4), pp.443-459. https://doi.org/10.1002/j.2168-9830.2000.tb00551.x.

Zimmerman, B., 2001. Ralph Stacey's agreement & certainty matrix. *Schulich School of Business, York University, Toronto, Canada, available on http://www. plexusinstitute. org/edgeware/archive/think/main_aides3. html*.

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Investigating Economic Management Factors in the Development of Sports Equipment and Facilities in Iran

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ABSTRACT

This research aims to identify and analyze the managerial factors affecting the development of sports equipment and facilities in Iran, with an emphasis on economic indicators. In terms of purpose, the research is applied, and in terms of nature, it is exploratory. The research method is combined (qualitative-quantitative) and with a descriptive-survey approach. The statistical population included all professors and managers of state sports centers in the country in 2023, and the sampling was purposefully carried out using the snowball technique until theoretical saturation was reached. In the qualitative part, data were collected through semi-structured interviews with 15 experts in the field of sports facility management and analyzed using open and axial coding. In the quantitative part, a structured self-interaction questionnaire was used to classify the barriers and explain the relationships between them. Experts confirmed the validity of the tool, and its reliability was confirmed by the test-retest method (reliability coefficient 0.875). The findings showed that the most important economic barriers to the development of sports facilities include the country's economic barriers, structural barriers, and low quality of domestic products, which are at the first level. Also, weak management skills and lack of authority were categorized at the second level, and facility deterioration and chronic budget deficit were categorized at the third level. Social and human barriers were also at the lowest level. In a situation where the country is facing economic problems and restrictions, identifying these barriers can pave the way for effective use of resistance economy policies in the field of sports.

Keywords

Economy, Places, Equipment, Management, Sports.

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1. Introduction

The development of sports in Iran requires a long-term vision. For this reason, a comprehensive plan is needed in which the strengths, weaknesses, opportunities, and threats of sports are identified, and based on them, an appropriate vision and strategies are designed and developed. One of the things that can have a great impact on the development of sports is economic issues. From the second half of the 20th century, the economic boom in the West and the need to have a market to sell goods at the international and domestic level made investors think about using the economic potential of sports (Khazaei et al., 2018). The sports industry is a leading element in the economy as well as an active element in the formation of personal identity, and is very important in both the micro and macro-economic levels. It is also a market in which people, activities, businesses, and organizations are involved in production, facilitating, promoting, or holding any activity with a focus on sports. In this market, businesses offer products to their buyers. These products include any goods, services, people, places, or ideas related to sports. Among these, sports facilities are considered the most basic hardware part of sports and a part of human facilities and organizations, and a large part of the effects related to sports on society and the environment are affected by them (Eschenfelder and Li, 2007). Resistance economy is a term that was first mentioned by the Supreme Leader in 2009 in a meeting with a group of entrepreneurs from the country. After that, he emphasized it in his many speeches. In fact, this term is used for an economy that has the ability to deal with shocks to the economy. Such an economy should have flexibility in various situations and the ability to overcome a crisis. In short, a resistance economy can be considered as an economy in which, in addition to dynamic interaction with the outside world and the use of free trade facilities, the economic security of the country is maintained. The fluctuations of the international economic environment and its threats have the least negative impact on the long-term trend of macro variables. They are economical (Saif, 2012). Correct and principled management of sports facilities directly affects the productivity of sports facilities as well as the quantity and quality of sports programs and events. The increase in population and the development of living standards in today's societies have increased the demand and use of sports resources and facilities. This increase in demand and the consequent increase in production or services has caused more use of sports resources and facilities. Identifying managerial obstacles in increasing the productivity of sports facilities is of particular importance (King, 2014). Sports can be one of the most important influential areas in implementing the resistance economy. Today, resistance economy has been used as a belief and a desirable truth in many societies under certain conditions, and it is considered a platform for economic self-sufficiency and economic stability, which provides an invulnerable background to sanctions, threats, and damages. It is definitely beneficial for the country and especially sports (Khazaei et al., 2018). Austerity measures in sports are usually accompanied by budget cuts in services, staff, and most importantly, the development of sports and community recreation (King, 2014). In this research, based on the theory of resource dependence (Walker and Hayton, 2019; Pfeffer and Salancik, 1978), the challenges of managing sports facilities in the economic resistance era are examined to cover both the existing knowledge and theoretical gap, and policymakers. Consider appropriate solutions to overcome these obstacles and challenges. This research provides an original insight that is able to inform policymakers about the correct design of management strategies for sports venues, while they have to use forced economic changes. Saif (2012), with research entitled The Proposed Model of the Resistance Economy of the Islamic Republic of Iran (Based on the View of the Supreme Leader), showed that the implementation of the resistance economy causes economic growth. Mozafari (2013), in his research titled "Resistance economy and national self-confidence, opportunities and challenges of its realization", stated that the resistance economy has conditions and requirements that use all government and people's capacities, change in economic conditions through the implementation of principle 44 policies, empowerment of the private sector, and reducing dependence on oil are among them. Based on the components that were extracted from the Supreme Leader's statements, it is possible to propose the model of Iran's resistance economy with four basic components, including economic growth, economic justice, economic stability, and economic resilience.

According to the review of the conducted researches, it is clear that very limited researches have been done on sports in the period of economic austerity and resistance economy (Parnell et al., 2017), which due to its role in education, health and social cohesion It is surprising, sports can contribute significantly to the country's strategic goals in policies related to health, education, and community cohesion, and the evolution of sports can help increase inequality (Widdop et al., 2019). Pfeffer and Salancik (1978) stated that dependence on external resources can reduce the autonomy of organizations. It also affects the power relations between organizations that provide services and those that provide funding. Yeager et al. (2015) identify three particularly significant factors in the environment in which any organization operates: equipment or resources, dynamics, and competition. The first one refers to the availability of resources. Yeager et al. (2015) have pointed out that organizations that operate in low-privileged environments should reduce their dependence on specific resources and find alternative resources. Dynamics can be described as environmental change or innovation (Dess and Beard, 1984).

A dynamic and changing environment creates uncertainty and can destabilize organizations. Finally, competition is reflected in the number of stakeholders an organization thinks it is likely to rely on when formulating its strategy. In fact, increasing the number of stakeholders involved in funding and providing services can also increase uncertainty and thus lead to reluctance to test new strategies (Parnell et al., 2017). In the era of resistance economy and economic austerity, most sports organizations and especially sports complexes are not able to produce all the resources they need, and this leads to a degree of dependence on external resources (Kenyon et al., 2019). Sports facilities and complexes are heavily dependent on the government budget (Aharoni et al.,1981; Kenyon et al., 2019) and improper management at this critical time can have irreparable consequences, the negative consequences of managing sports facilities in It is faced with two-way resistance economy conditions, on the one hand, these consequences cause small and large destructive effects in various directions on the environment and the lives of citizens, and on the other hand, it causes a decrease in productivity and in some cases, a change in the use of the sports facilities themselves. Ramchandani et al. (2019) conducted a study titled The performance of local sports facilities in England during recession and austerity. In this article, the performance of public sports in England, which is dependent on subsidies from local authorities, has been investigated during the period of economic recession and austerity. In previous research, the application of resource dependence theory in the fields of sports management (Wicker and Breuer, 2011), development of sports for all (Collin and Hauden huyse, 2015), governing bodies of sports (Berry and Manoli, 2018), and the effect of economic austerity on Sports organizations (Walker and Hayton, 2019) has been used. Using this theory, this research examines the challenges of sports venue managers in the period of resistance economy. Afshari et al., (2019) conducted research entitled Causal Analysis of the Effect of Transnational Management, Resistance Economy and Sports Development in the Economic Development of Iran's Sports Industry. Based on the findings of this research, after correcting the causal relationship model in some assumptions, all relationships between significant research variables and the research model based on the effect of trans-oriented management variables, resistance economy, and sports development in the economic development of Iran's sports industry had the necessary fit.

2. Research methodology

In terms of classification, the present research is of the applied and exploratory research. The reason for the applicability of this research is its ability to help managers of venues and sports facilities solve the problems and dilemmas of venues in the period of the resistance economy. In this way, venues can gain a competitive advantage and expand their services, since this research identifies the challenges of facility managers; Therefore, it is exploratory. Also, in terms of the research method, it is survey descriptive research that is conducted in a combined (qualitative-quantitative) method. The approach used is a structural analysis method that is based on the interpretative paradigm. This work has been done using the opinions of 15 experts and managers of places, with an emphasis on semi-structured interviews. The statistical population of this research includes all professors and managers of state sports centers and venues in Iran in 2023, which, according to statistics, included five academic staff members of the sports management group and 60 managers of sports facilities. More precisely, the sampling was targeted, and the use of the snowball technique was continued until the theoretical saturation of sampling was reached. Due to the start of the Corona epidemic, the work process progressed slowly in the interview section, and in the qualitative section, to answer the questions of the research on documents and interviews. A semi-structured interview form has been considered for the research questions for experts. The main questions of the researcher in the interview with experts were focused on 12 questions that were the basis of the researcher's exploration of obstacles:

Finally, 15 people participated in this study. In this research, the researcher pays attention to those who have a reputation and credibility in the field in question, or who are more likely to reveal more and deeper findings in the research problem, through examining their opinions. Also, in order to answer the second question of the research, a structured self-interaction questionnaire was used to identify the obstacles and specify the relationships between the obstacles. Due to the fact that sports facilities and equipment were a specialized matter, the Emari community used professors and managers of government sports facilities and facilities who have specialized in specialized sports facilities and equipment for many years, and in-depth interviews were conducted with these people.

By reviewing the literature on the subject, interview questions were designed, and to avoid bias, the questions were determined in advance. The questions asked are:

What are the problems and issues that exist for better management of the supervised sports complex at present?

What are the things that cause weakness in decisions and planning?
What problems are there in the direction of the development and more productivity of sports facilities? To what extent are managers responsible for these problems?
To what extent have chronic and persistent budget deficits created problems for a sports complex manager? What are the manager's duties regarding this problem?
According to the leadership's emphasis on the need to use resistance economy solutions for the development of sports equipment, what obstacles do you face?
How do you evaluate obstacles such as the high costs of maintenance and repair of sports facilities, or administrative bureaucracy in this era?
What are the management obstacles and problems within the sports complex, with an emphasis on resistance economy policy?
What are the management obstacles and problems outside the sports complex, with an emphasis on resistance economy policy?
Are the obstacles and problems mentioned only related to the management of the sports complex itself?
Who can be responsible for removing the obstacles and problems, other than the management of the places?
What solutions do you suggest for providing material and financial resources to increase the productivity of sports venues?
What suggestions do you have to solve the management problems due to the severe currency fluctuations and sanctions in the country, as well as the lack of supply sources?

The content validity of the structured self-interaction questionnaire (ISM) was confirmed by using the opinions of a group of experts, specialists in the field of sports management, and university professors. In the next step, the test-retest method was used to examine the reliability of the tool as mentioned above. For this purpose, the questionnaire was sent to three senior experts and specialists who could be accessed again at two separate times with a specific time interval. After collecting the responses in both stages, the correlation coefficient between the obtained results was calculated, and the value of this coefficient was equal to 0.875. This correlation coefficient indicates a high level of stability and internal consistency of the measurement tool and confirms the acceptable and reliable reliability of the questionnaire for use in scientific research. The main purpose of using the structured self-interaction method is to identify, analyze, and explain the relationships between key and influential variables in a complex and multifaceted system that has different levels of cause-and-effect interactions. Within the framework of this study, the variables under study are a set of management obstacles to the development of sports venues and facilities in the country, which have been identified, categorized, and analyzed with an approach emphasizing the principles and goals of the resistance economy. Using this method allows for the drawing of a hierarchical structure of relationships between obstacles and the determination of the level of effectiveness and impact of each. It allows the researcher to present a logical and scientific model for intervention and decision-making in this area.

Table 1. Characteristics of the expert panel

number of samples	Sampling	The method of determining the sample size	Number of communities	Statistical Society
15	Targeted and with the snowball technique	Using the theoretical saturation criterion	Unknown	Professors and managers of state sports facilities

2.1. Steps in drawing an interpretive structural model (ISM)

The interpretive structural modeling (ISM) method was used to identify and analyze the relationships between management barriers to the development of sports venues and facilities, with an emphasis on resistance economy policies. The steps in implementing ISM in this study are as follows:

Identification of key variables and barriers

First, by reviewing the research background and conducting semi-structured interviews with 15 experts and senior managers in the field of sports venue management, a set of management barriers was identified. The data was analyzed using open and axial coding, and ultimately, nine main barriers and 93 initial codes were obtained.

Preparation of the final list of barriers (expert consensus)

The initial list of barriers was reviewed using the Delphi technique and expert consensus so that only the key and influential barriers remained in the final model.

Formation of self-structured interaction matrix (SSIM)

To determine the binary relationships between the barriers, the experts compared both barriers and determined the type of relationship. Four symbols were used in this step:

- V: Variable i affects variable j.
- A: Variable j affects variable i.
- X: Mutual and two-way relationship.
- O: No relationship.

Conversion of SSIM into Reachability Matrix

The SSIM matrix was converted into a reachability matrix to determine direct and indirect relationships. In this matrix, the number 1 indicates the existence of a relationship and the number 0 indicates the absence of a relationship. Transitive closure was also examined and corrected.

Determination of access and prerequisite sets

For each barrier, an access set (obstacles that are affected by it) and a prerequisite set (obstacles that affect it) were determined.

Level partitioning of barriers

By comparing the access and prerequisite sets, barriers with equal access and commonality sets were placed at the highest level of the model. This process continued iteratively until the levels of all barriers were determined.

Drawing an interpretive structural model

After leveling, barriers were placed at different levels of the model, and the direction of relationships was determined using arrows. Upper levels include key and influential barriers (such as economic barriers in the country), and lower levels include dependent barriers (such as social and human barriers).

MICMAC analysis

Finally, MICMAC analysis was used to examine the influence and degree of dependence of barriers. Accordingly, the barriers were divided into four groups: independent, dependent, linked, and autonomous influencers.

2.2. Structured self-interaction questionnaire (ISM)

A structured self-interaction questionnaire was used to determine the causal relationships between management barriers to the development of sports venues and facilities, with an emphasis on the economy of resistance. This questionnaire was designed in a tabular form and based on pairwise comparisons, and all identified barriers were compared with each other in pairs. For each pair of barriers, the experts determined the type of relationship by selecting one of the following four symbols:

V: The row barrier affects the column barrier.
A: The column barrier affects the row barrier.
X: Both barriers interact with each other.
O: There is no relationship between the two barriers.

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Sample questionnaire question:

"In your opinion, to what extent does the barrier "economic barriers of the country" affect the deterioration and low quality of sports venues"? Please specify the type of relationship by selecting one of the options V, A, X, or O."

This questionnaire was developed for all nine identified barriers, and the results were used to form the Self-Structured Interaction Matrix (SSIM) and then the Modified Access Matrix.

3. Findings

In the qualitative part, using interviews with experts, the most important obstacles to the management of places were identified with an emphasis on resistance economy, and then using a structured self-interaction questionnaire, an interpretive structural model of the obstacles was presented.

3.1. The characteristics of the samples in the interviews section

In the qualitative part of this study, 15 people were selected purposefully using the snowball method, after which theoretical saturation was achieved. Among these people, 4 were faculty members of the sports management department of universities. Of these four people, one had the rank of professor, two were associate professors, and one was an assistant professor. Also, 11 other people were executive managers of government sports facilities and venues in the country. In the education section, seven people had a master's degree in sports science and four people had a doctorate in sports management. The average work experience of these people was more than 10 years, and all of them had experience in the field of sports facility leadership and management. The diversity in academic rank, education level, and job experience led to the collection of diverse and in-depth perspectives on managerial and economic obstacles. The interviewees were selected in such a way that they could provide a more accurate understanding of the existing challenges. The composition of this group well represents the target population of the study at the scientific and executive levels of the country.

Table 2. Characteristics of the sample population in the qualitative part of the research

Row	Interviewee group	Number of people	Educational qualification	Academic level/position
1	University faculty members	4	1 Assistant Professor 2 Associate Professor 1 Professor	Sports Management Group
2	Sports facility managers	11	7 people have a Master's degree in Sports Science 4 people have a PhD in Sports Management	Executive managers of government sports centers and venues

In the qualitative part of this study, 15 people were selected purposefully using the snowball method to ensure scientific, administrative, and geographical diversity of the data. These people were from different provinces of the country, especially Tehran, Isfahan, Fars, Khorasan Razavi, and Kermanshah provinces, to obtain a comprehensive view of the management conditions of sports venues in different regions of Iran. The composition of the participants included four faculty members of the sports management department of universities (1 full professor, two associate professors, and one assistant professor) and 11 executive directors of government sports venues and facilities. In terms of education level, seven people had a master's degree in sports sciences and four people had a doctorate in sports management. The average work experience of the participants was more than 10 years, and most of them had direct experience in the field of management and supervision of large-scale sports venues and facilities (multipurpose halls, stadiums, and aquatic complexes). This geographical, educational, and occupational diversity allowed the research to identify and analyze diverse and multidimensional perspectives on managerial obstacles to the development of sports venues and facilities, with an emphasis on resistance economy policies.

4. *Identifying managerial obstacles to the development of sports facilities and facilities with an emphasis on resistance economy*

This part of the research was designed and implemented to answer the first research question, and a semi-structured interview method was used, drawing on the perspectives and experiences of specialists and experts in the field of sports venue management. The main goal of using this method was to identify in-depth and systematically the existing management obstacles in the development of sports venues and facilities in the country, with special emphasis on the principles and strategies of the resistance economy. To extract rich and reliable data, a set of strategic and purposeful questions was designed and raised during the interview process with the participants. The interviews were conducted in person and face-to-face with 15 academic experts, executive managers, and experienced experts in the field of sports management and macro-sports policymaking. These individuals were sampled using a purposeful sampling method, observing the criteria of expertise, field experience, and familiarity with topics related to the resistance economy. To strengthen the validity of the results obtained, the Delphi technique was used in the various stages of data collection and refinement. Each interview session lasted between 40 and 60 minutes, during which open-ended questions allowed for diverse and in-depth perspectives to emerge, ensuring the richness of the information content of the interviews. The validity of the interview content was confirmed through review and approval of comments by the project supervisors and advisors, and to assess reliability, the interview data were reviewed and re-analyzed by two independent researchers, which led to convergence in the results. In general, the use of the semi-structured interview method at this stage is considered a scientific and methodological choice because it allows for in-depth analysis of qualitative data and access to hidden and multi-layered dimensions of the phenomenon under study.

The researcher recorded the interviews by observing all the ethical principles of qualitative research and with the complete consent of the interviewees. Then, all the interviews were accurately translated into the text. In this regard, after conducting the interviews, the data from the interview process in the form of written texts were studied and revised many times. On the other hand, related research articles and existing documents were also studied, and by combining these in two ways, a list of codes was created. Open coding was done paragraph by paragraph. In open coding, which is the first step in the implementation of the qualitative analysis strategy, the key points of the interviews were identified and coded in relation to the managerial obstacles to the development of sports facilities and places, with an emphasis on the resistance economy. By re-examining and further refining the codes, we tried to make the codes sufficiently specific, separate, non-repetitive, and macro to include the set of ideas raised in parts of the text. It allowed the data to be reduced and converted into a set of important codes. More precisely, the axial coding stage includes the classification of different codes in the form of selective codes and arranging all coded data summaries. In fact, the researcher begins the analysis of his codes and considers how different primary concepts can be combined to create an overall code; Therefore, many duplicate and similar codes are observed between them; To be able to work with fewer codes, the researcher, after reviewing several times and determining the similarities and differences, merged the codes that had common content and named them with a common code that was more abstract than the initial codes; This was done by considering the theoretical findings with successive shifts between open codes and primary focal categories. Finally, categories that had more conceptual power and could better link concepts and subcategories were selected. The following table shows the results of open and axial coding.

Table 3. Results of open and axial coding

Number of codes	Primary or open coding	Axial coding
9	People's unwillingness to spend money on sports Improper use of the infrastructure of sports facilities (such as water, electricity, gas) and heating and cooling systems. Lack of financial ability of the public to use sports services Not considering the basket of sports goods for people Inadequate access to sports facilities for all Ignoring the possibility of women using sports complexes Lack of enough advertising in the community for health and wellness Irresponsibility of users Failure to promote the reputation and social benefits of sports venues	Social barriers
7	Weak work culture among employees Low level of productivity and enthusiasm among human resources Different shifts of service forces Low salaries and benefits for human resources Lack of coordination and synergy of the administrative elements of sports complexes Lack of motivation and low commitment of employees Lack of technical, experienced, and educated sports science and practical experts in managing sports venues	Human barriers
5	Weaknesses in the production technology of products used in places Lack of a competitive environment in the field of sports products Lack of products related to sports facilities in the country Low quality of domestic products for equipping sports halls Dependence of sports complexes on foreign products	Lack of quality of domestic products
12	-It was a stable economic income Inadequacy of facilities (bank loan(Allocation of insufficient funds in proportion to the existing inflation Lack of sustainable financial resources to carry out repairs and improvements High cost of maintenance and repair of sports facilities High cost of setup and construction The high cost of purchasing sports equipment Delay in providing the necessary funds Failure to return collection revenues to the collection itself Spending the revenues of the sports complex in other sectors Full deposit of the income of sports complexes into the pocket of the government Not allocating 10-15% of the collection's income to maintenance and improvement	Chronic and persistent budget deficit
10	The strong dependence of the country's annual budget on revenues from the sale of crude oil Multiple fluctuations in stock market indices High and continuous inflation in the country Many disturbances in the country's foreign exchange market	Economic obstacles of the country

Number of codes	Primary or open coding	Axial coding
	Intensification of sanctions Increase in rent, embezzlement, and administrative corruption in the state economy Inefficient tax system Failure to fully implement the policies of Article 44 of the Constitution in the direction of liberalization and privatization Inadequate determination to prevent corruption Carrying out illegal imports	
12	Poor support Top-down decision-making centralized structure The inflexible structure of sports complexes Bureaucracy, heavy administrative paperwork The difficulty of handing over collections to the private sector It is time-consuming and difficult to allocate credits and to repair equipment Formal and unnecessary administrative activities Inflexible and inappropriate rules and regulations The linearity of communication between administrative elements Absence of a comprehensive plan for the development of sports facilities Improper decision-making and planning	Structural barriers
13	Lack of multipurpose halls Low-quality construction and production of sports facilities and equipment Lack of sports facilities and equipment Depreciation of the structure of sports spaces or the hardware part of sports spaces Wear and tear of the physical part Lack of proper location of sports facilities (decentralization(Lack of neatness and attractive appearance of facilities Lack of development of the country's infrastructure according to the drawn vision Lack of necessary international standards Exploitation and non-sporting use Malpractice and negligence in handling sports spaces Neglecting the basic maintenance of sports facilities Lack of a detailed study to build sports complexes	Dilapidation and low quality of sports facilities
11	Inability to deliver creatively The involvement and influence of non-specialists and upper management in the management of collections Lack of independent decision-making by managers Inability to control income and expenditure Lack of influence of sports officials in the upper hand system Managers' lack of authority to use the exclusive income of sports complexes Managers' lack of authority for the cost of developing, equipping, and maintaining the collection Lack of proper support from managers Lack of job security for managers Lack of ability and authority of managers to encourage and punish human resources Preventing the creativity of managers	Lack of sufficient authority

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Number of codes	Primary or open coding	Axial coding
14	Lack of scientific and practical expertise Lack of financial literacy Low communication skills Inadequate diagnostic skills Poor time management Weak change management skills Lack of proper perception of the situation Lack of criticism and flexibility Failure to create a sense of responsibility among the managers of the premises Negligence and delay in maintaining the sports space Lack of experience in the assigned responsibility Lack of consecutive correct training Lack of understanding of the resistance economy policy Low knowledge of managers in the field of sports	Skill weakness of upstream and downstream managers

Finally, 93 basic codes were extracted from the interviews. In the next steps, the obtained open coding was categorized into similar and coherent groups, and the codes were analyzed and revised several times. Finally, nine core codes and 93 basic codes were identified and extracted to identify the management barriers of places and facilitiesthe reliability of the structured self-interaction questionnaire. The retest method is used. To evaluate the said questionnaire twice, it was sent to 3 experts and experts who could be contacted again, and finally, the total correlation of the answers announced for both stages by the experts was 0.875, which indicates the acceptable reliability of the questionnaire. A qualitative approach with open and axial coding and interpretive structural modeling was used to analyze the obstacles of the managers of sports facilities and facilities with an emphasis on resistance economy.

Table 4. Identified barriers

Number of open codes	Axial code
9	Social barriers
7	Human barriers
5	Lack of quality of domestic products
12	Chronic and persistent budget deficit
10	Economic obstacles of the country
12	Structural barriers
13	Dilapidation and low quality of sports facilities
11	Lack of sufficient authority
14	Skill weakness of upstream and downstream managers

As it is known, the managerial barriers to the development of sports facilities and facilities with an emphasis on resistance economy according to the interviewees to answer the first question of the research include nine barriers including social barriers, human barriers, lack of quality of domestic products, chronic and stable budget deficit, barriers The country's economy is structural obstacles, wear and tear and low quality of sports facilities, lack of sufficient authority and weak skills of upstream and downstream managers.

4.1. The relationship between managerial obstacles to the development of sports facilities and facilities with an emphasis on resistance economy

In order to provide a suitable model and examine the relationship between barriers, using the interpretive structural analysis method, the management barriers of sports facilities have been leveled with an emphasis on resistance economy. To implement the structural-interpretive technique, to obtain the internal relationships and priorities of the elements in a system, the following process must be followed: First, a structured self-interaction matrix (structural matrix of internal relationships of variables) was formed to create a structured self-interaction matrix of all identified obstacles two by two in terms of relationship or the lack of relationship was compared with each other. The way of scoring the type of relationship between obstacles is as shown in Tables 3 and 4, which is the structured self-interaction matrix. Next, to make the matrix compatible, the questionnaire was filled out again by the samples, and then the compatibility of the access matrix was checked and confirmed again. In order to determine the level of obstacles in the final model, input, output, and joint sets were formed for each of them. The more shared sets and the output of a factor, the higher the level of that variable.

Table 5. Scoring key for the structural self-interaction matrix

O	**X**	**A**	**V**
Absence of a relationship	Bilateral relationship	Variable j affects i	Variable i affects j

Table 6. Structural Self-Interaction Matrix (SSIM)

I	H	G	F	E	D	C	B	A	
									A
								X	B
							O	V	C
						X	V	V	D
					V	X	V	V	E
				X	X	O	V	V	F
			X	A	X	A	X	V	G
		V	X	A	V	O	V	V	H
	X	V	X	X	V	O	X	V	I

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According to the final structured self-interaction matrix, the adapted access matrix was designed.

Table 7. Final reachability matrix

infiltrate	I	H	G	F	E	D	C	B	A	
2	0	0	0	0	0	0	0	1	1	**A**
4	1	0	1	0	0	0	0	1	1	**B**
5	0	0	1	0	1	1	1	0	1	**C**
6	0	0	1	1	0	1	1	1	1	**D**
9	1	1	1	1	1	1	1	1	1	**E**
8	1	1	1	1	1	1	0	1	1	**F**
4	0	0	1	1	0	1	0	1	0	**G**
7	1	1	1	1	0	1	0	1	1	**H**
8	1	1	1	1	1	1	0	1	1	**I**
	5	4	8	6	4	7	3	8	9	**dependency**

Table 8. Level partitioning of barriers to the development of sports facilities and facilities with an emphasis on resistance economy

Level	Subscription	Input: Effectiveness	Output: Effect	
4	A,B	A,B,C,D,E,F, H,I	A,B	A
4	A,B,G,I	A,B, D,E,F,G,H,I	A,B,G,I	B
1	C,D,E	C,D,E	A,C,D,E,G	C
3	C,D,F,G,	C,D,E,F,G,H,I	A,B,C,D,F,G,	D
1	C, E,F,I	C, E,F,I	A,B,C,D,E,F,G,H,I	E
1	,D,E,F,G,H,I	,D,E,F,G,H,I	A,B, D,E,F,G,H,I	F
3	B, D, F,G	B,C,D,E,F,G,H,I	B,D,F,G	G
2	,F,H,I	E,F,H,I	A,B, D,F,G,H,I	H
2	B,E,F,H,I	B,E,F,H,I	A,B,D,E,F,G,H,I	I

The final pattern of identified obstacles is shown in the figure below. In this picture, the meaningful relationships of the elements of each level on the elements of the lower level, as well as the meaningful internal relationships of the elements of each line, are considered.

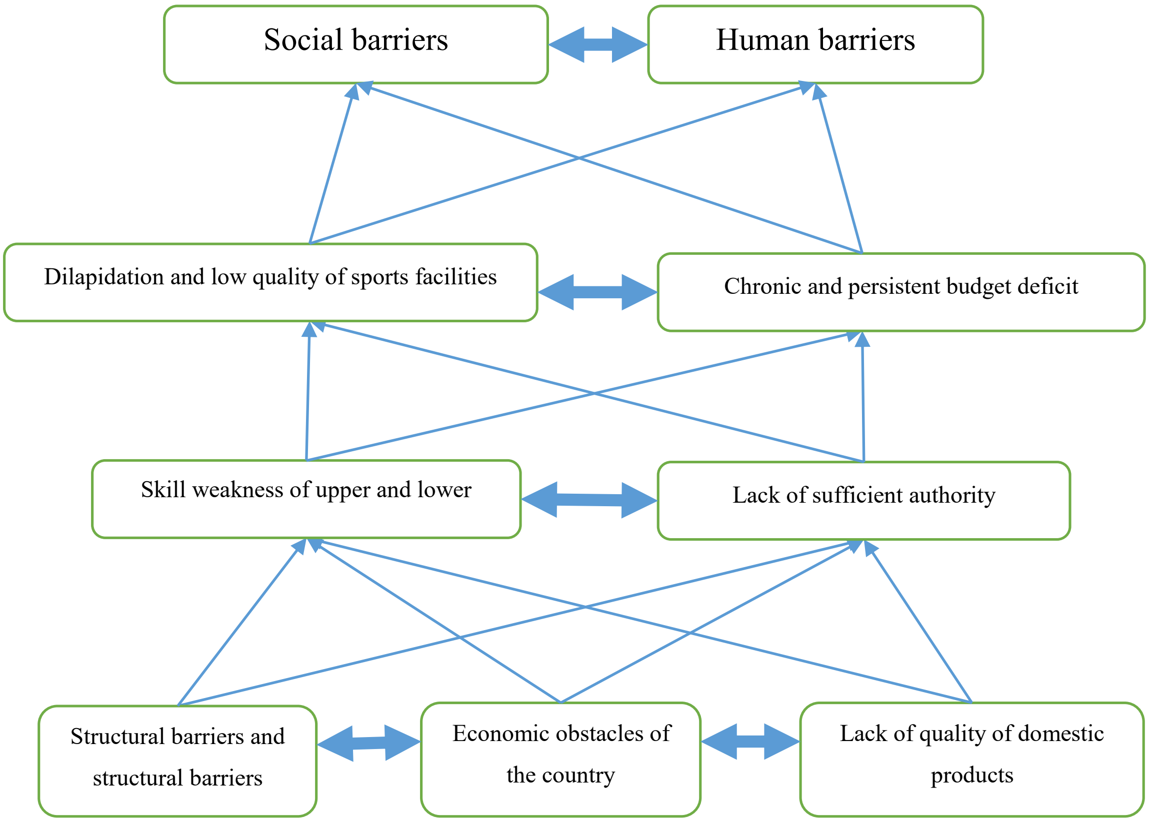

Figure 1. Structural model of the researchers' identified interpretation

After drawing an interpretive structural model and using the MICMAC method, by creating a penetration-dependence matrix of the barriers, they were classified into four main groups: 1) independent variables, 2) linked (related) variables, 3) dependent variables, and 4) autonomous variables (Pankal et al., 2016). The results of this analysis are as follows:

1. Independent variables (High driving power and low dependence)

Three barriers country economic barriers, structural barriers, and poor quality of domestic products were placed in this group. These barriers are located at the first level of the model and are known as key and underlying barriers, whose control and improvement can also affect other barriers.

2. Linking variables (High driving power and high dependence)

Two barriers chronic and persistent budget deficit and wear and tear and low quality of sports facilities were placed in this group and at the third level of the model . These barriers are strongly influenced by independent barriers and at the same time affect other dependent barriers.

3.Dependent variables (Low driving power but high dependence)

Social barriers and human barriers are located at the fourth level of the model and have the greatest dependence on other barriers. These barriers are a direct result of the conditions created by key and link barriers.

4. Autonomous variables (Low driving power and low dependence)

None of the barriers identified in this study were included in this group, which indicates the interaction and chain and systematic connection of all barriers with each other.

The results also showed that lack of skill of upstream and downstream managers and lack of sufficient authority are located at the second level of the model and on the border between independent and link variables; these two barriers have a mediating role and can directly affect the intensity of the impact of key barriers.

Based on the findings of Table 8, the variables of social barriers, human barriers, wear and tear, and low quality of sports facilities are more influenced by other factors and are effective and dependent elements from a systemic perspective. In other words, many factors are involved in removing these obstacles, and they themselves are less likely to become the basis of other variables. Variables that have a weak influence and weak dependence include the lack of quality of domestic products. Also, the variables of the country's economic obstacles, the skill weakness of upstream and downstream managers, and the lack of sufficient authority have a high influence power and low dependence. These variables have a great influence on overcoming other obstacles. In this research, the variables of structural obstacles and chronic and stable budget deficit are among the linking factors. These obstacles are both highly dependent and have a lot of influence.

5. Conclusion and suggestions

To highlight the results and findings of the research, the results are compared with previous research. Also, the necessary interpretations are provided to determine the place of this research among the conducted research, as well as the deficiencies and deficiencies related to the management of sports facilities and facilities with an emphasis on economy. Resistance appears. According to the results of the open and central coding, it was found that the administrative barriers to the development of sports facilities and facilities with an emphasis on resistance economy include social barriers, human barriers, lack of quality of domestic products, chronic and stable budget deficit, economic barriers of the country, structural barriers, The deterioration and low quality of sports facilities, lack of sufficient authority and weak skills of upstream and downstream managers are now interpreted separately for each of these factors.

Iran is facing economic problems and limitations, and its non-compliance with the ruling structures of the world in various areas. It is the understanding of these limitations in sports that clarifies the importance of implementing the general policies of the resistance economy.

Regarding social barriers, it can be said that the incorrect use of the infrastructure of sports facilities (such as water, electricity, gas) and heating and cooling systems by users can lead to the fact that more money is needed to operate the facilities, and this is a form of irresponsibility. Users leave destructive works on sports facilities, in line with this result of researchers such as Ebrahimi and Zirak (2012); Moharramzadeh et al. (2015); Ramchandani et al. (2019) have pointed out the social factors and obstacles for managing sports facilities and Moharramzadeh et al. (2015) has considered the impact of the economic recession on home sports expenses in Ireland to be positive. On the other hand, the general public's lack of financial ability to use sports services and the lack of budget for buying and using sports facilities in the household goods basket automatically limit the percentage of sports participation and thus the statistical population of the facilities. Another social obstacle may be that it is not possible for all members of society to have enough access to sports, and more importantly, the possibility of women using sports complexes has been neglected. Regarding human obstacles, it should be stated that human resources are the most important resource of any organization, and emphasizing this resource can be the source of huge changes in sports venues. Ebrahimi and Zirak (2012) and Iversen (2019) have considered human obstacles as important in their research for better management of sports complexes, therefore, the low salaries and benefits of human resources and the lack of technical, experienced and educated experts in scientific and practical sports management Sports venues have severely affected the management of sports venues, and in a way, the lack of motivation and low commitment of employees has greatly reduced the level of productivity and has caused the inconsistency and synergy of the administrative elements of sports complexes to face a problem. The lack of quality of domestic products is another obstacle that has been identified in this research. No research was found that considered the quality of domestic products as a management obstacle in the field of sports. However, based on the results of the interviews, this obstacle has been considered very important. In this regard, the weakness in the production technology of the products used in the places is quite evident, considering the current dynamic environment, and the production tools and materials inside the country in the field of sports products are largely competitive. They do not have foreign-produced products because there are many restrictions for manufacturing companies in the country. Also, according to the existing demand, there is no competitive space in the field of sports products. In many cases, we are facing a shortage of products related to sports facilities in the country, which is important. The quality of domestic products for equipping sports halls is low, and in this regard, the dependence of sports complexes on foreign products is high.

Another main category identified for managerial obstacles to the development of sports venues and facilities is the category of chronic and stable budget deficit. In this context, for all places, the lack of sustainable economic income, the lack of sustainable financial resources to carry out repairs and improvements, and the delay in providing the necessary budget cause irreparable damage to the management of the places. On the other hand, insufficient facilities (bank loans) and allocation Insufficient budget compared to existing inflation are other factors that make the budget of sports facilities with many problems, so the high cost of setting up and building, the high cost of maintaining and repairing sports facilities, or the high cost of purchasing equipment for sports facilities are the main concerns of the managers of the facilities, perhaps the source of these problems. Can be related to the non-return of the income of the complex to the complex itself and the spending of the income of the sports complex in other sectors, the full deposit of the income of the sports complex into the pocket of the government seems unreasonable to a large extent. It allows the managers to use their income, and somehow, they lose their motivation to work. Despite severe international sanctions, our country faces many economic obstacles, and Moharramzadeh et al. (2015) and Khazaei (2016), in their research, have considered economic factors as factors that can affect the management of places. In this research, it has also been considered as one of the management obstacles for the development of sports places and facilities, while the annual budget of the country is highly dependent on the revenues from the sale of crude oil. The increase in rent, embezzlement, and administrative corruption in the state economy is increasing day by day. The full implementation of the policies of Article 44 of the Constitution in the direction of liberalization and privatization has not yet been implemented. More importantly, there is high and continuous inflation in the country's economy, which has involved not only sports venues but all organizations and companies. It remains closed, and they cannot implement their goals as they should.

Structural obstacles are another category of obstacles that the managers of sports facilities face, with emphasis on resistance economy. And an inflexible organizational focus. It is very clear that in a system where decisions are made at the top, the communication between administrative elements is linear, and delegation of authority rarely happens. When there are bureaucracy and intense administrative paperwork, the manager is more than involved in the transformation and thinking about their duties. Therefore, in this situation, inflexible and inappropriate rules and regulations, the time-consuming and difficult allocation of credits, and the repair of the equipment inflict severe blows on the management body of the places, and they cannot properly implement resistance economy policies. Another factor that managers face in this difficult situation is the deterioration and low quality of sports facilities. Many of the sports facilities are old or existing, or if they are newly built, they are facing many deficiencies, and many of these complexes do not have standard qualities. A kind of wear and tear of places is quite evident in these conditions; the management of sports facilities and facilities is more challenging than before. Perhaps it is the use of low-quality materials or the neglect of basic maintenance and protection of these places. It is clear that in many cases, sports places are used for non-sports purposes without the slightest benefit reaching these places, and they are expensive.

Another category that was identified in this research is the lack of sufficient authority for the managers. Considering the centralized and inflexible administrative system of the country, this category is extremely harmful for the managers. It makes them look more like simple and orderly employees than worthy managers. It can be seen that every day, the involvement and influence of non-specialists and upper management in the management of collections is increasing, so the managers are losing their decision-making independence more and more. When a manager does not have enough authority and cannot have enough control over his income and expenses, he certainly cannot act according to the policies of the resistance economy and cause the transformation of the group under his supervision, because the lack of sufficient authority for managers deprives them of the ability to deliver creatively. In a way, the creativity of managers is questioned. The last main category of identified obstacles is dedicated to the skill weakness of upstream and downstream managers. The identification of this obstacle is in line with the research of Moharramzadeh et al. (2015) and Parnell et al. (2019) The reason for the scientific and practical expertise, or the lack of expertise, related to sports management, especially the management of sports venues, is that the managers do not have the necessary skills and do not have proper diagnostic skills. The expertise in the financial field is also very low, and this inability of them in times when the country should show resistance. The economic approach deals with its own phenomena and increases. Every manager must have several skills, and these skills, from human and communication skills to crisis management and diagnostic

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and perceptive skills, help overcome many obstacles. Unfortunately, many managers of places do not have a proper understanding of the existing resistance economy policy, and their lack of criticism and flexibility makes them unable to perform their duties properly.

In response to this question, it was found that the country's economic obstacles, structural obstacles, lack of quality of domestic products are placed on the first level and are among the most important obstacles that, if more attention is paid to these obstacles, can facilitate the removal of other obstacles, on the second level are the obstacles of lack of skills. There are upper and lower managers, and a lack of sufficient authority. These obstacles, in turn, can be influenced by the first-level obstacles, which are the country's economic obstacles, structural obstacles, and lack of quality of domestic products, and they themselves can influence the third- and fourth-level obstacles. In addition to the third-level barriers of obsolescence and low quality of sports facilities and chronic and stable budget deficit, there are third-level barriers from the first-level barriers, i.e., economic barriers of the country, structural barriers, lack of quality of domestic products, and second-level barriers, i.e., the barriers of the lack of skills of upper and lower managers. Manual and lack of sufficient authority have a great impact; that is, if the first and second level obstacles are partially removed, the third level obstacles, i.e., the obstacles of wear and tear, low quality of sports facilities, and chronic and stable budget deficit, will be removed with ease. Chronic and stable budget deficits can affect the fourth-level barriers. Finally, social barriers and human barriers are placed in the fourth level. These two barriers are affected by all other barriers.

On the other hand, the analysis of Mik Mak showed that the variables of social barriers, human barriers, wear and tear, and other factors more influence the low quality of sports facilities, and from a systemic point of view, they are effective and dependent elements. In other words, many factors are involved in removing these obstacles, and they themselves are less likely to become the basis of other variables. Variables that have a weak influence and weak dependence include the lack of quality of domestic products. Also, the variables of the country's economic obstacles, the skill weakness of upstream and downstream managers, and the lack of sufficient authority have high influence and low dependence. These variables have a great influence on overcoming other obstacles. In this research, the variables of structural obstacles and chronic and stable budget deficit are among the linking factors. These obstacles are highly interdependent and have a lot of influence.

In general, based on the findings, it should be said that the economic obstacles of the country, the lack of skills of the upstream and downstream managers and the lack of sufficient authority are important factors that focusing on them can transform the management of places in these difficult conditions and solve their problems with. The economic consequence of the direct and indirect effects of sports in development has caused an increasing attention to this industry. In line with other areas, it is necessary to turn to the policy of resistance economy when facing difficult conditions to turn threats into opportunities. Knowing that the realization of this requires a road map for the implementation of a resistance economy in the field of sports, in this regard, Afshari et al., (2019) considered it necessary to focus on the resistance economy and the development of sports. Based on Giannoulakis et al. (2017), the main strategies for dealing with the economic recession have included administrative downsizing, limiting the number of competitions, reducing the size of delegations, and using alternative sources of funding. Harun et al. (2013) have also given great importance to the basic maintenance of sports facilities.It is very clear that in a system where the economy is declining every day.

It is very clear that in a system where the economy is declining every day. People are facing many problems, and currency fluctuations are happening with power and political and economic sanctions increasing. The skill of a manager in managing a complex environment is crucial. Power and political and economic sanctions are increasing, the skill of a manager in managing a complex environment with emphasis on resistance economy is subject to tensions. Of course, these factors are mostly related to external factors. At the same time, inside organizations and complexes, managers do not have much decision-making independence and have an inflexible structure, so all these factors work hand in hand in a continuous and unfortunately regular system of facilities management. Sports for the transformation and promotion of the complex under the management and with emphasis on resistance economy policies will face innumerable tensions.

This study aimed to identify management barriers to the development of sports venues and facilities with an emphasis on the economy of resistance. The results showed that management barriers include several key dimensions that can be classified into three levels: structural, economic, and human. At the first level, the country's economic barriers, poor quality of domestic products, and inefficient organizational structures are the most important limiting factors that have the greatest impact and the least dependence and can affect other barriers. These findings are consistent with the studies of Moharramzadeh et al. (2015), which emphasize the impact of economic and structural factors on sports management. The second level of barriers is dedicated to the weakness of the skills of upstream and downstream managers and their lack of authority. The lack of specialized knowledge, managerial skills, and decision-making autonomy has created serious problems in the management of stadiums, which is consistent with the findings of Ebrahimi and Zirak (2012) and Iverson (2024). These weaknesses have also reduced staff motivation and productivity and weakened organizational coordination. At the third level, the deterioration of sports facilities and facilities, chronic and persistent budget deficits, and poor quality of equipment were identified as major operational barriers that are closely related to the first and second level barriers. In particular, the budget deficit, which is affected by inflation and inadequate resource allocation, has severely limited the possibility of maintaining and developing venues. This is consistent with the studies of Harun et al. (2013), which have pointed out the importance of sound budgeting and maintenance. Finally, social and human barriers, such as abuse of infrastructure by users and lack of equitable access to sports venues, are ranked at the fourth level and are highly influenced by other barriers. For example, the role of gender constraints and social inequalities in the use of sports services is one of the prominent challenges that has been less addressed in previous studies. The MICMAC analysis showed that economic, skill, and structural barriers play a pivotal and effective role in creating and perpetuating other barriers, while social and human barriers are more dependent on other factors and require comprehensive and systematic approaches to overcome. This multilayered and interdependent structure highlights the need to develop comprehensive management plans that simultaneously address all dimensions of barriers. Based on the results, it is suggested that effective steps be taken to realize a resistance economy in the field of sports through a systems thinking approach and increasing managerial capabilities, optimal budget allocation, and support for domestic production. Also, delegating sufficient authority to managers and developing social and communication networks can improve productivity, increase managers' motivation, and contribute to the sustainability of sports facilities. Creating a clear roadmap for implementing a resistance economy in sports, considering the specific economic conditions of the country, seems essential. These results, emphasizing the importance of a resistance economy and modern management of sports venues, are consistent with recent studies such as Afshari et al., (2019) and Giannoulakis et al. (2017), and can be a basis for future research and macro-policies in sports in the country.

Based on the results, it is recommended to pay attention to all management obstacles with a systems thinking approach so that none are ignored. Saving on public costs and optimal use of energy, along with improving the quality of domestic products, can improve the performance of sports facilities and reduce their wear and tear. Delegation of authority to managers and the use of internal revenues of complexes, along with fair distribution of sports budgets at the national level, are solutions to reduce budget deficits and remove financial obstacles. Also, the development of social networks and social interactions can be effective in improving sports services.

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References

Afshari M., Seyed Ameri, M.H. and Honari, H., 2019. Attending to resistance economy and its role on the economic development of Iran's sports industry. *Journal of Sustainable Development in Sport Management*, 3(9), pp. 1–22. doi:10.22054/qrsm.2019.11098. [in Persian].

Aharoni, Y., Maimon, Z. and Segev, E., 1981. Interrelationships between environmental dependencies: A basis for tradeoffs to increase autonomy. *Strategic Management Journal*, *2*(2), pp.197-208. https://doi.org/10.1002/smj.4250020208.

Berry, R. and Manoli, A.E., 2018. Alternative revenue streams for centrally funded sport governing bodies. *International Journal of Sport Policy and Politics*, *10*(3), pp.429-450. https://doi.org/10.1080/19406940.2017.1387587.

Collin M. and Haudenhuyse, R., 2015. Social exclusion and austerity policies in England: The role of sports in a new area of social polarisation and inequality?. *Social inclusion*, *3*(3), pp.5-18. https://doi.org/10.17645/si.v3i3.54

Dess, G.G. and Beard, D.W., 1984. Dimensions of organizational task environments. *Administrative science quarterly*, pp.52-73. https://doi.org/10.2307/2393080.

Eschenfelder, M.J. and Li, M., 2007. *Economics of sport*. 2nd ed. Morgantown, WV: Fitness Information Technology. Available at: https://search.library.berkeley.edu.

Giannoulakis, C., Papadimitriou, D., Alexandris, K. and Brgoch, S., 2017. Impact of austerity measures on National Sport Federations: evidence from Greece. *European sport management quarterly*, *17*(1), pp.75-97. https://doi.org/10.1080/16184742.2016.1178795.

Harun, M.T., Salamudin, N. and Hushin, H.F., 2013. Appraisal of the sport facilities maintenance management practices of Malaysian Stadium Corporations. *Asian Social Science*, *9*(12), p.93.

Iversen, E.B., 2019. Public management of sports facilities in times of austerity. In *Sport Policy and Politics in an Era of Austerity* (pp. 77-92). Routledge. https://doi.org/10.1080/19406940.2018.1426621.

Kenyon, J.A., Mason, C. and Rookwood, J., 2019. Emerging third-sector sports organisations and navigating uncertainty in an 'era of austerity': a single ethnographic case study from Liverpool. In *Sport Policy and Politics in an Era of Austerity* (pp. 24-41). Routledge. https://doi.org/10.1080/19406940.2018.1425732.

Khazaei, A., 2016. *Identify the challenges of implementing the resilient economy in the country's sport industry*, Master's thesis, Allameh Tabataba'i University. [in Persian].

Khazaei, A., Honari, H. and Shahlaee Bagheri, J., 2018. Identify the challenges of implementing the resilient economy in the country's sport industry. Sport Management Studies, 10(49), pp. 59–78.https://doi.org/10.22089/smrj.2017.4610.1886. [in Persian].

King , N., 2014. Local authority sport services under the UK coalition government: retention, revision or curtailment?. *International journal of sport policy and politics*, *6*(3), pp.349-369. https://doi.org/10.1080/19406940.2013.825873.

Moharramzadeh, M. and Ghayebzadeh, S., 2015. Investigating the administrative challenges of privatization of sport facilities in city sports. *Contemporary Studies on Sport Management*, 5(10), pp. 73–84. URL: https://smms.basu.ac.ir/article_1310.html. [in Persian].

Ebrahimi, M. and Zirak, M., 2012. The causal relationship of resistive economy and investment in Iran: An empirical analysis of the resistive-based approach to economy. *Economic Journal of Iran*, 12(9–10), pp. 25–46. Available at: http://ejip.ir/article-1-478-fa.html**.** [in Persian].

Mozafari, S.A.A., 2013. *Planning and management of sport facilities*. Tehran: Research Institute of Physical Education and Sport Sciences. . Available at: https://digitallib.qut.ac.ir/dL/search/default.aspx?Term=6377&Field=0&DTC=2. **.** [in Persian].

Parnell, D., Spracklen, K. and Millward, P., 2017. Sport management issues in an era of austerity. *European sport management quarterly*, *17*(1), pp.67-74. https://doi.org/10.1080/16184742.2016.1257552.

Parnell, D., May, A., Widdop, P., Cope, E. and Bailey, R., 2019. Management strategies of non-profit community sport facilities in an era of austerity. *European Sport Management Quarterly*, *19*(3), pp.312-330. https://doi.org/10.1080/16184742.2018.1523944.

Pfeffer, J., and Salancik, G.R., 1978. *The external control of organizations: A resource dependence perspective*. New York: Harper & Row.

Ramchandani, G., Shibli, S. and Kung, S.P., 2019. The performance of local authority sports facilities in England during a period of recession and austerity. In *Sport Policy and Politics in an Era of Austerity* (pp. 93-109). Routledge. https://doi.org/10.4324/9780429057625-7.

Saif, A.M., 2012. The proposed model of resistance economy of the Islamic Republic of Iran (based on the view of the Supreme Leader). *Security Horizons*, 5(16). Available at: https://ps.ihu.ac.ir/article_200411.html?lang=fa . [Persian].

Walker, C.M. and Hayton, J.W., 2019. An analysis of third sector sport organisations in an era of 'super-austerity'. In *Sport Policy and Politics in an Era of Austerity* (pp. 42-60). Routledge. *https://doi.org/*10.4324/9780429057625-4.

Wicker, P. and Breuer, C., 2011. Scarcity of resources in German non-profit sport clubs. *Sport management review*, *14*(2), pp.188-201. https://doi.org/10.1016/j.smr.2010.09.001.

Widdop, P., King, N., Parnell, D., Cutts, D. and Millward, P., 2019. Austerity, policy and sport participation in England. In *Sport policy and politics in an era of austerity* (pp. 6-23). Routledge. *https://doi.org/*10.4324/9780429057625-2.

Yeager, V.A., Zhang, Y. and Diana, M.L., 2015. Analyzing determinants of hospitals' accountable care organizations participation: A resource dependency theory perspective. *Medical Care Research and Review*, *72*(6), pp.687-706. https://doi.org/10.1177/1077558715592295.

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A Hybrid Feature Selection and Classification Framework for Predicting Entrepreneurial Competency Using Machine Learning and Binary Grey Wolf Optimizer

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ABSTRACT

Entrepreneurial competency is a fundamental element of economic development and innovation in education. Research has shown that there is a relationship between psychological, educational, and environmental factors that lead to entrepreneurial capability. However, the combination of machine learning with accurate feature selection has not been thoroughly investigated. This study offers a hybridized framework combining the Binary Grey Wolf Optimizer and machine learning classification to predict the entrepreneurial competency of university students. The Binary Grey Wolf Optimizer features flexible options while grounded in the EntreComp framework and systematically captures multidimensional aspects of entrepreneurial competence as reflected in a theoretical framework. This work applied mutual information filtering, ADASYN to resolve class imbalance, and Optuna to adjust the hyperparameters for 16 different machine learning classifiers on a student data set with 219 records. The LightBGM algorithm demonstrated the highest level of accuracy, achieving 70.7%, followed by F1 with 68.3%, and an ROC AUC measure of 70.5%. Furthermore, SHAP analysis clearly demonstrated that entrepreneurial environments, physical health, and resilience play a pivotal role in assessing an individual's entrepreneurial potential. A comparison with Sharma and Manchanda's (2020) benchmark, which utilized standard classifiers and achieved a maximum accuracy of 59.18%, showcases the clear benefits of this integrated, optimization-based method. In addition to offering greater accuracy, this study presents a scalable and interpretable framework for academic institutions to assess and encourage entrepreneurial growth and advancement. Future research may expand upon this work by conducting longitudinal studies, utilizing cross-cultural datasets, and exploring alternative metaheuristic algorithms.

Keywords

Binary grey wolf optimizer, Entrepreneurial competency, Entrepreneurship education, Feature selection, Machine learning, Predictive modeling.

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1. Introduction

The global economy relying on innovation means it is crucial to know what skills successful entrepreneurs bring to the table. A blend of knowledge, skills, attitudes, and behaviors is part of what we call competencies, allowing someone to complete entrepreneurial tasks effectively (Martínez-Martínez et al., 2025). Shah and Lala (2022) argue that these abilities strongly indicate who will thrive as entrepreneurs, mainly in conflict zones. As a result, how entrepreneurial skills connect with education and the environment is a subject of interest among researchers; these studies confirm that they can boost motivation and accomplishments among entrepreneurs (Rotimi et al., 2022). Recently, research has brought together the main skills needed for entrepreneurship and organized them so they can be used in education and students' development (Tittel and Terzidis, 2020). Nevertheless, current models are limited because they lack robust use of machine learning methods. Even though there has been considerable progress in relating entrepreneurial competency to various studies, current research has not fully embraced exploring what machine learning algorithms can do to predict, quantify, and ideally inform entrepreneurs' decision-making process that involves competence. Traditional methods of arriving at the entrepreneurial competence measure have exclusively focused on qualitative measures and hence do not capitalize on the quantitative dominance of machine learning and feature selection in contexts containing large datasets. By employing machine learning, particularly ensemble methods and optimization algorithms, researchers have an opportunity to explore and quantify the different qualities, or components, of entrepreneurial competencies more effectively and efficiently (Sarker, 2021).

The use of traditional linear models to capture nonlinear relationships between facets and the thought of the interacting features of entrepreneurial data are strong reasons to develop interesting frameworks to incorporate structural complexities and individualized interaction in the datasets (Yi et al., 2023). Sharma and Manchanda (2020) used machine learning to predict whether university students have entrepreneurial competence. Even though this research makes an early effort to use data in entrepreneurship, it does not have a detailed set of theories, and it fails to easily arrange the different psychological, educational, and environmental elements together in one method. The present study fills these gaps by basing its study on the EntreComp approach and applying advanced machine learning techniques, like parameter optimization through Optuna, using the Binary Grey Wolf Optimizer for feature selection, and explaining model outcomes with SHAP. Thanks to these new methods, the model is more solid, easy to explain, and in line with theoretical thinking, helping to show all the different parts of entrepreneurial competence. While various researchers have examined what makes entrepreneurs successful in tough circumstances, there is still little agreement on how to predict and measure these abilities. Most existing studies depend on descriptive statistics or easy forms of regression, without making full use of modern computing tools (Ding, 2023). For that reason, attaching a hybrid feature selection method to machine learning algorithms, including the BGWO algorithm, serves as a main path to improve the accuracy and relevance of predictive models (Essien et al., 2024). Moreover, discussions about ensemble methods in literature are increasing; however, few implementations have been carried out in entrepreneurial competencies (Pintelas and Livieris, 2020).

This work targets the design and testing of a unified feature selection and classification approach for predicting the skills required for entrepreneurship through the use of machine learning and BGWO. Some of the research questions used in this study are:

1. What factors are most important for building entrepreneurial skills, and how can BGWO help choose them effectively?
2. Is a hybrid framework more accurate in dealing with entrepreneurial competencies than classic machine learning algorithms?
3. What findings from the classifications might positively shape training and education in entrepreneurship?

Its main significance is that it adds to the body of literature in entrepreneurship and applies knowledge in various business areas. It seeks to connect business theories about entrepreneurial skills with real-world ways of collecting data in order to offer structure and guidance to policymakers, teachers, and experts. It also demonstrates how new computational methods are helping to develop entrepreneurship research focused on using data more effectively (Sarker, 2021). For this reason, the results may be used to update curricula and train students in schools, helping entrepreneurial classes adjust to current and future problems in the business world. This paper is organized to systematically and clearly answer the research questions and provide a better understanding of the proposed methodology. The Introduction highlights the research context by developing the problem statement, the aims of the research, and the relevance of the study. In the Literature Review, we examine research studies of entrepreneurial competencies and the available body of research exploring the application of machine learning to predictive modeling tasks. In the Methodology section, we describe the hybrid feature selection framework, including the application of the Binary Grey Wolf Optimizer (BGWO) and several machine learning classifiers. In the Results and Discussion section, we will present the empirical findings, comparative evaluation against previously established models, and discussion of the practical application of the results obtained through this research process. The Conclusion and Future Work section summarizes the highlights of the research, our limitations, and suggestions for future research activities.

2. Theoretical foundations and research background

2.1. Predicting entrepreneurial competency

The study of entrepreneurial competence is built on an understanding of how competencies relate to each other, can be learned by experience, and can support improving other competencies. Entrepreneurship is broadly defined as the process through which individuals identify, evaluate, and exploit opportunities to introduce new goods or services, organize ventures, or create value in dynamic environments (Ahmed and Harrison, 2022; Long, 1983) . As outlined by Shane and Venkataraman (2000), entrepreneurship is the academic study of how, by whom, and with what consequences opportunities to create future goods and services are discovered, evaluated, and exploited. This definition of entrepreneurship indicates its many aspects, including cognitive, behavioral, and contextual elements, all of which are relevant in understanding behavioral competency as an entrepreneur.

The EntreComp[1] framework captures three interconnected competence areas: “Ideas and Opportunities,” “Resources,” and “Into Action,” divided into 15 competence areas and descriptors. These competencies represent the amalgamation of knowledge, skills, and attitudes in the process of converting ideas into action within professional and personal environments (Stenholm et al., 2021; Margherita et al., 2016). This framework is a commonly used way within entrepreneurship education to facilitate curriculum development and competency-based assessment, as they relate to creativity, ethical thinking, sustainability, resource mobilization, taking initiative, and learning or being empowered by experience (Botha, 2023). Thus, it offers a theoretical extension for predictive models aiming at measuring entrepreneurial potential in student populations(Stenholm et al., 2021). Research efforts have helped create a list of necessary entrepreneurial abilities to use in forming predictive models. Draksler and Širec (2018) built a model that merges 17 constructs of entrepreneurial competencies from the earlier work of Botha (2023) and Yin et al. (2022). The model represents a detailed set of abilities required for being an entrepreneur in the modern-day economy (Draksler and Širec, 2018). All of these skills, as described in the frameworks, point out that entrepreneurs use both knowledge

[1] Entrepreneurship Competence

and behavioral methods, mainly in areas such as communication, self-confidence, and flexibility (Morris et al., 2013; Morris and König, 2020). Bolzani and Luppi point out that assessing these competencies is tough because they are quite varied (Bolzani and Luppi, 2021). The authors are summarizing the common view among scholars that entrepreneurship education needs to show both the methods and the place where such skills are developed. Since development is important with assessment, there should be a way in the model to measure how much someone's abilities progress and how they self-assess their skills.

Besides this, the awareness of sustainability's place in entrepreneurship has opened up studies of what it means to be a sustainable entrepreneur (SEC) and how that impacts entrepreneurial intentions (Joensuu-Salo et al., 2022; Ploum et al., 2017). There is a new focus in this area on creating entrepreneurial skills that also align with social and environmental goals, which in turn influence what is taught and how it is measured in schools (Reis et al., 2020). According to Reis et al., (2020), developing entrepreneurial skills should consider the whole economic and social environment, leading to a broader understanding of what it means to be entrepreneurial. In particular, adding self-directed learning to important competencies means that entrepreneurs should always be willing to adapt. In today's quickly changing marketplace, learning and putting what you know into practice are very important for being successful. Integrating these skills into several educational models proposes that we promote more than knowledge sharing by also nurturing the ability to face changes as entrepreneurs. All in all, assessing entrepreneurial competence calls for a wide theoretical basis that shows how various skills are related, addresses the evaluation concerns, and responds to leading tendencies towards sustainability. In schools, developing different competencies helps explain what individuals need to do well as entrepreneurs.

2.2. Machine learning and binary grey wolf optimizer

Machine learning represents a fundamental barrier of artificial intelligence, employing computational methods to recognize patterns, automate decisions, and improve efficiency across multiple applications. ML is founded on ideas from various mathematical and statistical domains, which influence how algorithms are constructed and used in practice (Jafarnejad Chaghoshi et al., 2024a). ML models have been developed to read data and perform prediction and support methods of supervised learning, unsupervised learning, and reinforcement learning (Mehregan et al., 2025a). Algorithms function this way because they rely on strong mathematical fields, like probabilitya theory and statistics, that allow us to derive models that

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we can use in general cases from data in sample sets (Qu et al., 2019). Much of the current research is focused on addressing the combination of ML, data science, and computational methods, while emphasizing more complex big data, now focused on improving the learning algorithms and addressing their main weaknesses of overfitting and underfitting.

The Binary Grey Wolf Optimizer (BGWO) is not a core element of machine learning but serves as a metaheuristic optimization algorithm inspired by the social hierarchy and hunting behavior of grey wolves. It is often employed in specific ML tasks, particularly for feature selection and hyperparameter tuning. BGWO enhances optimization tasks by simulating leadership dynamics in wolf packs to explore the solution space (Wang, 2024) efficiently. There are heuristic features of BGWO, and it draws on elements of competitive swarm intelligence that facilitate advancing solutions to challenging problems in finance (Chen, 2024), neuroinformatics (Glaser et al., 2020), and operational research (Mills et al., 2022). Incorporating BGWO, in conjunction with learning algorithms, creates multiple opportunities for strengthening and improving the efficiency of algorithms. The notion and application of information-theoretic principles in optimization processes demonstrate variations in algorithmic behavior and effectiveness (Bashir et al., 2020). Metaheuristic algorithms like BGWO have gained attention as complementary tools to enhance specific machine learning tasks such as feature selection and hyperparameter tuning, especially in complex problem domains (Schuld and Killoran, 2019). Accordingly, engaging in BGWO requires consideration of the main principles underlying ML and deciding on the algorithm depending on the organizational methods and styles of data (Adjodah et al., 2019). All in all, with machine learning, change continues as we develop, in large part, because of the advancements in algorithm design with natural heuristic approaches in systems such as BGWO. This rapid change provides opportunities for prospective theoretical principles to be considered with the now-expanding range of machine learning applications.

2.3. Research background

In order to situate this research within existing research, a review of existing literature that has used machine learning methods to predict entrepreneurship is summarized in Table 1. The most notable studies are categorized by their aim, methodology, target population, and findings. This comparison shows the different ways machine learning has been used to model key entrepreneurial outcomes: entrepreneurial intention, spirit, competence, or startup success. In addition, this comparison starts to surface methodological gaps while setting the stage for the study at hand.

Table 1. Research background

Authors	Article title	Goals	Methods	Population	Conclusion
Chen et al. (2025)	What makes you entrepreneurial? Using machine learning to predict technology entrepreneurship	Prediction accuracy of technology entrepreneurship	Model development and comparison	Global Entrepreneurship Monitor in 2020	The XGBoost+SMOTE algorithm best predicted technology entrepreneurship, with education and opportunity perception as key factors.
Suryadi and Kurniawan (2024)	Predicting Entrepreneurial Spirit: A Machine Learning Approach	Entrepreneurial spirit levels	Model development and comparison	400 students	Random Forest predicted entrepreneurial spirit with a macro-averaged F1-score of 0.656.
Aristizábal et al. (2025)	Predicting entrepreneurial intention in Colombian academics: a machine learning approach	Entrepreneurial intention	Survey and machine learning-based data analysis	Colombian academic researchers	Entrepreneurial intention was higher among researchers connected to the private sector and lacking university support.
Bidgoli et al. (2024)	Predicting the success of startups using a machine learning approach	Prediction accuracy of startup success	Prediction accuracy of startup success	startups	Random Forest and Gradient Boosting predicted startup success.
Gosztonyi and Judit (2022)	Profiling (Non-)Nascent Entrepreneurs in Hungary Based on Machine Learning Approaches	Prediction accuracy of nascent entrepreneur identification.	Model development and comparison	Nascent entrepreneurs in Hungary	Machine learning algorithms can accurately predict nascent entrepreneurs in Hungary.
Kaur and Bhatt (2023)	Forecasting Student Entrepreneurial Competency: Machine Learning Approach	Predictive accuracy of entrepreneurial competency models	Model development and comparison	University students	XGBoost predicted entrepreneurial competency with 79% accuracy, outperforming prior models.
Rivera-Kempis et al. (2021)	Entrepreneurial Competence: Using Machine Learning to Classify Entrepreneurs	Entrepreneurial competence attributes	Model development and comparison	6649 individuals from the Latin American	Machine learning models accurately classified individuals as entrepreneurs based on 20 competence attributes.
Jabeur et al. (2021)	Forecasting the macro-level determinants of entrepreneurial opportunities using artificial intelligence models	Determinants of entrepreneurial opportunity, predictive accuracy of machine learning models	Model development and comparison	Panel data set from 149 countries covering the years 2007 to 2018	CatBoost regression best predicted entrepreneurial opportunity, outperforming other models.
Wei et al. (2020)	Predicting Entrepreneurial Intention of Students: An Extreme Learning Machine With Gaussian Barebone Harris Hawks Optimizer	Prediction accuracy of entrepreneurial intention	Model development and comparison	Students	GBHHO-KELM achieved superior classification performance and stability compared to other methods.

Machine learning is an effective means of predicting entrepreneurial abilities, intentions, and performance based on the assessment of intricate behavioral, sociocultural, demographic, and contextual data. Recent studies utilize a variety of ML algorithms and analysis techniques in order to estimate and predict which individuals will become entrepreneurs; the outcomes of their startups are predicted; and to inform the development of educational, training, and policy interventions aimed at increasing entrepreneurship. Simple to complex ML models have been used to study entrepreneurial mode, including random forest, support vector machines, XGBoost, kernel extreme learning machines, and ensemble methods. Studies consistently show that advanced ensemble models, such as XGBoost and gradient boosting, demonstrate more accuracy and stability than traditional statistical methods and simpler ML algorithms to predict entrepreneurial intention and activity (Gosztonyi and Judit, 2022; Jabeur et al., 2021; Suryadi and Kurniawan, 2024).

Key predictors of entrepreneurial ability comprise self-efficacy, opportunity identification, past entrepreneurial experience, education, social capital, and personality. Student factors may consist of major, campus innovation experience rated by students and/or staff, and competencies around leading teams. For emerging entrepreneurs and startups, social media use, access to funding and additional team members were important. Predictions that rely on ML inform talent discovery, curriculum development, and investment decisions to help policymakers and educators adjust interventions to nurture entrepreneurial ecosystems and identify gaps (e.g., gender gaps or lack of institutional support).

Table 2. Timeline of key studies on ML for entrepreneurial prediction

Focus area	Best-Performing algorithms	Key Predictors/Features	Citations
Student entrepreneurial intention	KELM, XGBoost, Random Forest	Major, innovation experience, personality	(Wei et al., 2020) (Suryadi and Kurniawan, 2024) (Kaur and Bhatt, 2023)
Startup success	Random Forest, Gradient Boosting	Social media, funding, team size	Bidgoli et al. (2024)
Entrepreneurial activity (general)	XGBoost, SVM, Ensemble Methods	Self-efficacy, opportunity, and social capital	(Jabeur et al., 2021) (Gosztonyi and Judit, 2022) (Chen et al., 2025)

As illustrated in Figure 1, machine learning (ML) techniques have recently been implemented successfully in a variety of entrepreneurial prediction problems, such as entrepreneurial intention (Wei et al., 2020; Aristizábal et al., 2025), startup success (Bidgoli et al., 2024), and entrepreneurial spirit (Suryadi and Kurniawan, 2024). However, most of these contributions have looked at either binary Classification Problems (e.g., Entrepreneur vs. Non-Entrepreneur) or wider macro-level factors (e.g., national indicators) (Jabeur et al., 2021), often ignoring competency-based contributions to enhance prediction at the individual level significantly. Moreover, some studies simply do not include hybrid modeling approaches that take advantage of advanced feature selection and ensemble learning, which has implications for limiting interpretability and generalizability.

This study addresses these limitations by focusing exclusively on predicting entrepreneurial competencies using individual-level data using the EntreComp framework conceptually. The approach taken combines the use of a Binary Grey Wolf Optimizer for feature selection as well as benchmarked predictive performance of 16 machine learning classifiers, thereby combining optimization and performance evaluation. This hybrid approach improves the predictive accuracy as well as identifies which competencies matter. Accordingly, this study adds to the literature by generating a novel, data-driven approach to identify entrepreneurial competencies in students so that they can experience value with their education or career development programs.

3. Research methodology

A complete and precise approach for selecting features and predicting entrepreneurial skills with machine learning and meta-heuristic methods is described in this study. Sharma and Manchanda (2020) provide the data used initially, including demographic, educational, psychological, and behavioral information about students. After all the data was preprocessed, encoded, and standardized, we fixed the class imbalance issue by applying the ADASYN algorithm. First, mutual information was used for a rapid screening of features, and next, the LightGBM model was optimized using both Optuna and the Binary Grey Wolf Algorithm (BGWO) to identify the best features. In addition, the model was examined using SHAP analysis to understand the effect of the chosen features. Subsequently, 16 machine learning algorithms were refined using Optuna and assessed using five evaluation criteria and five-fold cross-validation.

3.1. Data characteristics and preprocessing

In this study, we analyzed 219 samples of university students to assess their entrepreneurial competence. The data in this case study is from Sharma and Manchanda's (2020) work titled

"Predicting and Improving Entrepreneurial Competency in University Students using Machine Learning Algorithms." Every person represented in the study has specific personal, psychological, educational, and environmental attributes connected to their choice to become an entrepreneur. Along with the other features, the target variable (y) is also defined as a binary label specifying whether a person is an entrepreneur. As detailed in Table 3, the dataset features are described along with their types and corresponding categories or value ranges.

Table 3. Description of features

Feature	Description	Data Type	Range / Categories
EducationSector	Student's academic discipline	Nominal (categorical)	e.g., Economics, Humanities, Arts, Medicine, etc.
IndividualProject	Whether the student has done an individual project	Binary (text)	Yes / No
Age	Age of the student	Numeric	Between 17 and 26
Gender	Gender of the student	Binary (text)	Male / Female
City	Type of residence	Binary (text)	Yes / No
Influenced	Whether the student has been influenced by an entrepreneurial environment	Binary (text)	Yes / No
Perseverance	Level of perseverance	Ordinal (Likert scale)	Scale from 1 to 5
DesireToTakeInitiative	Desire to take initiative	Ordinal (Likert scale)	Scale from 1 to 5
Competitiveness	Degree of competitiveness	Ordinal (Likert scale)	Scale from 1 to 5
SelfReliance	Degree of self-reliance	Ordinal (Likert scale)	Scale from 1 to 5
StrongNeedToAchieve	Strong need for achievement	Ordinal (Likert scale)	Scale from 1 to 5
SelfConfidence	Self-confidence level	Ordinal (Likert scale)	Scale from 1 to 5
GoodPhysicalHealth	Physical health status	Ordinal (Likert scale)	Scale from 1 to 5
MentalDisorder	Whether the student has any mental disorder	Binary (text)	Yes / No
KeyTraits	Key personal traits (e.g., vision, positivity, resilience, work ethic)	Nominal (categorical)	Selected trait
ReasonsForLack	Reasons for not pursuing entrepreneurship	Textual (qualitative)	Descriptive text
y	Target label: Whether the person became an entrepreneur	Binary (numeric)	0: No, 1: Yes

Because it lacked structure, contained outliers, and had unbalanced content, the Reasons For Lack text variable—which provided a descriptive explanation of why some people did not wish to pursue entrepreneurship—was excluded from the analysis at this point. Label Encoding was used to convert IndividualProject, City, Influenced, Mental Disorder, and Gender into numerical values that could be used with machine learning algorithms. Lastly, One-Hot Encoding was used when working with KeyTraits and EducationSector, which contain more than two different values. In order to maintain clear and comprehensive results, no features were removed in this case. The ADASYN (Adaptive Synthetic Sampling) method was used to add balance to datasets. A useful technique for resolving imbalanced classes in classification problems is ADASYN. Although SMOTE and related techniques produce data in the same manner, this method chooses examples close to the boundary that are more difficult for the model to process (Mujahid et al., 2024; Tekkali and Natarajan, 2024).

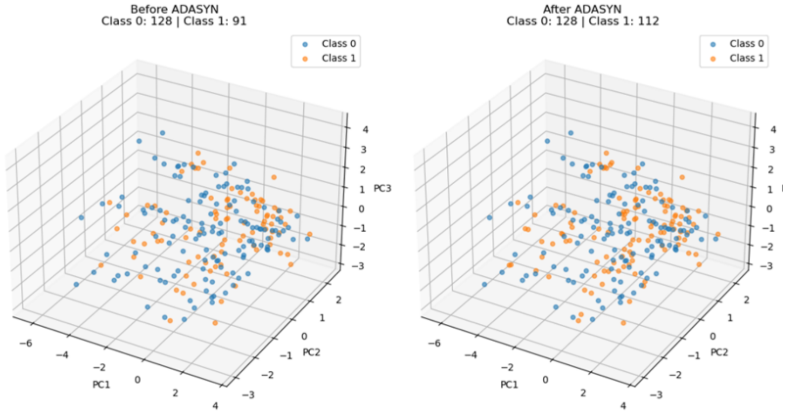

Figure 1. The impact of the ADASYN method on the data

Figure 1 illustrates the impact of the ADASYN method on class distribution. The initial data is presented in the left graph with 128 class 0 samples and only 91 class 1 samples(Toufighi et al., 2025). This can cause the model to prioritize the larger class and struggle to find attributes of the minority class. You can see in the right-hand graph that ADASYN has already applied to the data before presenting it in this manner. The new data class 1 samples increased to 112, and the distribution of samples across classes is now closer to equal. In order to provide an easy-to-see approach, PCA was applied to plot on both graphs in three-dimensional space. Clearly, ADASYN improved the way that new minority samples were added so that the distribution of class 1 samples more closely resembled that of the main class without changing the overall shape of the data. It is an important step to improving machine learning model performance. In this research, the StandardScaler was applied to the data to normalize the features so that the model would not depend mainly on larger numerical features.

3.2. Correlation analysis

In this work, the linear links between the dataset's variables were investigated using correlation analysis (Khani et al., 2022). This study sought variables with overlapping information with other features. A correlation matrix combined with a Heatmap diagram helped one to grasp the correlation structure between variables better intuitively (Malik et al., 2025).

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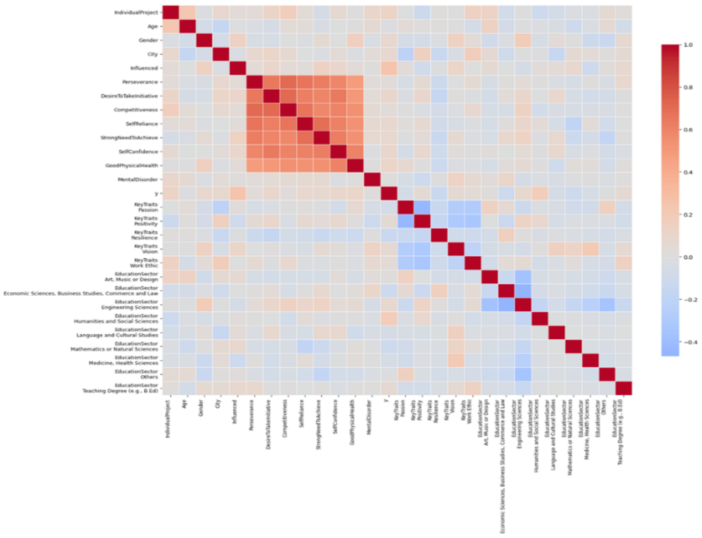

Figure 2. Correlation heat map

You can see the correlation matrix for all features of the dataset in Figure 2. It is easy to see the strength of the linear link between each pair of factors because the graph shades one color for positive (red) and another for negative (blue) dependencies. Red colors in the heat map are for high positive correlations, blue colors mark areas of negative correlations, and gray indicates there is no or a barely noticeable relation (Dudáš, 2024). On careful examination of the matrix, no correlation coefficient between the features goes above the value 0.8 in either direction. Consequently, since there were no strong and repeated correlations, we do not need to remove any features, so all remain in place for the following analyses(Hemdanou et al., 2024).

3.3. Selecting features and analyzing the importance and role of selected features

This work used an initial filter, metaheuristic optimization, and a machine learning model in concert for feature selection. Initially, the mutual information approach was used to determine if every feature included useful information connected to the target variable. Mutual information describes the link between two random variables that deviate from a straight line and is explained as:

$$MI(X,Y) = \sum_{x \in X} \sum_{y \in Y} p(x,y) \log \left(\frac{p(x,y)}{p(x)p(y)} \right) \tag{1}$$

p(x,y) is the probability of both feature X and label Y together, and p(x) and p(y) are the marginal probabilities of just feature X and label Y. Only those 25 features were chosen that had the largest level of mutual information. Following this, the Binary Grey Wolf Optimizer was used to find the best combination of attributes for optimum classification. Like wolves, which find food by cooperating in large groups, this algorithm runs by updating the population's position after considering the alpha, beta, and delta leaders at every iteration (Ataş, 2025). This version treats each position in the search space as a binary vector for selecting or deselecting an associated feature. Having updated the position of wolves in the algorithm, the model uses this process (Kitonyi and Segera, 2021):

$$X(t+1) = \frac{1}{3}\left(X_{\alpha} + X_{\beta} + X_{\delta}\right) \tag{2}$$

Where:

X_{α}, X_{β} and X_{δ} are the positions of the best, second, and third wolf,

The update value is adjusted using random and control parameters A_i and C_i, which are defined as follows:

$$A = 2a \cdot r - a, C = 2 \cdot r \tag{3}$$

where $r \in [0,1]$ is a random value and a is a linearly decreasing parameter:

$$a = 2 - \frac{2t}{T} \tag{4}$$

Where t is the iteration number and T is the total number of iterations.

The LightGBM model was applied to assess every wolf's performance—selected subsetwise. Before beginning the GWO process, this model was refined on the balanced data using the Optuna optimization tool. Optuna's objective function was defined in line with minimizing the mean F1 complement value in the five-fold cross-validation (Shao et al., 2024):

$$Objective = 1 - \frac{1}{k}\sum_{i=1}^{k} F1_i \tag{5}$$

Table 4. Optimized parameters for LightGBM

Hyperparameter	Best Value	Search Range
learning_rate	0.004822835283446929	[0.001, 0.2] (log-uniform)
num_leaves	57	[15, 64] (int)
max_depth	3	[3, 10] (int)
min_data_in_leaf	20	[20, 120] (int)
feature_fraction	0.8332671412310059	[0.6, 1.0] (float)
bagging_fraction	0.9172201780267553	[0.6, 1.0] (float)
bagging_freq	6	[1, 10] (int)
lambda_l1	0.17739736393705147	[0.0, 5.0] (float)
lambda_l2	0.23964992272362257	[0.0, 5.0] (float)
n_estimators	581	[100, 600] (int)

Using a population of 80 wolves (POP_SIZE = 80), the Binary Grey Wolf Optimizer algorithm was implemented with 500 (EPOCHS = 500) number of algorithm iterations set. The wolves' starting position vector was generated at random from a uniform distribution spanning [0.1]. The top three wolves were found in each iteration with positions α, β, and δ, respectively, and the position update process of the other wolves was carried out by applying the conventional relations of the GWO technique. Every iteration, the value of the linear parameter a dropped from 2 to 0 to progressively transition from exploration to exploitation behavior. The values of the random coefficients A and C were computed for every position; the formula of the average of the three modified positions relative to wolves α, β, and δ found the new position of every feature (in binary space). Every position's fitness value was computed with a LightGBM model with Optuna optimal parameters. Emphasizing maximum F1 score in the five-fold cross-validation, the objective function was defined to minimize the value of 1 - F1 Score. The Binary Grey Wolf Optimizer (BGWO) algorithm applied in this work has settings shown in Table 5:

Table 5. Binary grey wolf optimizer (GWO) algorithm settings

Parameter	Value	Description
Population Size	80	Number of candidate solutions (wolves) in the population
Number of Iterations	500	Number of optimization iterations (epochs)
a (initial value)	Linearly decreases from 2 to 0	Controls balance between exploration and exploitation
Position Initialization	Uniform in [0, 1]	Random initialization of the feature selection vector
Binarization Threshold	0.5	Real-valued positions are converted to binary using a threshold 0.5
Fitness Function	1 - F1 Score (5-fold CV)	Optimization objective using 5-fold cross-validated F1-score
Base Classifier	LightGBM (tuned by Optuna)	LGBM with hyperparameters optimized by Optuna

The Binary Grey Wolf Optimizer algorithm was used, and 15 of those features were picked to be retained. The data set consisted of the initial variables, plus the features added as new independent variables from the One-Hot Encoding process. In the process, every column produced by One-Hot encoding was regarded as a unique feature and added to the analysis of its impact on the model’s performance. These features were tested through the modeling process: EducationSector_Art, Music or Design, Influenced, Age, KeyTraits_Resilience, EducationSector_Humanities and Social Sciences, GoodPhysicalHealth, Competitiveness, KeyTraits_Positivity, Perseverance, DesireToTakeInitiative, EducationSector_Others, KeyTraits_Vision, KeyTraits_Work Ethic, EducationSector_Economic Sciences, Business Studies, Commerce and Law, EducationSector_Mathematics or Natural Sciences.

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This work applies the SHAP (SHapley Additive exPlanations) approach to investigate the significance and function of particular features in the output of a machine learning model. Based on the idea of cooperative games, this approach aims to clarify the contribution of every feature in the prediction of the model for every particular example (Wang et al., 2024a). SHAP shows its negative or positive contribution to the model's decision-making by valuing every feature, so that the total of these contributions equals the difference between the model's prediction and the average value of the whole output of the model (Santos et al., 2024). Mathematically, the SHAP value for a given feature i in a sample x is defined as follows:

$$\phi_i(f,x) = \sum_{S\subseteq F\setminus\{i\}} \frac{|S|!\,(|F|-|S|-1)!}{|F|!}\left[f_{S\cup\{i\}}(x) - f_S(x)\right] \quad (6)$$

1. F is the total set of features.
2. S is a subset of features without feature i.
3. $f_S(x)$ is the predicted value of the model using the features S.

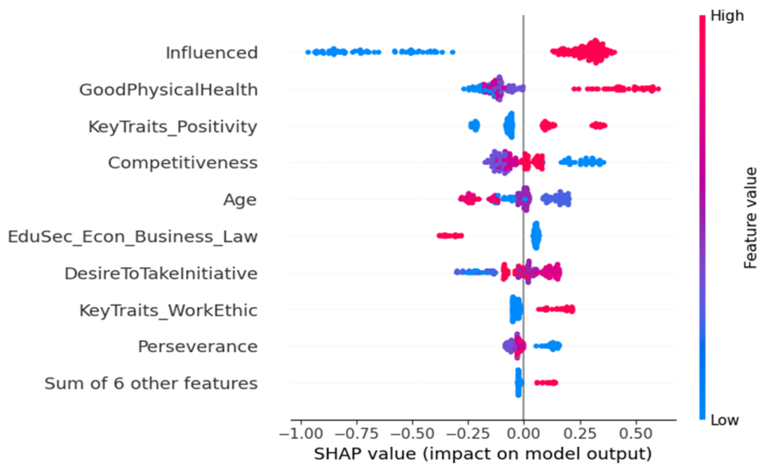

Figure 3. SHAP beeswarm plot

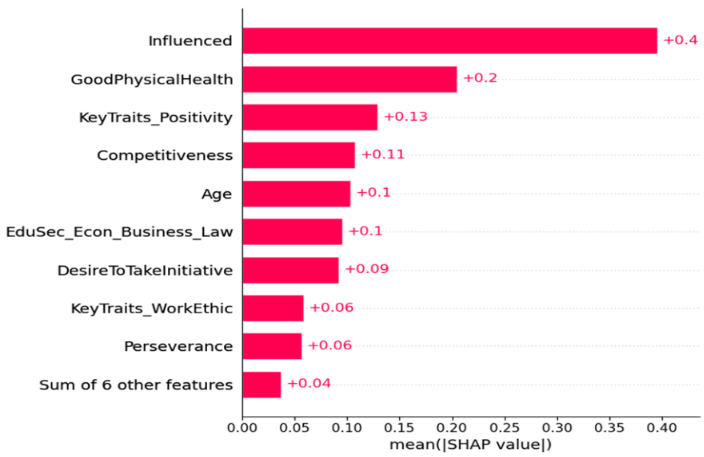

Figure 4. SHAP bar plot (mean absolute values)

Using color to indicate the degree of each feature—from light blue for low values to dark red for high values—the "Bee Swarm" plot in the figures shows the influence of each feature for every sample. To show the general significance of each feature in the model, the bar plot also shows its absolute value of the average SHAP for every feature. The features Influenced, GoodPhysicalHealth, and KeyTraits_Positivity dominated the model output based on the SHAP analysis. These results not only show the statistical relevance of the variables but also support an interpretable knowledge of the model's decisions. Consequently, the SHAP approach has been applied in this work as a useful instrument in analyzing the behavior of the model and clarifying its reasoning in feature application.

3.4. Machine learning models

This work employs a set of 16 different machine learning methods to find the most effective algorithm to predict entrepreneurial competency. Various methods are included in these algorithms, including linear, tree, reinforcement, statistical, and neural network. A hyperparameter optimization approach was used with the Optuna library to increase the exactness and performance of each algorithm. For each model, up to 2000 iterations of Bayesian search were completed to find the best mix of hyperparameters using the F1 criterion during 5-fold cross-validation. Table 6 indicates the list of best understood hyperparameters for all presented models.

Table 6. Machine learning models and optimal hyperparameters

Model	Description	Best Parameters	Reference
Logistic Regression	A simple linear model for binary classification, assuming feature independence	'C': 0.029, 'penalty': 'l2', 'solver': 'liblinear'	(Friedrich et al., 2022)
SVM	A margin-based classifier using the RBF kernel for non-linear separation	'C': 22.865, 'kernel': 'rbf', 'gamma': 'scale'	(Amaya-Tejera et al., 2024)
Decision Tree	A rule-based model that splits data into subsets based on feature thresholds	'criterion': 'gini', 'max_depth': 19, 'min_samples_split': 17, 'min_samples_leaf': 6	(Aaboub et al., 2023)
Random Forest	An ensemble of decision trees trained on bootstrapped samples	'n_estimators': 231, 'max_depth': 14, 'min_samples_split': 3, 'min_samples_leaf': 1, 'max_features': 'log2'	(Zhu et al., 2022)
Gradient Boosting	An iterative model that minimizes error using successive trees	'n_estimators': 325, 'learning_rate': 0.126, 'max_depth': 5, 'subsample': 0.508	(Fan et al., 2022)
AdaBoost	A boosting algorithm emphasizing difficult samples through adaptive weights	'n_estimators': 525, 'learning_rate': 0.024	(Khan et al., 2023)
Extra Trees	A randomized ensemble of decision trees for variance reduction	'n_estimators': 590, 'max_depth': 30, 'min_samples_split': 2, 'min_samples_leaf': 1	(Kaur et al., 2024)

Model	Description	Best Parameters	Reference
KNN	A non-parametric method based on nearest neighbors	'n_neighbors': 6, 'weights': 'distance', 'p': 2	(Halder et al., 2024)
MLP	A multi-layer feedforward neural network with nonlinear activation	'hidden_layer_sizes': (150, 100, 50), 'alpha': 0.000124, 'learning_rate_init': 0.0277	(Jafarnejad Chaghoshi et al., 2024b)
Naive Bayes	A probabilistic model with strong independence assumptions	default	(Gohari et al., 2023)
XGBoost	A gradient boosting model with efficient regularization and pruning	'n_estimators': 561, 'max_depth': 7, 'learning_rate': 0.016, 'subsample': 0.516, 'colsample_bytree': 0.875	(Mehdary et al., 2024)
LightGBM	A fast, histogram-based gradient boosting model optimized for performance	'n_estimators': 273, 'learning_rate': 0.298, 'max_depth': 9, 'min_data_in_leaf': 19, 'feature_fraction': 0.500, 'bagging_fraction': 0.607, 'bagging_freq': 3	(Lai et al., 2023)
CatBoost	A boosting model that handles categorical features internally	'iterations': 314, 'learning_rate': 0.0315, 'depth': 5	(Wang et al., 2024b)
LDA	A linear classifier assuming normal distribution and equal class covariances	default	(Gyamfi et al., 2019)
QDA	A quadratic version of LDA allowing for unequal class covariances	default	(Araveeporn, 2022)
GPC	A kernel-based probabilistic model using Gaussian processes	default	(Yang and Zhang, 2022)

In this research, four basic indicators (TP, TN, FP, and FN) were applied to assess machine learning models' performance in predicting entrepreneurial competence of students (Richardson et al., 2024). TP is the indicator of the successful prediction of entrepreneurial competence, while TN is the accurate identification of the incompetent (students lacking competence). FP is the prediction of competence where the student does not actually possess competence. FN is also the case where the model fails to identify the competent student. Based on the four basic indicators, accuracy, precision, recall, and the F1 score (weighted average of precision and recall) were calculated (Mehregan et al., 2025b). Furthermore, to assess the ability of models to discriminate groups of students (competent/incompetent), the Area Under the Curve—Receiver Operating Characteristic (AUC-ROC) index was used, which is most helpful in unbalanced datasets (Rainio et al., 2024). To avoid overfitting and maintain result validity, the 5-fold cross-validation method was used. In this system, the total data set is divided into five equal parts, and each time one of the five sections is used as the evaluation pool and the other four are used as the training pool. All five scenarios are run in a cyclic fashion where all of the data takes its turn as a test, and the mean of the report is the final answer to the performance of the model. This system also improves the reliability of the results and increases the performance of the parameters for the generalizability of models relative to ignored data. Table 7 presents the evaluation indicators for the machine learning models, including Accuracy, Precision, Recall, F1 Score, and ROC AUC.

Table 7. Evaluation indicators for machine learning models

Index	Definition	Formula
Accuracy	The ratio of correct predictions to total samples.	$\frac{TP + TN}{TP + FP + FN + TN}$
Precision	The ratio of correct predictions for a class to the total samples predicted as that class.	$\frac{TP}{TP + FP}$
Recall	The ratio of correct predictions for a class to the total actual samples of that class.	$\frac{TP}{TP + FN}$
F1 Score	The harmonic mean between Precision and Recall to balance them.	$\frac{2 \times Precision \times Recall}{Precision + Recall}$
ROC AUC	The area under the receiver operating characteristic curve; indicates the ability of the model to discriminate between classes. In this measure, for different thresholds, TPR (True Positive Rate = TP / (TP + FN)) and FPR (False Positive Rate = FP / (FP + TN)) are calculated and the area under their graph (ROC Curve) is calculated.	$\int_0^1 \text{TPR(FPR)}\ d(\text{FPR})$

4. Results and discussion

This section describes the performance of machine learning models. The study utilized the Python programming language, and the models were all run on a computer with an Intel Core i7-13700H processor, 16 GB of RAM, and Python 12.3. Table 8 indicates the performance of machine learning models based on the evaluation criteria.

Table 8. Comparison of models based on evaluation criteria

Model	Accuracy	Precision	Recall	F1 Score	ROC AUC
LogisticRegression	0.602571	0.572693	0.576285	0.573517	0.600450
SVM	0.669858	0.640993	0.676680	0.654396	0.670648
DecisionTree	0.644858	0.615631	0.613043	0.610155	0.642522
RandomForest	0.628280	0.620874	0.550593	0.605828	0.642375
GradientBoosting	0.623582	0.602078	0.586957	0.599811	0.629087
AdaBoost	0.619415	0.607137	0.531225	0.562860	0.613613
ExtraTrees	0.648848	0.632245	0.632016	0.623344	0.656707
KNN	0.632358	0.588668	0.668379	0.622317	0.635574
MLP	0.649025	0.656935	0.640316	0.642478	0.672744
NaiveBayes	0.535993	0.502074	0.675889	0.574405	0.545637
XGBoost	0.677926	0.657198	0.658498	0.651329	0.677403
LightGBM	0.707447	0.685383	0.684585	0.682897	0.705831
CatBoost	0.678280	0.658603	0.660079	0.648454	0.678347
LDA	0.577571	0.547254	0.532016	0.539325	0.574316
QDA	0.586082	0.533121	0.893676	0.665493	0.607607
GPC	0.623848	0.586029	0.640711	0.610972	0.625433

A thorough examination of the performance table of machine learning models with respect to five evaluation metrics has confirmed that models performed differently, demonstrating a range of performances in each facet of predicting applicants' performance. The LightGBM with an accuracy of 0.707 provided the best accuracy overall amongst all models, demonstrating it was able to make ~71% of the predictions correctly. These models also lead in terms of three of the main criteria: The precision value of 0.685 indicates that a high percentage of its positive predictors were correct; its recall value is also 0.684 which demonstrates that the model was able to correct a high percent of true positives; the F1 score for this model is 0.683, which has a good trade-off in correct detection when accounting for the trade-off in precision and recall; finally, the ROC AUC value of 0.705 for LightGBM demonstrates its relatively good resolving power being able to discriminate between two classes correctly. The XGBoost and CatBoost also performed well. With an accuracy of 0.678, a precision of 0.657, a recall of 0.658, an F1 of 0.651, and an ROC AUC of 0.677, XGBoost specifically ranks lower than LightGBM across all metrics. This demonstrates that XGBoost is a very competitive choice that has successfully balanced all the metrics. With an accuracy of 0.678, a precision of 0.658, and an ROC AUC of 0.678, CatBoost is also comparable to XGBoost and occasionally even outperforms it, despite having a slightly lower F1 value (0.648). SVM has performed reasonably well among the classical models. With an accuracy of 0.669, precision of 0.640, recall of 0.677, and F1 of 0.654, it comes in at number four. Its acceptable discrimination power between two classes is indicated by its ROC AUC value of 0.670. Additionally, tree-based models with intermediate performance included RandomForest, ExtraTrees, and GradientBoosting. Specifically, ExtraTrees, with an F1 of 0.623 and an accuracy of 0.648, performs more steadily than other tree models. In contrast, RandomForest achieves a relatively good accuracy (0.628), but recall was even worse (0.551), which would indicate a rise in the False Negative rate. MLP, which is a multilayer perceptron neural network, performed relatively well. The F1 of this model was 0.642. Although this value improves most classical models. And although this model was better in final accuracy than KNN or NaiveBayes models, it does not match the level of LightGBM. For all other models run at default parameters, such as NaiveBayes, LDA, QDA, and GPC, average or poor results were achieved. NaiveBayes in particular performed the worst with the lowest accuracy of 0.535 and ROC AUC of 0.546, indicating that their assumption of independence between features is not suited for this problem. Although QDA reached a very high recall (0.894), this model suffers from a low precision (0.533) and moderate F1 (0.665), therefore also suffers from a high Final Positive Rate (FPR), which can lead to wrong decisions in practice.

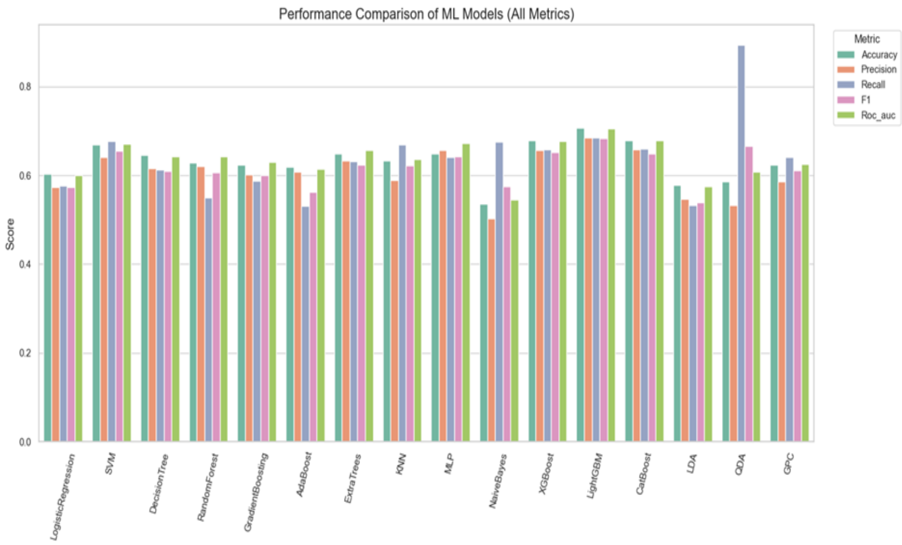

Figure 5. Comparison of model performance

According to Figure 5, LightGBM was measured to be the appropriate model for this classification problem. Out of 16 models observed, it had the best overall performance across all evaluation criteria, and the LightGBM model outperformed the next closest models. The next appropriate models were XGBoost, CatBoost, and SVM, which can be looked at as additional options.

5. Conclusion

The framework being proposed here unites machine learning and metaheuristic optimization to predict how well entrepreneurial skills are developed in university students. The study improves performance by applying the Binary Grey Wolf Optimizer for feature selection and applying Optuna to tune the hyperparameters, all while using SHAP analysis to maintain clarity. EntreComp is used as the basis for the predictive framework, helping to describe entrepreneurial skills in different areas such as thought, behavior, and circumstances. The research results point to the hybrid solution being superior to existing models. Of the 16 machine learning classifiers analyzed, LightGBM—which was hyperparameter-tuned via Bayesian search— subsequently performed the best overall on all assessment metrics with an accuracy of 70.7%, an average F1 score of 0.683, and an ROC AUC of 0.705. Overall, our results demonstrate the robustness, generalizability, and real-world applicability of our proposed model to consider entrepreneurial potential in an academic context.

An evaluation of the algorithms shows that the present study is stronger in predictive power and research methods when compared with the earlier work by Sharma and Manchanda (2020). The authors found that the highest accuracy was 59.18% with SVM, compared to the lowest at

40.81% from Random Forest when using 500 trees. However, for our study, we chose to include sixteen diverse machine learning models, backing them up with modern approaches such as hyperparameter tuning using Optuna, correcting unbalanced classes with ADASYN, and feature selection using Binary Grey Wolf Optimizer. Because of this, the LightGBM model displayed the best accuracy of 70.7%, far outperforming the prior study's models. As well, our assessment made use of F1 Score and ROC AUC in addition to accuracy to evaluate how the model truly performed. Our framework managed to improve the results of Naïve Bayes and Decision Tree, which previously had accuracies of 48.97% and 57.14% for Sharma and Manchanda (2020). Overall, our results prove that a hybrid optimization-based framework makes our approach stronger and more practical. By way of contrast, the current study employs a number of methodological innovations in this field. First, we take advantage of a three-step feature selection process that includes mutual information filtering, a BGWO, and SHAP to retain only the maximum relevance features with interpretability in mind. Secondly, ADASYN is used to address the class imbalance to balance the entrepreneurial and non-entrepreneurial cases. Thirdly, the ensemble models (LightGBM and CatBoost) that we optimized using extensive cross-validation and tuning provide better single-night prediction accuracy and stability. Finally, the SHAP values allow transparent interpretation that brings clarity of important features, undertaking (in-depth) responsibility, and giving understanding into the relevance of resilient, physical health, and motivational aspects.

In addition to the technical contributions offered, this work is a meaningful contribution to entrepreneurship education, both theoretically and practically. The linkage between predictive analytics and various existing models of competency development may provide educators, policy makers, and trainers with a reliable mechanism to assess entrepreneurial potential and suggest the steps necessary to develop it. Systematically identifying high efficacy competencies serves as a basis for data-informed curricular design and other interventions. After finishing this study, multiple directions for future research appear. To start, using longitudinal data allows us to capture the way entrepreneurial abilities change with time. Furthermore, by adapting the existing design, it could be known if entrepreneurship is treated similarly or differently in schools around the world. In addition to using DE, genetic algorithms, ant colony optimization, and particle swarm optimization can be tested within the same structure to examine how each one works and how fast it converges. Further, if statisticians further analyzed the model by differentiating between levels or styles of entrepreneurial orientation, they could discover new and valuable findings. Incorporating this predictive framework into applications in educational settings or online learning environments may encourage some form of real-time feedback, self-assessment tools, and personalized learning paths customized to students' own entrepreneurial strengths and developmental needs. Therefore, this study is the first step in understanding what it means to have an intelligent, theory-based, and computationally inspired assessment of entrepreneurial competency in education for the 21st century.

Disclosure statement

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

References

Aaboub, F., Chamlal, H. and Ouaderhman, T., 2023. Statistical analysis of various splitting criteria for decision trees. *Journal of Algorithms & Computational Technology*, *17*, p.17483026231198181. https://doi.org/10.1177/17483026231198181.

Adjodah, D., Calacci, D., Dubey, A., Goyal, A., Krafft, P., Moro, E. and Pentland, A., 2019. Leveraging communication topologies between learning agents in deep reinforcement learning. *arXiv preprint arXiv:1902.06740*. https://doi.org/10.48550/arxiv.1902.06740.

Ahmed, F and Harrison, C., 2025. Entrepreneurial leadership development in teams: A conceptual model. *The International Journal of Entrepreneurship and Innovation*, *26*(4), pp.267-279.https://doi.org/10.1177/14657503221143977.

Amaya-Tejera, N., Gamarra, M., Vélez, J.I. and Zurek, E., 2024. A distance-based kernel for classification via Support Vector Machines. *Frontiers in Artificial Intelligence*, *7*, p.1287875. https://doi.org/10.3389/frai.2024.1287875.

Araveeporn, A., 2022. Comparing the linear and quadratic discriminant analysis of diabetes disease classification based on data multicollinearity. *International Journal of Mathematics and Mathematical Sciences*, *2022*(1), p.7829795. https://doi.org/10.1155/2022/7829795.

Aristizábal, J.M., Tarapuez, E. and Astudillo, C.A., 2025. Predicting entrepreneurial intention in Colombian academics: a machine learning approach. *Journal of Entrepreneurship in Emerging Economies*, *17*(2), pp.260-288. https://doi.org/10.1108/jeee-04-2023-0141.

Ataş, P., 2025. A novel clustered-based binary grey wolf optimizer to solve the feature selection problem for uncovering the genetic links between non-Hodgkin lymphomas and rheumatologic diseases. *Health Information Science and Systems*, *13*(1), pp.1-22. https://doi.org/10.1007/s13755-025-00350-w.

Bashir, D., Montañez, G.D., Sehra, S., Segura, P.S. and Lauw, J., 2020, November. An information-theoretic perspective on overfitting and underfitting. In *Australasian Joint Conference on Artificial Intelligence* (pp. 347-358). Cham: Springer International Publishing. https://doi.org/10.48550/arxiv.2010.06076.

Bidgoli, M. R., Raeesi Vanani, I. and Goodarzi, M., 2024. Predicting the success of startups using a machine learning approach. *Journal of Innovation and Entrepreneurship*, *13*(1), p.80.https://doi.org/10.1186/s13731-024-00436-x.

Bolzani, D. and Luppi, E., 2021. Assessing entrepreneurial competences: Insights from a business model challenge. *Education+ training*, *63*(2), pp.214-238. https://doi.org/10.1108/ET-04-2020-0072.

Botha, M., 2023. Using entrepreneurial competencies and action to profile entrepreneurs: a CHAID analysis approach. *Journal of Research in Marketing and Entrepreneurship*, *26*(2), pp.337-367. https://doi.org/10.1108/JRME-07-2022-0091.

Chen, C., Huang, Y., Wu, S., Zhao, Y. and Xu, L., 2025. What makes you entrepreneurial? Using machine learning to predict technology entrepreneurship. *Baltic Journal of Management*. https://doi.org/10.1108/bjm-09-2024-0552

Chen, Z., 2024. Research on Portfolio Optimization Model based on Machine Learning Algorithm in Stock Market. *Transactions on Economics, Business and Management Research 2024*, *6*, pp.50-56. https://doi.org/10.62051/sdqv4p21.

Ding, R., 2023. Which network is stronger? Le Net, Alex Net and VGG on image classification. *Applied Computing and Engineering*, *4*(1), pp.294–300. https://doi.org/10.54254/2755-2721/4/20230476.

Draksler, T.Z. and Širec, K., 2018. Conceptual research model for studying students' entrepreneurial competencies. *Naše gospodarstvo/Our economy*, *64*(4), pp.23-33. https://doi.org/10.2478/ngoe-2018-0020.

Dudáš, A., 2024. Graphical representation of data prediction potential: correlation graphs and correlation chains. *The Visual Computer*, *40*(10), pp.6969-6982. https://doi.org/10.1007/s00371-023-03240-y.

Essien, U.D., Ansa, G.O. and Akpnobong, A., 2024. EnsembleForge: A Comprehensive Framework for Simplified Training and Deployment of Stacked Ensemble Models in Classification Tasks. *Journal of Information Systems and Informatics*, *6*(1), pp.68-82. https://doi.org/10.51519/journalisi.v6i1.643.

Fan, M., Xiao, K., Sun, L., Zhang, S. and Xu, Y., 2022. Automated hyperparameter optimization of gradient boosting decision tree approach for gold mineral prospectivity mapping in the Xiong'ershan area. *Minerals*, *12*(12), p.1621. https://doi.org/10.3390/min12121621.

Friedrich, S., Groll, A., Ickstadt, K., Kneib, T., Pauly, M., Rahnenführer, J. and Friede, T., 2022. Regularization approaches in clinical biostatistics: A review of methods and their applications. *Statistical Methods in Medical Research*, *32*(2), pp.425-440. https://doi.org/10.1177/09622802221133557.

Glaser, J.I., Benjamin, A.S., Chowdhury, R.H., Perich, M.G., Miller, L.E. and Kording, K.P., 2020. Machine learning for neural decoding. *eneuro*, *7*(4). https://doi.org/10.1523/eneuro.0506-19.2020.

Gohari, K., Kazemnejad, A., Mohammadi, M., Eskandari, F., Saberi, S., Esmaieli, M. and Sheidaei, A., 2023. A Bayesian latent class extension of naive Bayesian classifier and its application to the classification of gastric cancer patients. *BMC Medical Research Methodology*, *23*(1), p.190. https://doi.org/10.1186/s12874-023-02013-4.

Gosztonyi, M. and Judit, C.F., 2022. Profiling (non-) nascent entrepreneurs in Hungary based on machine learning approaches. *Sustainability*, *14*(6), p.3571. https://doi.org/10.3390/su14063571.

Gyamfi, K.S., Brusey, J., Hunt, A. and Gaura, E., 2019. A dynamic linear model for heteroscedastic LDA under class imbalance. *Neurocomputing*, *343*, pp.65-75. https://doi.org/10.1016/j.neucom.2018.07.090.

Halder, R.K., Uddin, M.N., Uddin, M.A., Aryal, S. and Khraisat, A., 2024. Enhancing K-nearest neighbor algorithm: a comprehensive review and performance analysis of modifications. *Journal of Big Data*, *11*(1), p.113. https://doi.org/10.1186/s40537-024-00973-y.

Hemdanou, A.L., Sefian, M.L., Achtoun, Y. and Tahiri, I., 2024. Comparative analysis of feature selection and extraction methods for student performance prediction across different machine learning models. *Computers and Education: Artificial Intelligence*, *7*, p.100301. https://doi.org/10.1016/j.caeai.2024.100301.

Jabeur, S.B., Ballouk, H., Mefteh-Wali, S. and Omri, A., 2021. Forecasting the macrolevel determinants of entrepreneurial opportunities using artificial intelligence models. *Technological Forecasting and Social Change*, *175*, p.121353. https://doi.org/10.1016/j.techfore.2021.121353.

Jafarnejad Chaghoshi, A., Khani, A.M. and Rezasoltani, A., 2024b. Risk Modeling in Banking Services for the Blind Using Fuzzy FMEA and Graph Neural Network (GNN). *Journal of Industrial Management Perspective*, *14*(4), pp.223-255. https://doi.org/10.48308/jimp.14.4.223.[in Persian].

Jafarnejad Chaghoshi, A., Rezasoltani, A., & Khani, A. M., 2024a. Unleashing the power of ensemble learning: Predicting national ranks in Iran's university entrance examination. *Industrial Management Journal*, *16*(3), 457–481. https://doi.org/10.22059/imj.2024.381521.1008178. [in Persian].

Joensuu-Salo, S., Viljamaa, A. and Varamäki, E., 2022. Sustainable entrepreneurs of the future: The interplay between educational context, sustainable entrepreneurship competence, and entrepreneurial intentions. *Administrative Sciences*, *12*(1), p.23. https://doi.org/10.3390/admsci12010023.

Kaur, B.P., Singh, H., Hans, R., Sharma, S.K., Sharma, C. and Hassan, M.M., 2024. A Genetic algorithm aided hyper parameter optimization based ensemble model for respiratory disease prediction with Explainable AI. *Plos one*, *19*(12), p.e0308015. https://doi.org/10.1371/journal.pone.0308015.

Kaur, S. and Bhatt, P.C., 2023, December. Forecasting student entrepreneurial competency: Machine learning approach. In *2023 IEEE 3rd International Conference on Social Sciences and Intelligence Management (SSIM)* (pp. 184-189). IEEE.

Khan, A.A., Chaudhari, O. and Chandra, R., 2023. A review of ensemble learning and data augmentation models for class imbalanced problems: Combination, implementation and evaluation. *Expert Systems with Applications*, *244*, p.122778. https://doi.org/10.1016/j.eswa.2023.122778.

Khani, A. M., Kazazi, A., and Taqhavi Fard, M. T., 2022. Evaluating the quality of services of the cultural and social deputy of Tehran municipality in the field of culture and art. *Social Development & Welfare Planning*, *13*(50), 205–250. https://doi.org/10.22054/qjsd.2021.58035.2110. [in Persian].

Kitonyi, P.M. and Segera, D.R., 2021. Hybrid gradient descent grey wolf optimizer for optimal feature selection. *BioMed Research International*, *2021*(1), p.2555622. https://doi.org/10.1155/2021/2555622.

Lai, J.P., Lin, Y.L., Lin, H.C., Shih, C.Y., Wang, Y.P. and Pai, P.F., 2023. Tree-based machine learning models with optuna in predicting impedance values for circuit analysis. *Micromachines*, *14*(2), p.265. https://doi.org/10.3390/mi14020265.

Long, W., 1983. The meaning of entrepreneurship. *American Journal of small business*, *8*(2), pp.47-59.https://doi.org/10.1177/104225878300800209.

Malik, S., Patro, S.G.K., Mahanty, C., Hegde, R., Naveed, Q.N., Lasisi, A., Buradi, A., Emma, A.F. and Kraiem, N., 2025. Advancing educational data mining for enhanced student performance prediction: a fusion of feature selection algorithms and classification techniques with dynamic feature ensemble evolution. *Scientific Reports*, *15*(1), p.8738. https://doi.org/10.1038/s41598-025-92324-x.

Margherita, M., Kampylis, P., Punie, Y. and Van den Brande, G., 2016. *EntreComp: het Entrepreneurship Competence-raamwerk*. Europese Commissie-Joint Research Centre. https://doi.org/10.2791/160811.

Martínez-Martínez, S.L., Ventura, R. and Santos-Jaén, J.M., 2025. Creativity Vs Grit: key competences to understand Entrepreneurial Intention. *The International Journal of Management Education*, *23*(2), p.101143. https://doi.org/10.1016/j.ijme.2025.101143

Mehdary, A., Chehri, A., Jakimi, A. and Saadane, R., 2024. Hyperparameter optimization with genetic algorithms and XGBoost: a step forward in smart grid fraud detection. *sensors*, *24*(4), p.1230. https://doi.org/10.3390/s24041230.

Mehregan, M. R., Rezasoltani, A., and Khani, A. M., 2025b. A novel hybrid machine learning model for defect prediction in industrial manufacturing processes. *Contributions of Science and Technology for Engineering*, *2*(4), pp.43–58. https://doi.org/10.22080/cste.2025.29099.1037. [in Persian].

Mehregan, M.R., Taghavifard, M.T., Khani, A.M., Rezasoltani, A. and Nikkhah, M.A., 2025a. A Hybrid Machine Learning Model Based on Deep Learning for Air Quality Prediction. *Pollution*, *11*(4), pp.1199-1215. https://doi.org/10.22059/poll.2025.388743.2750.[in Persian].

Mills, A.W., Goings, J.J., Beck, D., Yang, C. and Li, X., 2022. Exploring potential energy surfaces using reinforcement machine learning. *Journal of Chemical Information and Modeling*, *62*(13), pp.3169-3179. https://doi.org/10.1021/acs.jcim.2c00373.

Morris, M.H., Webb, J.W., Fu, J. and Singhal, S., 2013. A competency-based perspective on entrepreneurship education: conceptual and empirical insights. *Journal of small business management*, *51*(3), pp.352-369. https://doi.org/10.1111/jsbm.12023.

Morris, T.H. and König, P.D., 2020. Self-directed experiential learning to meet ever-changing entrepreneurship demands. *Education+ Training*, *63*(1), pp.23-49. https://doi.org/10.1108/ET-09-2019-0209.

Mujahid, M., Kına, E.R.O.L., Rustam, F., Villar, M.G., Alvarado, E.S., De La Torre Diez, I. and Ashraf, I., 2024. Data oversampling and imbalanced datasets: an investigation of performance for machine learning and feature engineering. *Journal of Big Data*, *11*(1), p.87. https://doi.org/10.1186/s40537-024-00943-4.

Pintelas, P. and Livieris, I.E., 2020. Special issue on ensemble learning and applications. *Algorithms*, *13*(6), p.140. https://doi.org/10.3390/a13060140.

Ploum, L., Blok, V., Lans, T. and Omta, O., 2017. Toward a validated competence framework for sustainable entrepreneurship. *Organization & environment*, *31*(2), pp.113-132. https://doi.org/10.1177/1086026617697039.

Qu, K., Guo, F., Liu, X., Lin, Y. and Zou, Q., 2019. Application of machine learning in microbiology. *Frontiers in microbiology*, *10*, p.827. https://doi.org/10.3389/fmicb.2019.00827.

Rainio, O., Teuho, J. and Klén, R., 2024. Evaluation metrics and statistical tests for machine learning. *Scientific Reports*, *14*(1), p.6086. https://doi.org/10.1038/s41598-024-56706-x.

Reis, D.A., Fleury, A.L. and Carvalho, M.M., 2020. Consolidating core entrepreneurial competences: toward a meta-competence framework. *International Journal of Entrepreneurial Behavior & Research*, *27*(1), pp.179-204. https://doi.org/10.1108/IJEBR-02-2020-0079.

Richardson, E., Trevizani, R., Greenbaum, J.A., Carter, H., Nielsen, M. and Peters, B., 2024. The receiver operating characteristic curve accurately assesses imbalanced datasets. *Patterns*, *5*(6). https://doi.org/10.1016/j.patter.2024.100994.

Rivera-Kempis, C., Valera, L. and Sastre-Castillo, M.A., 2021. Entrepreneurial competence: Using machine learning to classify entrepreneurs. *Sustainability*, *13*(15), p.8252. https://doi.org/10.3390/su13158252.

Rotimi, M.E., IseOlorunkanmi, J.O., Rotimi, G.G. and Doorasamy, M., 2022. Does Entrepreneurship Education Determine Entrepreneurial Motivation among University Graduates: An Empirical Investigation. *Jurnal Ekonomi, Bisnis & Entrepreneurship*, *16*(2), pp.107-123. https://doi.org/10.55208/jebe.v16i2.257.

Santos, M.R., Guedes, A. and Sanchez-Gendriz, I., 2024. Shapley additive explanations (shap) for efficient feature selection in rolling bearing fault diagnosis. *Machine Learning and Knowledge Extraction*, *6*(1), pp.316-341. https://doi.org/10.3390/make6010016.

Sarker, I.H., 2021. Machine learning: Algorithms, real-world applications and research directions. *SN computer science*, *2*(3), p.160. https://doi.org/10.1007/s42979-021-00592-x.

Schuld, M. and Killoran, N., 2019. Quantum machine learning in feature Hilbert spaces. *Physical review letters*, *122*(4), p.040504. https://doi.org/10.1103/PhysRevLett.122.040504.

Shah, M.S. and Lala, M.F., 2022. Are competencies of an entrepreneur determinant of success in a conflict zone: an evidence from conflict zone Kashmir. *Deleted Journal*, *1*(2), pp.77–83. https://doi.org/10.26480/mbmj.02.2022.77.83.

Shane, S. and Venkataraman, S., 2000. The promise of entrepreneurship as a field of research. *Academy of management review*, *25*(1), pp.217-226. https://doi.org/10.5465/amr.2000.2791611.

Shao, H., Liu, X., Zong, D. and Song, Q., 2024. Optimization of diabetes prediction methods based on combinatorial balancing algorithm. *Nutrition & Diabetes*, *14*(1), p.63. https://doi.org/10.1038/s41387-024-00324-z.

Sharma, U. and Manchanda, N., 2020, Predicting and improving entrepreneurial competency in university students using machine learning algorithms. In *2020 10th International Conference on Cloud Computing, Data Science & Engineering (Confluence)* (pp. 305-309). IEEE. https://doi.org/10.1109/Confluence47617.2020.9058292.

Stenholm, P., Ramström, J., Franzén, R. and Nieminen, L., 2021. Unintentional teaching of entrepreneurial competences. *Industry and Higher Education*, *35*(4), pp.505-517. https://doi.org/10.1177/09504222211018068.

Suryadi, D. and Kurniawan, D., 2024, August. Predicting Entrepreneurial Spirit: A Machine Learning Approach. In *2024 International Conference on Information Management and Technology (ICIMTech)* (pp. 399-403). https://doi.org/10.1109/icimtech63123.2024.10780930.

Tekkali, C.G. and Natarajan, K., 2024. An advancement in AdaSyn for imbalanced learning: An application to fraud detection in digital transactions. *Journal of Intelligent & Fuzzy Systems*, *46*(5-6), pp.11381-11396. https://doi.org/10.3233/JIFS-236392.

Tittel, A. and Terzidis, O., 2020. Entrepreneurial competences revised: developing a consolidated and categorized list of entrepreneurial competences. *Entrepreneurship Education*, *3*(1), pp.1-35. https://doi.org/10.1007/s41959-019-00021-4.

Toufighi, S. P., Khani, A. M., Rezasoltani, A., Sahebi, I. G., & Vang, J. (2025). Forecasting stock market anomalies in emerging markets: An OPTUNA-optimized isolation forest and K-means approach. Machine Learning With Applications, 22, 100770. https://doi.org/10.1016/j.mlwa.2025.100770

Wang, H., Liang, Q., Hancock, J.T. and Khoshgoftaar, T.M., 2024a. Feature selection strategies: a comparative analysis of SHAP-value and importance-based methods. *Journal of Big Data*, *11*(1), p.44. https://doi.org/10.1186/s40537-024-00905-w.

Wang, Q., Yan, C., Zhang, Y., Xu, Y., Wang, X. and Cui, P., 2024b. Numerical Simulation and Bayesian Optimization CatBoost Prediction Method for Characteristic Parameters of Veneer Roller Pressing and Defibering. *Forests*, *15*(12), p.2173. https://doi.org/10.3390/f15122173.

Wang, Y., 2024. Strengthen the foundation and practice orientation: exploration of teaching reform in machine learning courses. *Academic Journal of Science and Technology*, *12*(1), pp.145–148. https://doi.org/10.54097/a4xeav89

Wei, Y., Lv, H., Chen, M., Wang, M., Heidari, A.A., Chen, H. and Li, C., 2020. Predicting entrepreneurial intention of students: An extreme learning machine with Gaussian barebone Harris hawks optimizer. *Ieee Access*, *8*, pp.76841-76855. https://doi.org/10.1109/access.2020.2982796.

Yang, N. and Zhang, Y., 2022. A Gaussian process classification and target recognition algorithm for SAR images. *Scientific programming*, *2022*(1), p.9212856. https://doi.org/10.1155/2022/9212856.

Yi, F., Yang, H., Chen, D., Qin, Y., Han, H., Cui, J., Bai, W., Ma, Y., Zhang, R. and Yu, H., 2023. XGBoost-SHAP-based interpretable diagnostic framework for alzheimer's disease. *BMC medical informatics and decision making*, *23*(1), p.137. https://doi.org/10.1186/s12911-023-02238-9.

Yin, Z., Liu, Z. and Tong, P., 2022. Core entrepreneurial competences of Chinese college students: expert conceptualisation versus real-life cases. *The Asia-Pacific Education Researcher*, *31*(6), pp.781-801. https://doi.org/10.1007/s40299-022-00656-3.

Zhu, N., Zhu, C., Zhou, L., Zhu, Y. and Zhang, X., 2022. Optimization of the random forest hyperparameters for power industrial control systems intrusion detection using an improved grid search algorithm. *Applied Sciences*, *12*(20), p.10456. https://doi.org/10.3390/app122010456.

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- Eberlein RL. 1984. Simplifying dynamic models by retaining selected behavior modes. PhD Thesis, Massachusetts Institute of Technology, Cambridge, MA.
- Forrester, JW. 1991. Longer-term economic changes. D-4207-1, MIT System Dynamics Group Literature Collection. Available from the System Dynamics Society: https://www.systemdynamics.org/mit-sdgroup-literature-collection.
- Graham AK. 1980. Parameter estimation in system dynamics modeling. In Randers J. (ed.) *Elements of the System Dynamics Method*. Productivity Press, Cambridge MA, 143-161.
- Homer JB. 1983. Partial-model testing as a validation tool for system dynamics. In *Proceedings of the 1983 International System Dynamics Conference*. Chestnut Hill, MA, System Dynamics Society.
- Naumov S, Oliva R. 2018. Structural Dominance Analysis Toolset. Retrieved September 17, 2019, from http://people.tamu.edu/~roliva/research/sd/sda/.
- Sterman JD. 2000. *Business Dynamics: Systems Thinking and Modeling for a Complex World.* Irwin/McGraw-Hill, Boston.
- Tan B, Anderson EG, Dyer JS, Parker GG. 2010. Evaluating system dynamics models of risky projects using decision trees: Alternative energy projects as an illustrative example. *System Dynamics Review*26(1): 1-17.

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