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In the Name of God, the Compassionate, the Merciful

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Investigating the Implementation and Application of Blockchain Technology in Tourism Supply Chain: A System Dynamics Approach

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ABSTRACT

Presently, the tourism industry confronts a multitude of challenges, such as the mismatch between the quality of services provided and tourists' expectations and the management of tourist identity and security. These challenges can be addressed with the emergence of advanced technologies, including blockchain technology. This research uses the system dynamics approach to investigate the implementation and application of blockchain technology in the tourism supply chain of travel agencies in Isfahan. This research has a practical purpose, aiming to address real-world issues. Additionally, the nature and methodology of the study are descriptive-causal, and the data collection method employed in this research is a survey. At first, based on the existing research literature, the factors influencing the implementation and application of blockchain technology in the tourism supply chain of Isfahan travel agencies were identified. Subsequently, using a judgmental sampling method and gathering opinions from 45 experts, managers, and university tourism professionals, the relationships between the identified factors were determined, and a causal loop diagram was drawn. Then, employing a convenience sampling method and gathering information from 15 selected travel agencies in Isfahan, mathematical relationships between the identified factors were determined, and a stock and flow diagram was designed. The simulation results of this research indicated that the quality of using blockchain technology in the early years of its implementation was not favorable, but it would improve over time. Furthermore, the findings demonstrated a positive correlation between the quality of using blockchain technology with service quality and the level of tourist attraction. The scenarios designed in this research showed that by allocating more resources to employee training and enhancing information technology infrastructure, the quality of using blockchain technology and the quality of the services could significantly improve during the initial years of implementation of blockchain technology.

Keywords

Keywords: Blockchain technology, Tourism supply chain, Tourist attractions, System dynamics.

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1. Introduction

Tourism is a complex and multifaceted industry encompassing many stakeholders, including tourists, tourism service providers, governments, and international organizations (Annamalah, Paraman and Ahmed, 2023). Tourism is one of the most important industries in the world and can contribute to the economic growth and sustainable development of countries (Roodbari and Olya, 2024). The tourism industry in Iran also has the potential to become a tourist destination for domestic and foreign tourists due to its abundant natural and historical attractions, rich history and culture, beautiful natural scenery, and diverse tourist attractions (Akbarian Ronizi, et al., 2023). Government policies to develop the tourism industry, increase tourism facilities and services, and fundamentally develop tourism infrastructure, including airports and hotels, have contributed to the growth of this industry in Iran (Shabankareh, et al., 2023). In addition, more extensive promotional programs have played an important role in attracting foreign tourists to Iran (Khodadadi, 2016). The growth of the tourism industry in Iran has positively effected the country's economy (Seyfi, et al., 2021). This growth has led to new job opportunities in various tourism industry sectors, including hospitality, transportation, handicrafts, and cultural tourism, and increased foreign exchange earnings for the country (Khoshkhoo, et al., 2017).

Isfahan is one of the most significant cities in Iran for attracting tourists and developing the country’s tourism industry. Despite its numerous historical, cultural, and natural attractions, the level of tourist attraction in Isfahan has not aligned with the expectations and capacities in recent years (Saghafi, et al., 2023). One of the reasons for this is the various challenges in the tourism sector in Isfahan. One of the most important challenges of tourism in Isfahan is the mismatch of the quality of services provided with the needs and expectations of tourists (Masoud, et al., 2019). This challenge is evident in various aspects of Isfahan city's tourism supply chain, including transportation and insufficient parking spaces, the lack of four- and five-star hotels, difficulties in making reservations at such establishments, inadequate resort quality, and the lack of high-quality intercity restaurants. Additionally, there are issues concerning the poor quality of sanitary facilities and other related amenities (Khoshkam and Rahimi, 2023). The mismatch between the provided service quality and the needs and expectations of customers results in an unpleasant experience and a surge in tourist complaints, giving rise to a negative perception of the tourism industry in Isfahan. This issue contributes to a decrease in tourist satisfaction. It can diminish the overall attractiveness of Isfahan as a tourist destination, leading to a decline in recommendations and positive word-of-mouth. Another challenge within

Isfahan's tourism supply chain is managing tourist identities, ensuring security, and safeguarding personal information (Ghaderi, et al., 2018). Another challenge is managing tourist identities and protecting their security and personal information (Ghorbani et al., 2023). This challenge has become increasingly critical with the rise in foreign tourists visiting Isfahan. There is no comprehensive system to manage tourists' identities in Isfahan. It can lead to issues such as identity theft and fraud, posing significant problems for tourists and ultimately eroding their trust in the tourism industry in Isfahan (Gorji, et al., 2023). To fully realize the potential of tourism in Isfahan, the government and the private sector need to take steps to address these challenges. As the tourism industry is considered a vital part of the economy, contributing to economic growth, job creation, and personal well-being, using new technologies, including those in Industry 4.0, is essential to sustaining its activities (Pereira and Romero, 2017). One of these technologies is blockchain technology (Silva, et al., 2020).

Implementing and applying blockchain technologies in the tourism supply chain can significantly transform it (Rashideh, 2020). A blockchain is a digital ledger in which data is stored in a chain of blocks (Bamakan, et al., 2022). Each block contains time-stamped encrypted data (Xu, et al., 2019). The blockchain is verified and maintained by a network of computers known as nodes. Nodes verify the data and add new blocks to the chain (Komalavalli, et al., 2020). Blockchain offers transparent, secure, reliable, and collaborative solutions as a stand-alone technology or in collaboration with other technologies. (Zutshi, et al., 2021). It means that using and deploying blockchain could help solve problems like the inefficiency in the tourism supply chain, the reliability and transparency of information, fraud, the opportunistic behavior of middlemen, and foreign exchange risks (Fohlin and Ysberg, 2019). For example, implementing blockchain and tracking tourism products and services along the supply chain can help identify and solve the challenges and problems in the tourism supply chain in Isfahan (Prados-Castillo, et al., 2023a). One of the important applications for implementing blockchain in the tourism supply chain is automating the tourism service booking process (Prados-Castillo, et al., 2023b). By using blockchain and automating these steps, the user experience of tourists in the online tourism service market is improved, and the efficiency of the tourism supply chain is increased (Pradhan, et al., 2023). Ultimately, blockchain technology can significantly effect the tourism industry and contribute to economic development, job creation, and personal well-being by promoting transparency, trust, efficiency, and risk reduction (Tan and Saraniemi, 2023).

Literature reviews show that the application of blockchain technology in various industries has been widely studied. However, comprehensive research on the application of blockchain technology in the tourism industry is still in its early stages. It is worth noting that the research conducted on blockchain applications in tourism has largely focused on specific areas or limited use cases. For example, Önder and Treiblmaier (2018) focused on cryptocurrencies, while Sarhadi et al. (2023) addressed the crowdsourcing of blockchain technology in tourism. On the one hand, Balasubramanian, et al. (2022) pointed to the blockchain applications in medical tourism. Also Balasubramanian, et al. (2022) and Tham and Sigala (2020) focused on the application of blockchain in sustainable development.

In the studies conducted, the impact of blockchain technology in the field of tourism has been investigated in areas such as eliminating intermediaries in the tourism supply chain (Rashideh, 2020), reducing costs (Aghaei, et al., 2021), increasing transparency (Treiblmaier, 2022), creating new markets in the field of tourism (Coita and Ban, 2020) and so on. Also, some studies have addressed the challenges of using blockchain technology, including the lack of cooperation (Alshahrani and Alshahrani, 2021) and the infrastructure of information and communication technology (Ølnes and Jansen, 2017). In the studies, only the factors affecting the implementation of blockchain technology in the tourism industry and the benefits of its use were identified. In these studies, a clear picture of how the factors affecting the implementation of blockchain technology communicate with each other and the consequences of the implementation of blockchain technology in the tourism supply chain have not been investigated. According to systemic theory, the elements of a system interact with each other, and a change in one of the elements of the system can affect the entire system (Safaie, et al., 2023). Therefore, creating a systemic perspective and identifying the communication between factors and their interactions will play an effective role in better understanding the implementation and application of blockchain technology in the tourism supply chain. System dynamics methodology is a research approach that analyses complex relationships and interactions between system elements and their changes (Khajehpoura, et al., 2024). The system dynamics methodology can be used to understand the long-term and complex effects of blockchain technology in the tourism supply chain in Isfahan's travel agencies due to the lack of a study with a systemic approach and a comprehensive look at the impact and effectiveness of factors affecting the implementation and application of blockchain technology on the tourism industry and the existence of various challenges mentioned of Isfahan's tourism supply chain, including quality mismatch services with the expectations of tourists, identity management of tourists, maintaining the security of tourists' information. This research aims to investigate the implementation and application of blockchain technology in tourism agencies in Isfahan using system dynamics methodology.

2. Literature review

Nowadays, blockchain technology has digitally transformed the activities of the tourism supply chain. As a result, the tourism industry, which has been facing growing potential for years, seeks to align its supply chain with blockchain technology. By providing new solutions, this technology leads to innovation and digitalization in tourism organizations (Stankov and Filimonau, 2020). One of the important aspects of blockchain in the tourism supply chain is providing superior and reliable services to guests. The potential of this technology can improve business performance and increase the transparency and efficiency of companies (Ioannidis, 2023). Blockchain technology has positively effected business models, tourism services, and companies' supply chain performance. For example, blockchain solutions such as digital identity management, digital payments, and smart contracts can significantly reduce inefficient paper-based processes in the tourism industry. These solutions can also increase transparency and reduce the risk of fraud and error, processing time, and transaction costs for all parties involved. This technology is currently being used in various fields, and numerous studies have also been conducted. For example, Sarfraz, et al., 2023 conducted a study on the impact of sustainable supply chain strategy (SSCS) on sustainable competitive advantage (SCA) in the hospitality and tourism industries using blockchain technology. The findings of this study showed that blockchain technology plays a mediating role in the impact of a sustainable supply chain on competitive advantage. It means that adopting blockchain technology within the framework of a sustainable supply chain strategy can significantly contribute to a sustainable competitive advantage. Rana, et al., 2022 conducted a study to examine the pros and cons of blockchain technology (BC) for the tourism industry in the context of COVID-19's digital acceleration and the shift towards Industry 4.0. This study aimed to investigate the advantages and disadvantages of adopting BC in the tourism industry, as well as potential solutions to overcome challenges. This study conducted a systematic literature review (SLR) to analyze relevant academic articles on BC in tourism. The findings showed that most studies highlight the benefits of BC implementation, showcasing its potential through various models of BC-based systems. Prados et al. (2023a) conducted a study to examine the adoption of blockchain technology in the tourism industry from a sustainability perspective. The study used a systematic review methodology, descriptive biometric analysis, and network analysis based on co-authorship, co-citation, and keyword analysis criteria. This multifaceted approach provides valuable insights into the research landscape and key points where blockchain penetrates the tourism sector. The findings showed that there is a growing interest in blockchain in academic circles, especially in the fields of sustainable management and supply chain optimization. It suggests that the potential of this technology to help create a sustainable tourism industry is being increasingly recognized. In addition, the analysis of this study suggests that marketing, logistics, and the development of innovative business models have been identified as the main areas where blockchain is gaining traction.

Corne et al. (2023) conducted a study to examine the motivation for adopting blockchain technology in the tourism accommodation sector. The study focused on applying this technology in the context of loyalty programs, online bookings, customer review validation and tracking, and metaverse data security. The study used the Technology Acceptance Model (TAM) for analysis, which considers four key factors: perceived usefulness, perceived ease of use, trust in technology, and perceived social influence. To collect data, researchers used a questionnaire for 100 tourism management graduates. Then, they used fuzzy-set Qualitative Comparative Analysis (fsQCA) to understand the complex relationships between influencing factors and technology adoption intention. The results of this study contribute to a better understanding of the motivational factors for adopting blockchain technology among future tourism accommodation managers. They can provide a basis for policy-making and facilitate the adoption of this technology in the tourism industry.

Jain et al. (2023) also examined the potential of blockchain technology to transform the tourism and hospitality industries. The authors conducted a systematic review of 56 peer-reviewed scientific articles published between 2012 and 2022 to provide a comprehensive overview of the state of research in this area. Through this review, they identified significant gaps in knowledge and awareness of blockchain, particularly regarding measuring the readiness of digital business models to integrate with blockchain. The result of this research is a categorization of research topics and future research directions in the field of blockchain-based smart tourism, presented based on the "Theory, Context, Method" (TCM) framework. Additionally, for a better understanding of the readers, several case studies of the interplay of these three elements are mentioned. Ratna et al. (2024) published an article entitled "Application of Blockchain, Fintech, and Knowledge Management Technologies in the Tourism and Hospitality Industry." The article's main purpose is to provide a new perspective and explore the opportunities that blockchain, fintech, and knowledge management technologies have created over the past ten years to create new value and innovation processes in the digital tourism and hospitality domains. In this study, a systematic review with a socio-technical approach was used. This paper showed that researchers have explored the benefits and challenges of digital twin technology, fintech, and knowledge management in this industry. This study suggests that using blockchain, fintech, and knowledge management can create new opportunities and markets in the tourism and hospitality industries. Puri et al. (2023) conducted a study to examine the potential and applications of blockchain technology in the tourism industry. In this study, the authors used advanced text extraction and machine learning methods to conduct a comprehensive analysis of 94 papers related to the application of blockchain in tourism between 2017 and 2022. This study uses advanced text mining to predict blockchain-related topics in tourism, which is a leading approach. The article’s findings show that there are still many opportunities for research on blockchain applications in the tourism industry.

3. Research method

The present study is applied in terms of its purpose, as the results of this study can be used in the tourism industry. It is also descriptive-causal in nature and method, as the factors affecting the implementation and application of blockchain in Isfahan travel agencies were not specified in advance and were identified during the research process. It is a survey in data collection, as the interview tool was used to collect the necessary data. To determine the relationships between the factors affecting the implementation and application of blockchain technology in the supply chain of Isfahan travel agencies, 45 academic experts, managers, and tourism experts were selected by judgmental sampling. Also, to collect the necessary data, information and documents available in Isfahan, travel agencies were used, and 15 travel agencies in Isfahan were selected by convenience sampling. This study used the system dynamics approach to investigate the implementation and application of blockchain technology in the tourism supply chain of Isfahan travel agencies. The system dynamics approach is based on systems thinking and supports the development of simulation models for the holistic assessment of complex systems (Morovati Sharifabadi and Ziaeian, 2023). System dynamics modeling is a multi-step process for converting a problem into a quantitative representation and then simulating it (Shen et al., 2009). The goal of the system dynamics approach aims to identify system variables and their time interactions (Wolstenholme, 1990). This approach effectively manages the assumptions of system configurations and dynamic structures and enables the management of changes within subsystems and interactions across the system (Bottero, et al., 2020). The process of conducting this research is shown in Figure 1.

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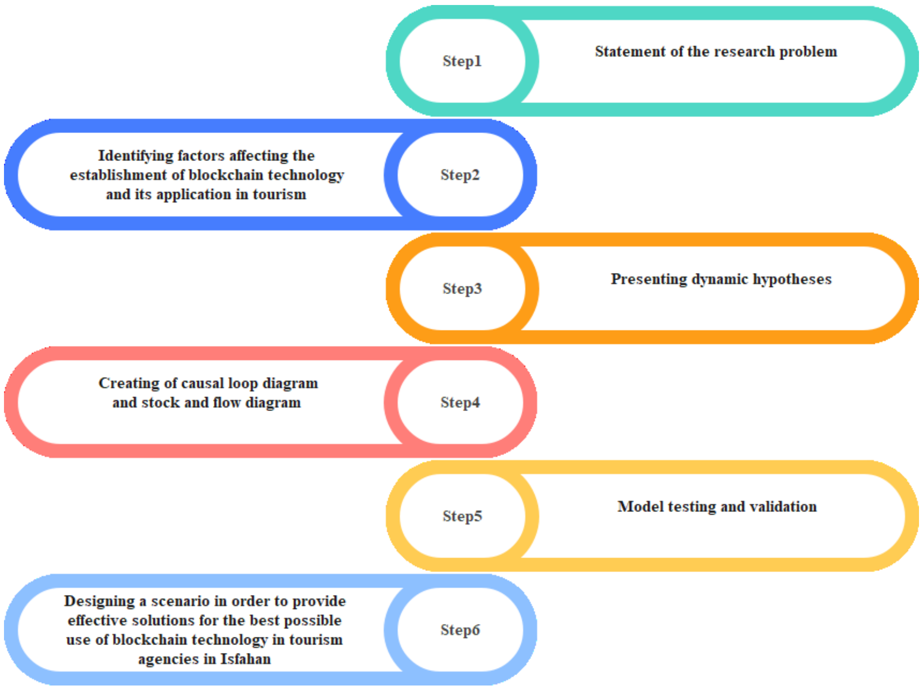

Figure 1. Research implementation steps

As shown in Figure 1, the first step investigated the problem statement and the rationale for the research , given the importance of the tourism industry in the growth and development of the country on the one hand and the existence of challenges such as the mismatch between tourist expectations and the quality of services provided, the management of tourist identity and security. On the other hand, this study has investigated the application of advanced technologies, including blockchain technology, in the tourism supply chain of travel agencies in Isfahan. In the second step, the factors affecting the implementation and application of blockchain in the tourism supply chain of travel agencies in Isfahan were investigated. In the third step, dynamic hypotheses were formulated. Dynamic hypotheses explain the causes and underlying mechanisms of observed behaviors. After defining the dynamic hypotheses, the model boundary diagram was designed. The model boundary diagram specifies the scope of the model by listing the endogenous and exogenous variables, and variables that are not included in the model. The causal loop diagram and the stock and flow diagram were designed in the fourth step. The causal loop diagram serves as a fundamental tool for showing the feedback structure of the system. A positive or negative sign is assigned to each causal link in the diagram. A positive sign indicates that variables changes in the same direction, while a negative sign indicates opposite changes (Rebs, et al., 2019). By conducting a series of online and face-to-face interview sessions with 45 experts, causal relationships between variables were identified, leading to the design of a comprehensive causal loop diagram. After constructing the causal loop diagram, the stock and flow diagram is used to formulate the relationships between the variables under study. The stock and flow diagram allows for examining system behavior over time. The stock and flow diagram was constructed using information obtained from 15 tourism agencies in Isfahan. Mathematical relationships between the variables in the causal loop diagram were determined, and these relationships were further validated and confirmed by experts in the field. Finally, the constructed stock and flow diagram was evaluated with various experiments, and scenarios were presented to provide appropriate solutions for the better implementation and application of blockchain technology in the tourism supply chain of travel agencies in Isfahan.

4. The proposed model

Using research literature and expert opinion, the relationships between the factors affecting the implementation and application of blockchain technology in the tourism supply chain of travel agencies in Isfahan were identified, and a causal loop diagram was designed.

4.1. Dynamic hypothesis

A dynamic hypothesis is a conceptual model the researcher provides based on the key variables of the issue. Dynamic hypotheses involve drawing the main reinforcing and balancing loops using the main variables, facilitating reasoning and knowledge extraction from the developed model. One of the main advantages of dynamic hypotheses is that they increase the readers' understanding of the complexity of the model. The dynamic hypothesis of the current research, the impact of blockchain technology on tourist attractions, is shown in Figure 2 and as follows:

1. Financial resources have a positive effect on blockchain technology.
2. Blockchain technology affects tracking capability.
3. Tracking capability affects transparency in communication and transactions.
4. Transparency in communication and transactions affects service quality.
5. Service quality affects the Tourist satisfaction.
6. Tourist satisfaction affects the tourist attraction.

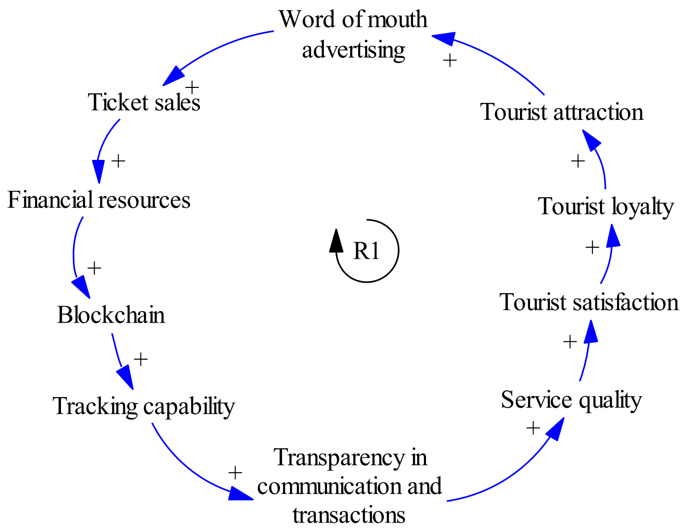

Figure 2. The feedback loops

As shown in Figure 2, blockchain technology can be deployed by allocating sufficient financial resources for the purchase, maintenance, and development of the necessary infrastructure. With the implementation of blockchain technology, the transparency level in transactions and communications with tourists will improve. In other words, with blockchain technology, the level of fraud and forgery in purchases and transactions between tourists and active sectors in the tourism sector, such as hotels, restaurants, and tourist attractions, will be reduced. Transparency in transactions and communications and understanding the needs of tourists will lead to identifying weaknesses in the provision of services by travel agencies. It will significantly help provide quality services to gain customer satisfaction. Tourist satisfaction and loyalty will increase with improved service quality from travel agencies. With increasing tourist satisfaction and loyalty and positive word-of-mouth advertising from them, the rate of tourist attraction will also increase.

4.2. System's boundary diagram

After analyzing the dynamic hypotheses, the indigenous and exogenous variables were created, and the model's boundary diagram was identified. The findings of this examination are summarized in Table 1.

Table 1. Classification of factors into indigenous and exogenous factors

NO	Factors		Description	References
1	Indigenous factors	Cooperation	Cooperation refers to the extent to which employees are engaged in learning and sharing knowledge to leverage blockchain technology in Isfahan's tourism and travel agencies.	Aghaei et al., (2021); Antoniadis et al., (2020)
2		Top support management	Top support management encompasses the degree of support and efforts managers make in allocating adequate resources, motivating employees, creating suitable training conditions, and enhancing their skill levels to facilitate the adoption of blockchain technology in Isfahan's travel agencies.	Zhu and Kouhizadeh, (2019)
3		Organizational Commitment	Organizational commitment refers to the level of motivation and loyalty of employees to the organization and their deep connection with its goals, values, and mission.	Erol et al., (2022)
4		Employee resistance	Employee resistance refers to the unwillingness of employees in Isfahan's tourism and travel agencies to embrace and utilize blockchain technology.	Agarwal, er al., (2023); Jang, et al., (2023)
5		Skills of employees	Employee skills refer to the level of awareness and understanding they possess regarding the functionality and utilization of blockchain technology within Isfahan's tourism and travel agencies.	Chunmian, et al., (2022); Ozdemir, et al., (2023)
6		Financial resources	Financial resources refer to allocating funds for implementing blockchain technology, which includes upgrading information and communication technology infrastructure, employee training, and other related expenses in Isfahan's tourism and travel agencies.	Barreto,et al., (2019); Ratna et al., (2024)
7		Organizational motivation	Organizational motivation refers to the degree of willingness, interest, and motivation displayed by employees in Isfahan's travel agencies to adopt and utilize blockchain technology.	Chaudhuri, et al., (2023)
8		Blockchain technology	Blockchain technology encompasses implementing and utilizing blockchain technology quality across various segments of the tourism supply chain within Isfahan's travel agencies.	Antoniadis et al., (2020); Salunkhe, et al., (2024)
9		High-speed Internet	High-speed Internet refers to the availability and accessibility of fast and reliable Internet connections that enable blockchain technology's effective use and implementation.	Tang et al., (2019); Živanović and Živanović (2022)
10		Data security	Data security refers to the measures and protocols in place to ensure the protection and confidentiality of tourists' personal	Ozdemir and Erol, (2020)

NO	Factors		Description	References
			information and financial transactions and to prevent unauthorized access or impersonation of tourists within the context of Isfahan's travel agencies.	
11		Service fraud	Service fraud refers to deceptive practices such as the impersonation of tourists, unauthorized use or misuse of their personal information, and unauthorized access to their financial transactions within the context of Isfahan's travel agencies.	Banerji et al., (2021)
12		Trust	Trust refers to the level of confidence and reliance that tourists have in the services provided by Isfahan's travel agencies and their willingness to travel to Isfahan based on that trust.	Veloso, et al., (2019)
13		Transparency in communicatio n and transactions	Transparency in communication and transactions refers to the degree of access that tourists have to information and their awareness regarding prices, financial transactions, travel routes, reservation status, and other relevant details about tourism within Isfahan travel agencies.	Baralla, et al., (2021); Calvaresi, et al., (2019)
14		Service quality	Service quality refers to the standard of services provided to tourists in various areas, including hotel accommodations, services offered in Isfahan hotels, reservations, and overall tourist experience.	Raluca-Florentina, (2022); Veloso et al., (2019)
15		Tourist satisfaction	Tourists' satisfaction refers to their contentment with their travel experiences and the services they receive. It encompasses evaluating various factors, including the performance of tourism organizations and establishments, service quality, meeting tourists' needs and expectations, positive interactions with staff, effective communication, and the overall travel experience.	Pradhan et al., (2023)
16		Tourist attraction	Attracting tourists refers to the process of enticing and generating their interest in visiting the city of Isfahan.	Luo and Zhou, (2021)
17		Tourist loyalty	Tourist loyalty refers to the inclination of tourists to revisit Isfahan, engage in positive word-of-mouth promotion of the city, and demonstrate continued support for the travel agencies and services offered in this destination.	Pérez-Sánchez et al., (2021)
18		Ticket sales	Ticket sales refer to the revenue generated from the sale of tickets to tourists for their travel to Isfahan.	Polukhina, et al., (2019)
19		Knowing the expectations of tourists	Knowing tourists' expectations refers to understanding their needs and desires of tourists about the services they expect to receive during their trip to Isfahan.	Calvaresi et al., (2019); Fragnière et al., (2022)

NO	Factors		Description	References
20		Development of tourist attractions	The development of tourist attractions refers to enhancing tourists' awareness of the diverse attractions available in the city of Isfahan. It includes improving the visibility, accessibility, and promotion of key tourist sites, landmarks, cultural and historical destinations, natural landscapes, and other points of interest within the city.	Kwok and Koh, (2019)
22		Attracting investors	Attracting investors involves drawing in both domestic and foreign investors and providing them with opportunities to invest in securing the necessary financial resources for implementing blockchain technology.	Antoniadis et al., (2020)
23		Tracking capability	Tracking capability refers to accurately and transparently recording and tracking information related to travel routes, financial transactions, services provided, and other aspects of the tourism experience.	Valeri, (2020); Wong et al., (2024)
24		Travel motivation	Travel motivation refers to individuals' desire and interest in journeying to Isfahan.	Bodkhe et al., (2019)
25		Training	Training involves conducting various courses and programs to educate and familiarize employees with blockchain technology and its functioning. These training sessions aim to equip employees with the necessary knowledge, skills, and understanding of blockchain technology, its applications, and its potential effect on their work.	Erol et al., (2022)
26		Word of mouth advertising	Word-of-mouth advertising refers to the act of tourists from Isfahan sharing positive recommendations, experiences, and endorsements about their visit and encouraging others to travel to this city.	Kathuria and Tandon (2023)
27		Job Satisfaction	Job Satisfaction refers to employees' dedication, interest, and willingness towards their work in Isfahan's tourism and travel agencies.	Raluca-Florentina (2022)
28		Proper advertising	Proper advertising promotes the characteristics of Isfahan, including its historical and cultural attractions, through various advertising mediums. It utilizes different advertising channels such as print media, online platforms, television, radio, billboards, and other relevant promotional channels to convey information about the city's unique features and attractions.	Aghaei et al., (2021)

NO	Factors		Description	References
29	Exogenous factors	Government support	Government support refers to the assistance provided by the government in various areas, including financial support and support in information and communication technology, among others, to facilitate the implementation and adoption of blockchain technology in Isfahan travel agencies. This support can encompass financial incentives, grants, subsidies, tax benefits, and other forms of financial assistance to encourage the implementation and utilization of blockchain technology.	Li et al. (2021); Ozdemir et al., (2020)
30		Use of experts	The use of experts refers to the process of attracting highly skilled and capable individuals in the field of information and communication technology, specifically in the domain of blockchain technology. It involves recruiting and leveraging the expertise of professionals with specialized knowledge and experience in blockchain technology. By engaging these experts, organizations can benefit from their deep understanding of blockchain principles, best practices, and implementation strategies.	Dadkhah et al., (2022)

4.3. Causal loop diagram

Figure 3 shows the causal loop diagram after determining dynamic hypotheses and identifying the model's indigenous and exogenous variables.

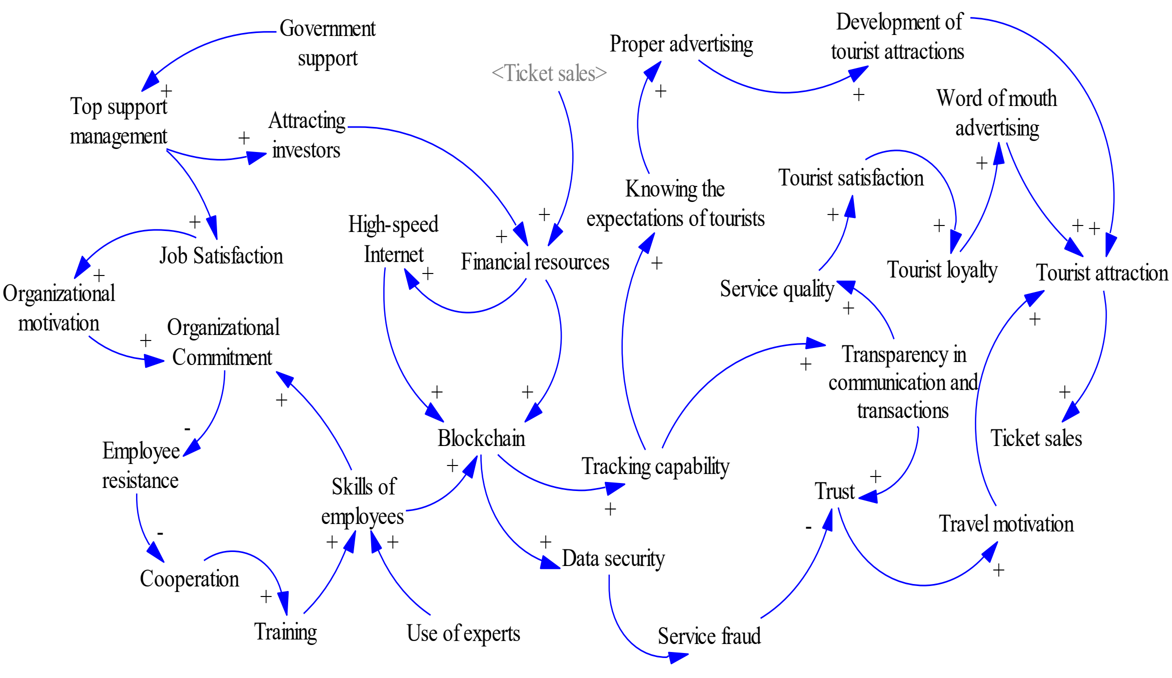

Figure 3. Causal loop diagram

Several feedback loops have been established in the causal loop diagram, which are examined below.

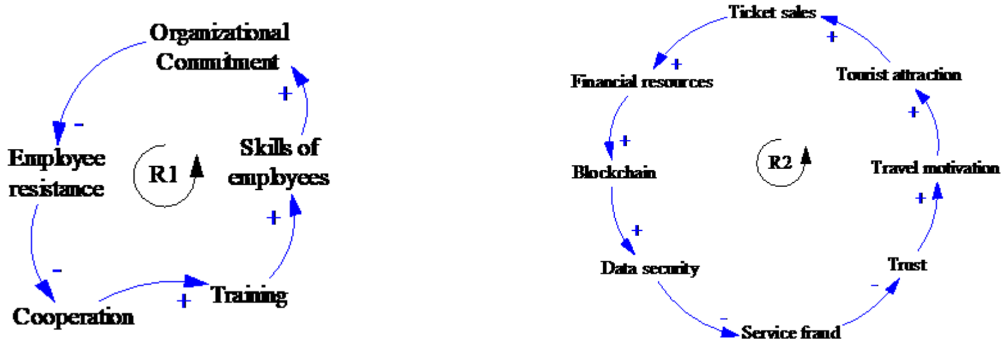

Figure 4. Feedback loops

As depicted in Figure 4 (left), a positive feedback loop is established. Employees' organizational commitment to Isfahan's tourism travel agencies diminishes their resistance to adopting blockchain technology. Minimizing employee resistance enhances their cooperation in learning and training for utilizing blockchain technology. Augmenting employees' training and learning duration elevates their proficiency and expertise in blockchain technology. Heightening employees' knowledge and skills and their awareness of the benefits associated with blockchain technology amplifies their motivation and organizational commitment to their workplace.

A positive feedback loop is illustrated in Figure 4 (right). Implementing encryption algorithms within the blockchain technology platform in Isfahan's tourism travel agencies enhances the security of tourist-related data, such as transactions, identities, and personal information. The improved security of tourist data reduces fraud, impersonation, and misuse of personal information. Decreasing fraud and fraudulent activities elevates trust and motivates tourists visiting Isfahan. Heightened tourist motivation leads to increased visitors attracted to Isfahan and the sales of travel tickets to the city. Ultimately, this results in a rise in available financial resources and consequently promotes utilizing blockchain technology through increased funding allocation.

4.4. Stock and flow diagram

After creating the causal loop diagram, the stock and flow diagram are developed by establishing relationships and mathematical equations among the variables under investigation. In the appendix, we outline several key relationships among variables in the current research. The stock and flow diagram are drawn in Figure 5.

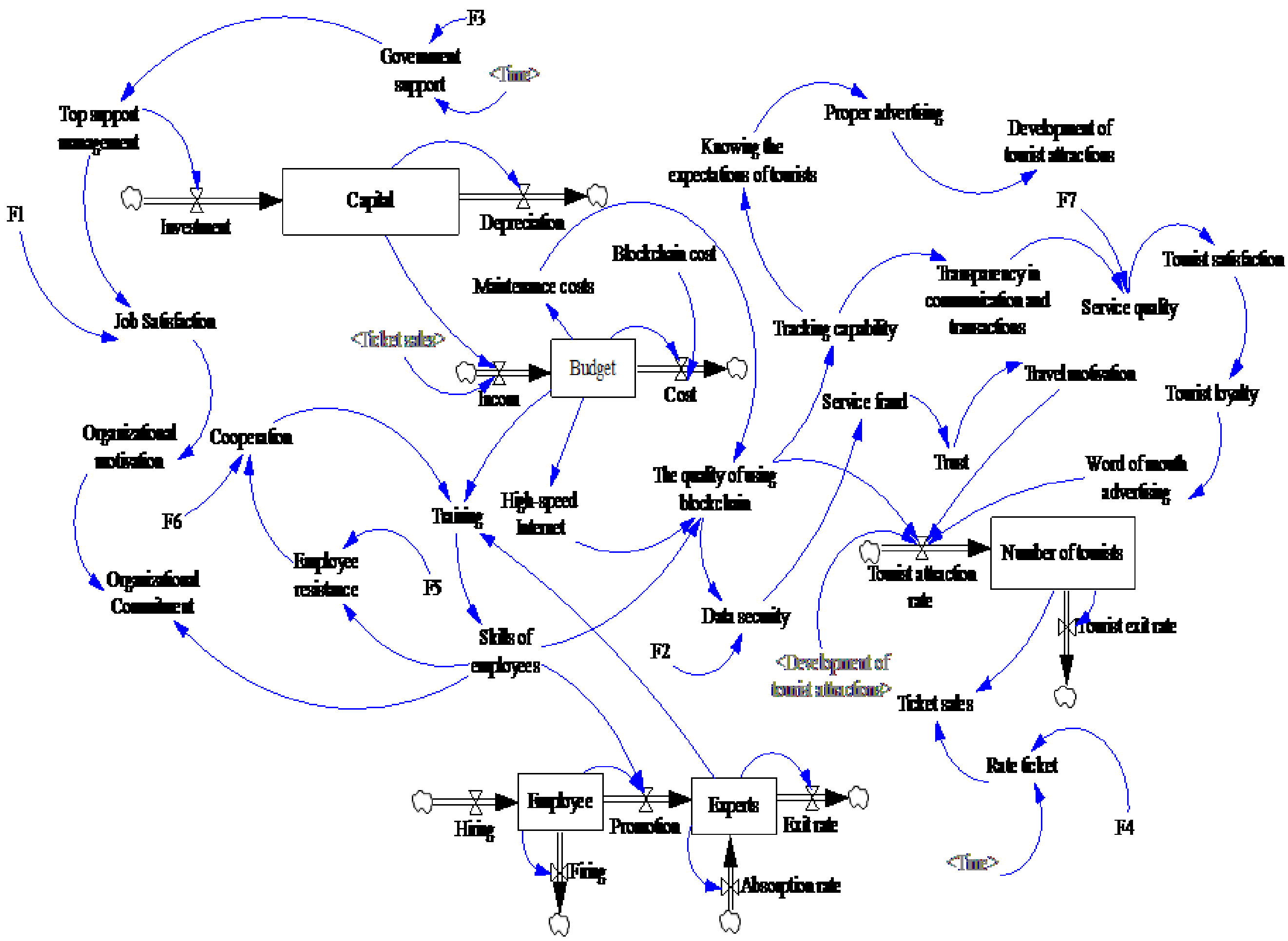

Figure 5. Stock and flow diagram

As shown in Figure 5, the stock and flow diagram comprises 44 variables, of which 5 are stocks, 10 are flows, and 29 are auxiliary variables. Stock and flow variables describe the current state of a system and can be quantified or measured at a specific moment. Sterman, (2002) suggests that stock and flow variables are typically quantitative. Based on those above, the variables examined in this research, such as capital, budget, number of tourists, employees, and experts, can be directly counted or measured at any given time. Furthermore, these variables change input and output flows. It is worth noting that the stock and flow variables considered in this research have received validation from experts. For the simulation of this study, a ten-year time horizon was considered in 12-month intervals.

5. Model validation

The model's validation process is conducted in three distinct phases.

5.1. Model structure evaluation test

The model structure evaluation test ensures that the structure of the designed model is consistent with existing knowledge. This study approved and designed the model structure based on the research background and the opinions of academic experts, managers, and tourism experts.

5.2. Parameter evaluation test

The parameter evaluation test ensures that the values assigned to the variables match their actual values. Since the variables in this study were derived from the research field, relevant literature, documents, records of 15 travel agencies in Isfahan, and expert opinions, the values provided in the relevant documents and research are consistent.

5.3. The limit condition test

This test determines whether the model behaves logically under extreme conditions. To this end, the value of one of the factors affecting the implementation of blockchain technology and its application in travel agencies in Isfahan in the model is driven towards zero, and the behavior of other factors is investigated. If the behavior of other factors is logical, this test is accepted and approved. In this study, the income variable was driven towards zero, and the behavior of some of the variables affected by it was investigated, as shown in Figure 6.

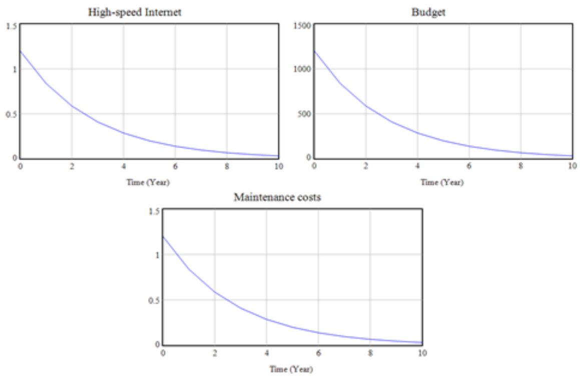

Figure 6. Model testing and validation

As shown in Figure 6, as the income approaches zero, the variables of broadband internet, budget, and maintenance costs will move towards zero.

5.4. Behavior reproduction test

This test will compare the simulation results with actual data to verify the correctness of the model's behavior. The figures' findings demonstrate how well the researched variable may be replicated. The results are shown in Figure 7.

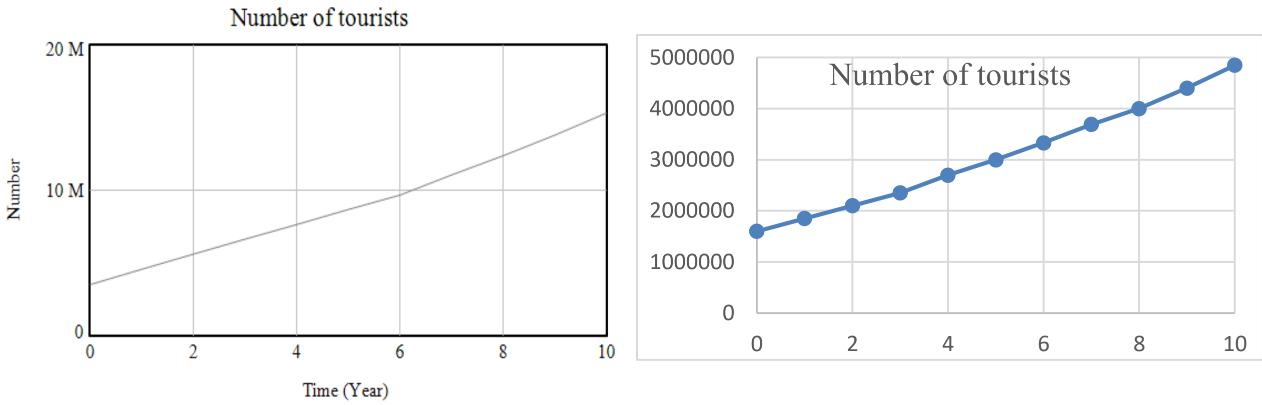

Figure 7. Comparison test with reference behavior

6. Simulation results

In this section, the simulation of the behavior of the key variables affecting the implementation of blockchain and its application in travel agencies in Isfahan is investigated.

6.1. Implementation and evaluation of policies

This section investigated the results of the simulation and analysis of three scenarios. In this study, three scenarios were evaluated. The first scenario investigated the increase in budget allocation to education and its effect on other key model variables. In the second scenario, attracting capital and increasing investment in technological infrastructure, including maintaining blockchain technology and broadband internet, were evaluated. The third scenario investigated the effect of simultaneously increasing the budget allocated to education, attracting capital, and increasing investment.

6.1.1. The policy of increasing the amount of investment in the tourism sector

Figure 8 shows the behavior of the key variables affecting the implementation and application of blockchain technology in the tourism supply chain of travel agencies in Isfahan when the budget allocation is increased.

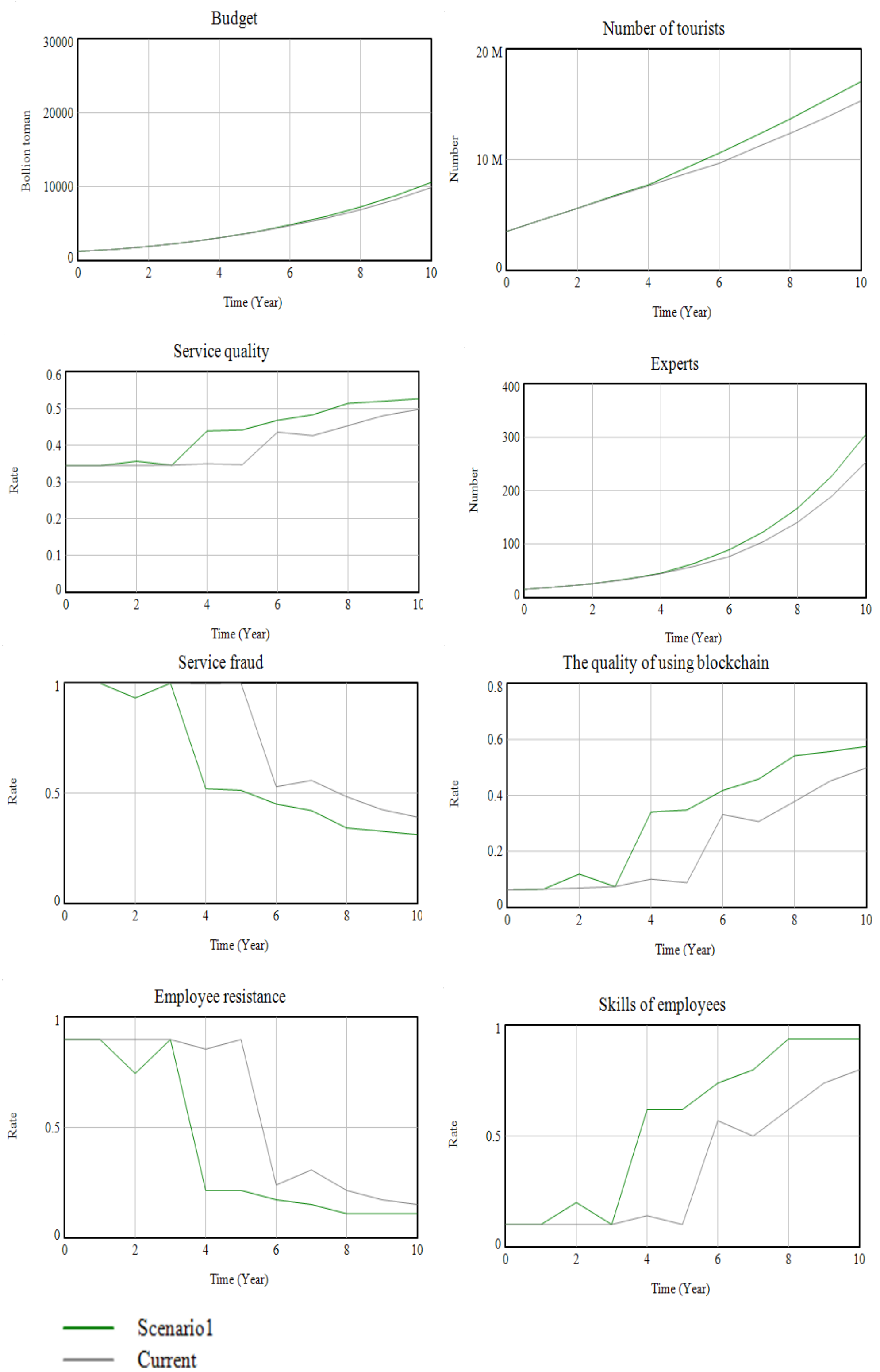

Figure 8. The results o f the policy of increasing budget allocation to training

As shown in Figure 8, increasing the budget allocated to education will significantly improve the number of experts in this field and the quality of use of blockchain technology. In addition, employee skills will reach its maximum level in the fifth year. The number of tourists will also change in an increasing trend. The budget amount will change with a smaller slope and an increased budget allocation to education. Employee resistance to forgery and fraud in services provided to tourists will also change in a fluctuating manner in the early stages of the simulation and will decrease significantly over time. By increasing the budget allocated to education for the implementation of blockchain technology, the quality of services provided to tourists exhibits a gradual change with a low slope and fluctuates over time. Specifically, during the middle of the simulation period, the service quality experienced a decline followed by an increase. The fluctuating pattern in service quality is attributed to the evolving nature of innovation in utilizing blockchain technology over time. Despite the increase in budget allocated to employee training, the quality of utilizing blockchain technology also displays fluctuations, particularly in the initial years. The fluctuating behavior of blockchain utilization quality can be attributed to factors such as information and communication technology infrastructure and the time-consuming learning process for employees when adapting to blockchain technology.

6.1.2. The policy of increasing capital attraction and allocating funds to technology infrastructure

Figure 9 shows the behavior of the key variables affecting the implementation and application of blockchain technology in the tourism supply chain of travel agencies in Isfahan, focusing on attracting capital and increasing investment in technological infrastructure.

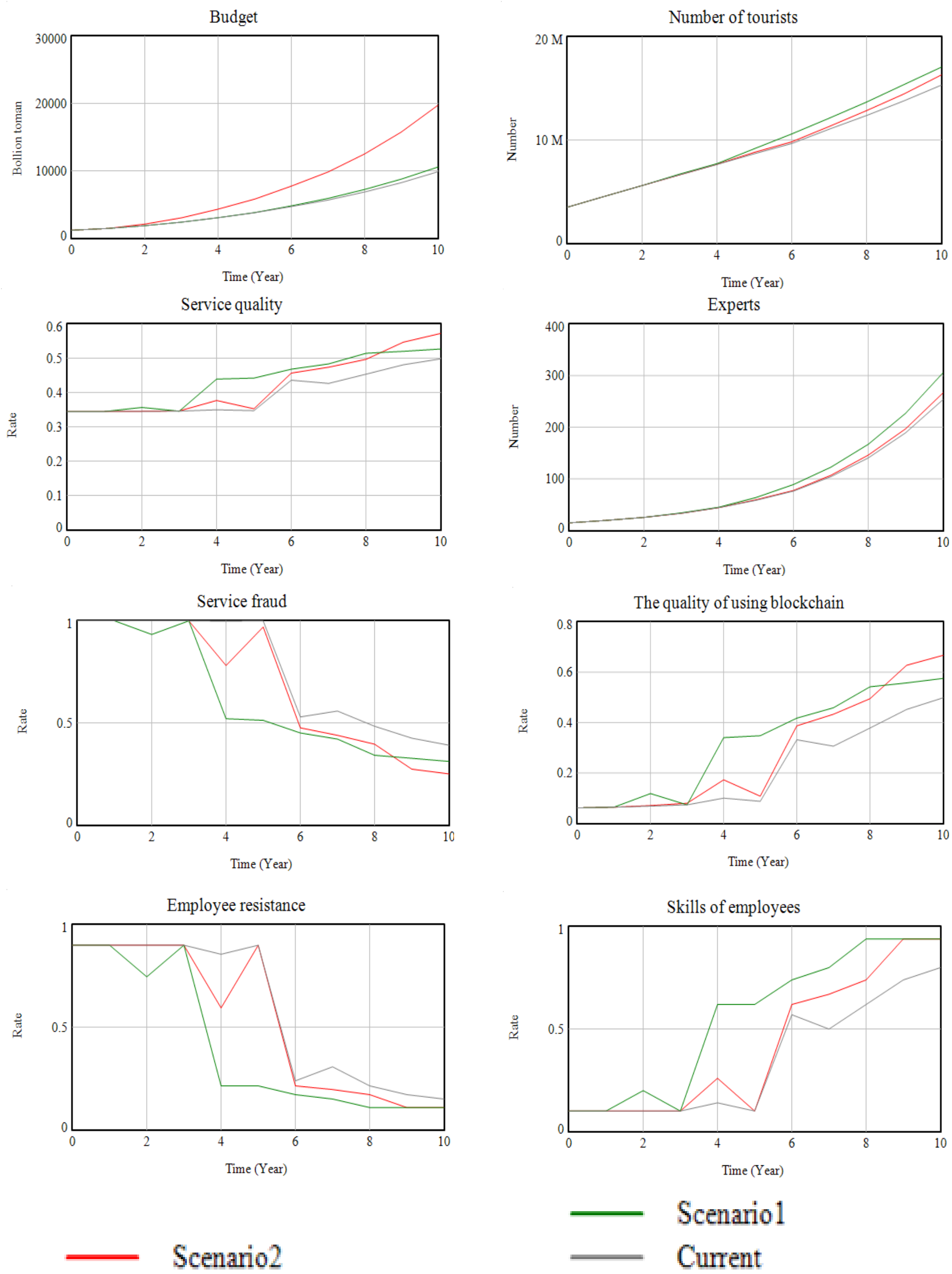

Figure 9. The results of the policy of increasing capital attraction and allocating funds to technology infrastructure

As shown in Figure 9, by attracting capital and increasing investment in technological infrastructure, the number of tourists attracted, experts in the field of blockchain technology, and budget will grow exponentially and with a significant slope. Also, with attracting capital and increasing investment in technological infrastructure, employee resistance, forgery, and fraud in the services provided will decrease significantly from about the third year. Employee skills and the quality of use of blockchain technology and services will also grow significantly from the third year of the simulation period.

6.1.3. The policy of increasing budget allocation to education and attracting capital and increasing investment in technology infrastructure

Figure 10 shows the behavior of the key variables affecting the implementation of blockchain technology and its application in travel agencies in Isfahan when the budget allocated to education is increased, the amount of investment from investors is increased, and the budget is allocated to technological infrastructure.

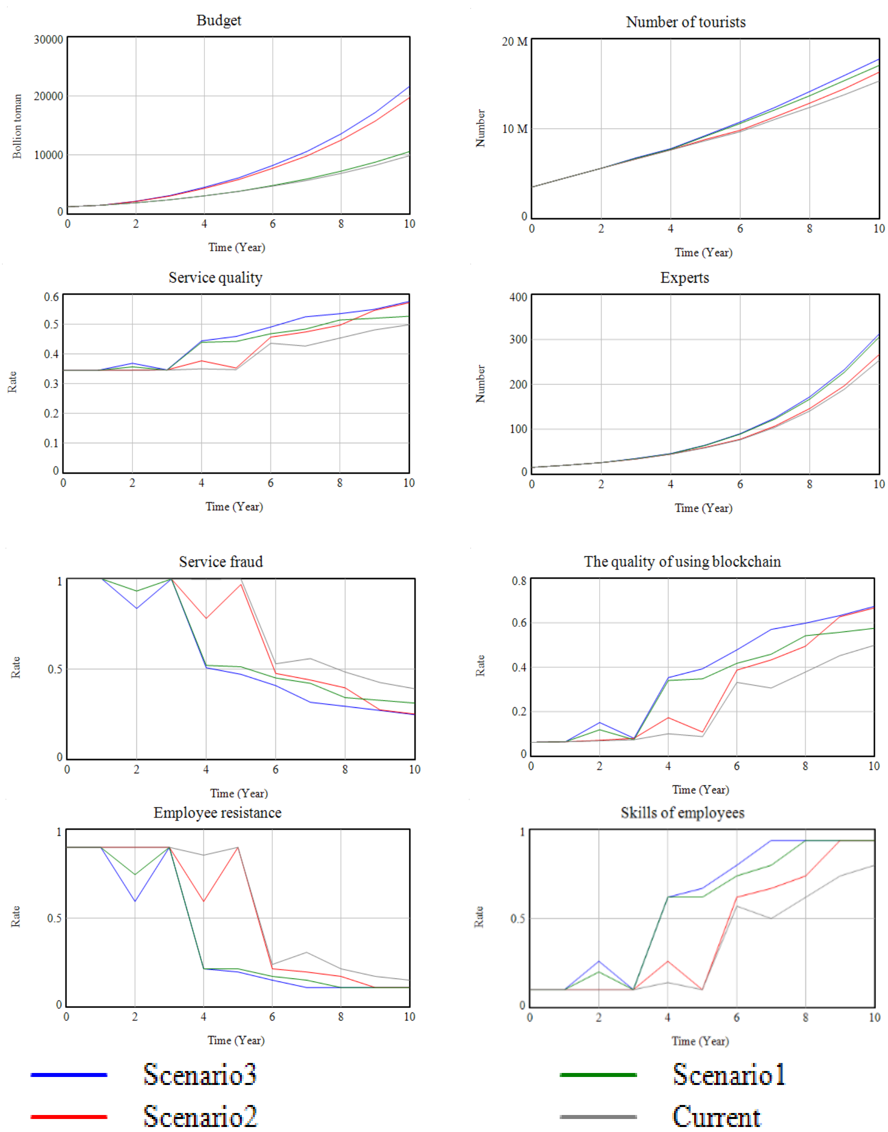

Figure 10. The result of the policy of increasing budget allocation to education and attracting capital and increasing investment in technology infrastructure

As shown in Figure 10, with the simultaneous increase in the budget allocated to education, attracting capital, and increasing investment in technological infrastructure, the number of tourists attracted, budgeted, and experts in the field of blockchain technology will grow significantly. Also, the level of changes in employee resistance, forgery, and fraud in services provided to tourists will fluctuate in the early years and decrease significantly over time. On the other hand, the number of variables, such as the quality of blockchain use, employee skills, and services, will change increasingly and increase to a certain extent.

7. Discussion

The tourism industry plays a significant role in the development of deprived areas and the economic, cultural, and social progress of different societies. Given the potential in the tourism industry, the number of domestic and international tourists attracted to different cities of the country, including Isfahan, is far from the desired level for several reasons, including the mismatch of the quality of services provided with the needs and expectations of tourists, the management of tourists' identities and the protection of personal information, the lack of sufficient knowledge of tourist attractions among tourists, the complexity and time-consuming nature of the reservation process. In recent years, the service and manufacturing industries have also made significant progress with the development and progress of information and communication technologies. Therefore, new technologies, including blockchain technology, can transform the tourism industry and improve its performance.

The purpose of this study is to present a simulation model for implementing and applying blockchain technology in travel agencies in Isfahan. This study identified the factors affecting the implementation and application of blockchain technology in the tourism industry based on the literature and research background. In the continuation, the identified factors were confirmed based on the opinions of academic experts, managers, and experts specializing in tourism. In continuation, using the system dynamics approach, the model of the implementation and application of blockchain technology in travel agencies in Isfahan was investigated.

The simulation of system dynamics in this research showed that allocating financial resources, developing technological infrastructure, and the knowledge and skills of employees are among the most effective factors in implementing blockchain technology as best as possible. The research is consistent with the findings of the studies conducted by (Ratna et al., 2024). Due to the lack of sufficient skills and knowledge of employees and their resistance to adopting blockchain technology, the quality of using it in the early years is unfavorable and will grow over time. By training employees and using experts specialized in blockchain technology, in addition to increasing the skills and abilities of tourism travel agencies in Isfahan, it is possible to reduce their resistance to adopting blockchain technology. In other words, with the increase in the knowledge and skills of employees, their understanding of the benefits and benefits of using blockchain technology will increase, and their possible resistance to accepting this technology will decrease. Also, the results of this research showed that if blockchain technology is established, the quality of services provided to tourists will improve for various reasons, including improving the level of security of tourists' personal information and knowing their expectations and needs through sharing. The experiences of tourists in the context of blockchain technology will improve the facilitation of transactions and reservations of accommodation and hotels, transparency in prices, and a better understanding of the matching of quality and price provided by travel agencies.

It should be noted that due to the time-consuming process of fully deploying blockchain technology and the quality of its use, the quality of services grew with a slight slope in the early years. With the passage of time and the improvement of the quality of blockchain technology, the quality of service will also grow significantly. Tourist attractions and financial resources will grow significantly as the services provided by travel agencies in Isfahan improve.This research examines three scenarios to provide solutions for the best possible use of blockchain technology and its application in travel agencies. The findings from the first scenario showed that by allocating more funds to the training of employees, their skills and ability to use blockchain technology in the early years grew significantly. The ten-year simulation will reach its maximum in the fifth year of the course. With the increase in the skill level and ability of the employees, their resistance to the adoption of blockchain technology will decrease significantly in the initial years. It will reach its minimum in the fifth year of the simulation period. The results of this section showed that the employees' resistance has decreased to a certain extent and will not reach zero. Also, by improving the quality of blockchain technology, fraud and forgery in the services provided to tourists will decrease over time, which aligns with the findings of audio studies by Banerji et al. (2021). In addition, with the increase in budget allocation for staff training, the number of tourist attractions, budget, and experts in this field in travel agencies in Isfahan will grow significantly. Due to the better mastery of blockchain technology, the value of the various variables in this research will change with a slight slope in the early years and with a significant slope from the middle of the simulation period.

The findings from the second scenario showed that by attracting capital and allocating funds to information technology infrastructure, including high-speed Internet access and maintenance costs related to blockchain technology, the quality of using blockchain technology increased. It will be improved if this research finding is consistent with the findings of the studies conducted by (Nuryyev et al., 2020). Other results obtained from the second scenario include:

- Increasing the amount of budget for tourism travel agencies in the city of Isfahan,

- Improving the quality of services provided to tourists,
- Increasing the rate of attracting tourists,
- Reducing the resistance of employees to accepting blockchain technology due to the development of technological infrastructure and facilitating the use of blockchain technology
- It is reducing fraud and forgery in the services provided

The results of the comparison of the two investigated scenarios showed that attracting capital and increasing investment will have a significant effect on the number of budget changes compared to the implementation of the first scenario (increasing budget allocation to education). Also, the change in the quality of blockchain use in the second scenario (budget allocation to the development of technological infrastructure) is greater than in the first scenario (increase in the budget allocation to education). In other words, the results of this section show that providing suitable infrastructure for the use of blockchain technology is a priority. Other results obtained from the comparison of the two scenarios include the significant effect of training on the development of employee's skills and the reduction of their resistance to accepting the use of blockchain technology in travel agencies in Isfahan to attract capital and increasing the amount invested in the development of technology infrastructure.

The findings from the third scenario showed that with the increase in budget allocation to education and capital attraction and the increase in investment in technology infrastructure, the quality of using blockchain technology will grow significantly compared to the implementation of the previous two scenarios. Also, employees' skills and knowledge will reach their maximum in a shorter period. Among the other results of this department the minimization of employee resistance and fraud in the services provided to tourists in a shorter period can be mentioned.

In general, the results of this research show that the use of blockchain technology will significantly affect tourist attractions and budgets. On the other hand, the results of this research showed that training employees, increasing their skill and knowledge level, and developing technology infrastructure are of particular importance in order to make better use of blockchain technology.

8. Conclusion

This research presents the simulation model for implementing and applying blockchain technology in travel agencies in Isfahan using the system dynamics approach. This study first identified the factors affecting the implementation and application of blockchain technology in the tourism industry. Then, they were approved by academic experts, managers, and experts in the field of tourism. In the following, the causal loop diagram and the relationship between the identified factors were examined based on the design of dynamic hypotheses. Based on the causal loop diagram, a stock and flow diagram was designed, and quantitative relationships were established between the variables and factors affecting the implementation and users of blockchain technology in travel agencies in Isfahan. This research showed that implementing blockchain technology significantly increases the quality of tourism services, the amount of tourist attractions, and financial resources. According to the findings of this research regarding the effect of two factors, employees' skills, and information technology infrastructure, on the enhancement of the quality of using blockchain technology, it is recommended that future studies employ system dynamics simulation to investigate the dynamic interactions and mutual effects of these factors.

Furthermore, it is suggested that future research explore other factors that influence the adoption of blockchain technology in the tourism supply chain and present a wider range of models in this field. Additionally, it is recommended that the application of blockchain technology in various types of tourism, such as religious tourism, sea tourism, sports tourism, and others, be investigated in future research. Finally, it is suggested that the application of other technologies of the fourth industrial revolution, such as the Internet of Things, cyber-physical systems, and digital twins, in the tourism industry should be investigated in future research.

Disclosure statement

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

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Appendix

(01) Absorption rate= INTEGER (0.3*Experts)

Units: Dmnl

(02) Blockchain cost= 0.27

Units: Billion toman

(03) Budget= INTEG (Incom-Cost)

Units: Billion toman

(04) Capital= INTEG (Investment-Depreciation)

Units: Billion toman

(05) Cooperation= (DELAY1I(F6(Employee resistance), 0.5, 0.8))*(0.4)

Units: Dmnl

(06) Cost=Blockchain cost+0.3*Budget

Units: Billion toman

(07) Data security= F2(The quality of using blockchain)

Units: Dmnl

(08) Depreciation=0.02*Capital

Units: Billion toman

(09) Development of tourist attractions= 0.85*Proper advertising

Units: ** Dmnl **

(10) Employee= INTEG (Hiring-Firing-Promotion)

Units: Number

(11) Employee resistance= F5(Skills of employees)

Units: Dmnl

(12) Exit rate= 0.001*Experts

Units: Dmnl

(13) Experts= INTEG (Absorption rate+Promotion-Exit rate)

Units: Number

(15) Firing= 0.01*Employee

Units: Dmnl

(16) Government support= F3(Time)

Units: Dmnl

(17) "High-speed Internet"= 0.001*Budget

Units: Billion toman

(18) Incom=Ticket sales+Capital

Units: Billion toman

(19) Investment= 100*Top support management

Units: ** Billion toman **

(20) Job Satisfaction= F1(Top support management)

Units: Dmnl

(21) Knowing the expectations of tourists= 0.75*Tracking capability

Units: Billion toman

(22) Maintenance costs= 0.001*Budget

Units: Billion toman

(23) Number of tourists= INTEG (Tourist attraction rate-Tourist exit rate)

Units: Number

(24) Organizational Commitment= (0.75*Organizational motivation)+(0.6*Skills of employees)

Units: Dmnl

(25) Organizational motivation= 0.8*Job Satisfaction

Units: Dmnl

(26) Promotion= 0.01*Employee*Skills of employees

Units: Dmnl

(27) Proper advertising= 0.7*Knowing the expectations of tourists

Units: Dmnl

(28) Rate ticket= F4(Time)

Units: Dmnl

(29) Service fraud= 1/Data security*0.1

Units: Dmnl

(30) Service quality= 0.3+F7(Transparency in communication and transactions)

Units: Dmnl

(31) Skills of employees= IF THEN ELSE(Training<0.03, 0.1, IF THEN ELSE(Training>0.03:AND:Training <=0.04, 0.14, IF THEN ELSE(Training>0.04:AND:Training<=0.05, 0.2, IF THEN ELSE (Training>0.05:AND:Training<=0.06, 0.26, IF THEN ELSE(Training>0.06:AND:Training <=0.07, 0.33, IF THEN ELSE(Training>0.07:AND:Training<=0.08, 0.41, IF THEN ELSE (Training>0.08:AND:Training<=0.09, 0.5, IF THEN ELSE(Training>0.09:AND:Training <=0.1, 0.57, IF THEN ELSE(Training>0.1:AND:Training<=0.2, 0.62, IF THEN ELSE (Training>0.2:AND:Training<=0.3, 0.67, IF THEN ELSE(Training>0.3:AND:Training <=0.5, 0.74, IF THEN ELSE(Training>0.5:AND:Training<=0.7, 0.8, IF THEN ELSE (Training>0.7:AND:Training<=0.1, 0.86, 0.94))))))))))))

Units: Dmnl

(32) The quality of using blockchain= ("High-speed Internet"*0.1+Maintenance costs*0.1+10*Skills of employees)

Units: Dmnl

(33) Ticket sales= Number of tourists*Rate ticket*0.1

Units: Billion toman

(34) Top support management= 0.6*Government support

Units: Dmnl

(35) Tourist attraction rate= ((Development of tourist attractions*1e+06)+(Travel motivation*1e+06)+(1e+06*Word of mouth advertising))+(The quality of using blockchain*1e+06)

Units: ** Dmnl **

(36) Tourist exit rate= 0.02*Number of tourists

Units: ** Dmnl **

(37) Tourist loyalty= 0.8*Tourist satisfaction

Units: Dmnl

(38) Tourist satisfaction= 0.2+0.85*Service quality

Units: Dmnl

(39) Tracking capability= 0.8*The quality of using blockchain

Units: Dmnl

(40) Training= (Cooperation)*0.001*Budget*(10*Experts*0.0003)

Units: Billion toman

(41) Transparency in communication and transactions= 0.2+0.7*Tracking capability

Units: Dmnl

(42) Travel motivation= 0.3+Trust*0.5

Units: Dmnl

(43) Trust= 1/Service fraud*0.1

Units: Dmnl

(44) Word of mouth advertising= 0.4+0.75*Tourist loyalty

Units: Dmnl

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A Spatial Agent-Based Consumer Model: Maximizing and Satisfying Behavior within Multi-Store Market

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ABSTRACT

In this paper, we propose using a mixed genetic-floyd-warshall algorithm in combination with a Floyd-warshall algorithm to model the satisficing behaviour of consumers across spatially differentiated stores. Consumer agents can pick a basket of goods from different stores to either maximize their utility or to "satisfice" by selecting the first basket with a utility that is higher than their satisfaction threshold. The Floyd-warshall algorithm is used to find the shortest path between two chosen stores by considering travel cost. Factors such as price, quality of goods, the cost of travel to the store, consumers' decision-making preferences, and store locations play significant roles in the decision-making process of consumer agents. The model is tested based on mechanisms at the individual level to show how the model works and at the macro-level to reproduce foundational theories in economics.

Keywords

Economic modeling, Consumer behavior, Knowledge-based decision, Spatial agent-based modeling.

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1. Introduction

Companies seek information on consumer behaviour so that they can tailor their marketing strategies to maximize sales (Bernabé-Moreno et al., 2015). Consumer choice involves at least six different stages, including need recognition, search for information, evaluation of alternatives, decision to purchase, purchase, and post-purchase learning. Within these stages, there are underlying cognitive processes that determine why consumers buy things. Psychological factors can affect consumers' purchasing rules and may lead the consumer to buy goods with near optimum utility rather than maximum utility. In this paper, we compare two of the most important purchasing rules: satisficing and maximizing. In satisfying behavior, consumers tend to buy any basket of goods with utility higher than their satisfaction threshold, considering their budget constraint (Schwartz et al., 2002). On the other hand, maximizing consumers select the basket of goods with the highest possible utility within their budget. Therefore, satisficers may buy goods more for convenience and enjoyment but consequently pay more (Schwartz et al., 2002). This is a form of bounded rationality (Simon, 1955; Schwartz, 2008).

There are many efforts to model consumer behavior. However, to the best of our knowledge, there is no agent-based model in which consumer agents choose their goods from spatially differentiated stores to maximize their utility or reach their satisfaction threshold. Selecting a basket of goods to maximize utility from different stores is a subset of the unbounded knapsack problem and is an NP-hard problem that has yet to be solved (Neapolitan and Naimipour, 2004). The NP-hard problem can be solved with pseudo-polynomial time complexity (Neapolitan and Naimipour, 2004).

To clarify the problem related to a multi-market situation, we use an example. Assume that in the bidirectional graph (Figure 1), nodes (rectangles) stand for stores and edges for the cost of moving from one node to another (including distance, gas, etc.). The first node (circle) indicates the consumer's location. In this situation, maximizers have the NP-hard problem of determining which stores they should select in order to maximize their net benefit from a purchase while minimizing search and travel costs. Satisficers do not seek to maximize, and so should have an easier time finding a satisfactory basket of goods, but even this is difficult a priori.

We solve both problems by breaking down the decision into two interrelated processes. We first use a Floyd-warshall algorithm as part of genetic algorithm to find the shortest (least expensive) path for each basket of goods and then incorporate this as part of the total utility for each basket of goods. We then incorporate this into a genetic algorithm that finds the satisfactory combination of path and purchase options for the entire system. This is similar to the way in which people learn the attributes of a spatial context and then use that information to plan their shopping trips based on what they need at any given point in time (Dellaert et al., 1998).

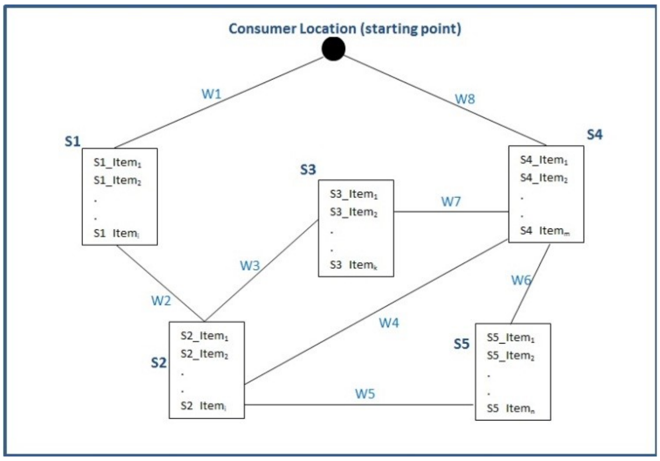

Figure 11. Example of market structure-problem definition

We use agent-based modeling (ABM) to implement this algorithm. ABM is an analytical technique for modeling complex systems (Gilbert, 2008). Agents are autonomous entities with an internal decision-making process. Taking human cognitive factors into account is important to make humans like agents, and ABMs are often used to explore the macro-level outcomes of individual-level decision processes (Fujita, Hakura and Kurematu, 2009). Most early ABMs had no real spatial component, as the focus was on developing more and more sophisticated decision processes. For instance, in their seminal paper, Jager and Janssen (1999) propose a consumer decision-process in which consumer agents are equipped with four cognitive processes: deliberation, imitation, social comparison, and repetition. Although the paper proposes a model of the agent's decision process, it mostly focuses on the internal part of the agent's mind rather than the environment. Goods are abstractly generated without physical location, and stores and agents choose from a single good category rather than a basket of goods. This simplification was useful for initial model runs but could be extended by incorporating spatial attributes into the environment and the decision process (Wang et al., 2021).

Zhang and Zhang (2007) created a model in which consumer agents choose a suitable good when encountering competing brands in a market with only a few stores. This allows them to evaluate the decoy effect, in which consumers change their preference for ordering two goods due to the presence of a third good that is asymmetrically dominant (inferior in all but one attribute). Agents make decisions based on a motivation function and are equipped with personality traits, but the model is not able to find the best basket of goods among all available stores. Also, there are no transportation costs in this model, so maximizing occurs only over the attributes of the goods sold, not the spatial location of the stores (Zhang and Zhang, 2007).

Roozmand et al. (2011) propose a model based on culture and personality for consumer agents' decision-making processes. The core of the model is human needs, where agents are motivated based on those needs which are important in their culture (Roozmand et al., 2011). It models the power distance dimension of Hofstede's model of national culture, social status and social responsibility needs, and the extroversion, agreeableness and openness of McCrae and Costa's five-factor model (McCrae and Costa, 1983, 1996, 2003; Hofstede and Hofstede, 2005; Hofstedeet al., 2010). The model is validated in eleven European countries, even though the results do not fit two other countries, Great Britain and the Netherlands. All in all, there is great detail regarding consumer decision processes in the model, but it does not consider the location of stores. Also, the consumer agent buys one good at a time and is not able to choose a basket of goods.

ABMs have also been used to explore the role of trust in market transactions. Roozmand et al. (2007) describes a market model including buyer and seller agents. Buyer agents apply reinforcement learning to model reputable sellers and seller agents use reinforcement learning to model reputable buyers. Similarly, Khosravifar et al. (2012) propose a trust model for computing agents which is evaluated with service consumer agents based on different trust models.

All of the above decision processes are more difficult when consumer agents maximize over a basket of goods rather than one good or a few different brands. Baptista et al. (2014) describe a greedy algorithm to solve the problem of finding the maximized basket of goods. The proposed algorithm does not always provide an optimal solution; however, it has linear complexity. Roozmand and Webster (2014) use a dynamic algorithm to find the best basket of goods, namely a basket of goods with the highest possible utility. They also used a genetic algorithm to find the satisficing basket of goods. Consumer multichannel choice behavior has been studied in the research conducted by Sonderegger (Sonderegger-Wakolbinger and Stummer, 2015). Heterogeneity of customers, social dynamics, and different purchasing stages have been taken into account in this research (Sonderegger-Wakolbinger and Stummer, 2015). Here again, although these models are built on sophisticated cognitive models, they do not include the spatial component.

The incorporation of spatial elements began in parallel with some of the most advanced decision-processes described above. Here, we review a few of these spatially explicit models of consumer decision-making, along with spatial economic agent-based models. Tsekeris and Vogiatzoglou (2011) propose a model based on new economic geography that simulates the complex interactions of household and firm location choices based on agent-based modeling. It considers transport costs as part of agents' decision-making processes in a system of cities. The model contains households, the production sector, firms, and central and local government agents. Household agents, as end consumers, use a utility function to choose a basket of goods that is affordable given their budget constraints. However, the model is not able to find the best basket of goods.

Also, He et al. (2014) propose an agent-based spatial model including four types of agents: the world, manufacturers, firms and consumers. In this paper, firms utilize a genetic algorithm to evaluate their location and pricing strategies. Therefore, the position of firms evolves over time to find the optimal location. The manufacturer agent provides an infinite quantity of goods for consumer agents. The world agent contains all other agents and is used to update the values of all the variables, such as price, position and other endogenous parameters, as well as provide results for later analysis. Consumer agents use a utility function to find a suitable basket of goods considering their budget constraints. The utility function contains the price of goods from each firm and the distance to that firm. Consumer agents' positions are fixed. The main problem of such consumer agent algorithm is that it does not find the optimal product basket. Consumer agents always choose one firm to purchase all of the goods that they need. However, the best basket of goods might be found in different stores, and so the consumer may improve utility by going to different stores as long as travel costs are relatively low (He et al., 2014).

According to the reviewed research, optimizing baskets of goods has not been studied in a spatially differentiated stores where stores are located at different geographical locations. In this case, not only the utility and price of each good should be considered, but also the time and cost of traveling from one store to another. In this paper, we apply a mixed genetic-floyd-warshall algorithm (Chen and Jian, 2007). The paper is organized as follows: Section 2 describes the proposed algorithm. In subsection 2-1, we use an example to show how the algorithm works. Section 3 provides the results, including verification to show the model works properly (subsection 3-1) and validation based economics theories (subsection 3-2). Finally, in section 4 we conclude the paper and propose future works.

2. Proposed algorithm

As explained in the introduction, maximizing consumer choice across a range of stores is a complex decision process and an NP-hard problem. There are a few techniques that could be used to search the problem space to find the best or satisficing basket of goods, such as brute-force which needs to search the whole solution space, dynamic programming, or local search algorithms. This problem is similar to the unbounded knapsack problem (Chen and Jian, 2007; Srisuwanna and Charnsethi, 2007) where consumer agents can choose one or more goods from different types as far as the price does not exceed the consumer's budget; therefore, dynamic programming is a solution. However, in knapsack problem, dynamic programming is still time-consuming and, moreover is usually used for maximizing utility (Neapolitan and Naimipour, 2004) rather than satisficing problems. Therefore, we apply dynamic programming for minimizing the path among stores and genetic algorithms to find the satisficing basket of goods (Roozmand and Webster, 2014). However, the proposed dynamic programming model by (Roozmand and Webster, 2014) must be modified to accommodate multiple stores with different spatial locations (and therefore transport costs).

This spatially-explicit genetic algorithm should take two features into account: the net utility from various items and the shortest path regarding transport costs. We use the Floyd-Warshall algorithm (Neapolitan and Naimipour, 2004) to find the shortest path between any two nodes in a weighted graph, which is explained in details later. That is then included in the total utility for each basket of goods, which allows us to efficiently use a genetic algorithm to find the satisfactory combination of goods and stores at each decision point.

Assume that we have n number of stores. The following vector shows the stores in Equation 1:

$$Stores = < S_1, S_2, \dots, S_n > \quad (1)$$

In which S_i indicates store i. Each store contains items as shown in Equation 2:

$$S_i = \{S_{i}\_item_1, S_{i}\_item_2, \dots, S_{i}\_item_{k_i}\} \quad (2)$$

Which $S_i\_item_j$ shows the jth item in store i and ki is the maximum number of items in store i. Each product has a specific quality and price (Equation 3):

$$item_{ij} =< q_{ij}, p_{ij} > \quad (3)$$

Where $q_{ij}$and p_{ij}show the quality and price of item j of store i, respectively.

Stores are connected to each other by roads. We assume the roads between stores are bidirectional and both directions can have different weights and thus are not symmetrical. The adjacency matrix represents how stores are connected to each other. This matrix is used to calculate the shortest path by the use of Floyd-Warshall algorithm to move from one store to another (one node to another). Figure 2 shows the matrix.

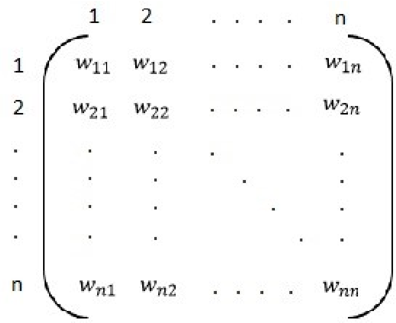

Figure 12. The matrix is used for finding shortest path by the use of Floyd-warshall algorithm

Where numbers 1 to n are used as identifiers for each store (or node), and weight w_{ij}shows the cost for moving from store i to store j. The cost is the sum of all costs including distance, gas, time, etc which for the sake of simplicity we use a simple value w_{ij}.

As we mentioned before we use a genetic algorithm. The key element in genetic algorithm is choosing the structure of the chromosome. The chromosome in our model is defined as follows:

$$CH = \{<item_{11}, item_{12}, \ldots, item_{1k_1}>, <item_{21}, item_{22}, \ldots, item_{2k_2}>, \ldots, <item_{n1}, item_{n2}, \ldots, item_{nk_n}>, <sel_1, sel_2, \ldots, sel_n>\} \quad (4)$$

In which, $item_{ij}$ indicates the item j from store i. $K_i$is a constant value and shows the maximum number of items in the store i. Therefore, the first set includes the items of store 1, the second set contains items of store 2, and so on. The last part of chromosome $<sel_1, sel_2, \ldots, sel_n>$ shows the selected stores. Having stores in the chromosome allows the agent to calculate the costs of travel as part of total cost of each chromosome. sel_i is a binary variable. If sel_i is 0, it means that consumer does not choose the store i and does not buy anything from that store, and if 1, it means that consumer buys at least one item from store i. The total benefits of the chromosome is calculated as follows:

$$TotalBenefits = \sum_{i=1}^{n} \sum_{j=1}^{k_i} n_{ij} * q_{ij} \quad (5)$$

Where i counts the stores, and j the items in that store. Therefore, n_{ij} indicates the number of item j selected from store i, and q_{ij} is the quality of the item. Also, the total cost of the chromosome is calculated as the sum of all prices of items as well as moving costs between chosen stores:

$$TotalCosts = \left[\sum_{i=1}^{n}\sum_{j=1}^{k_i} n_{ij} * p_{ij}\right] + MC \tag{6}$$

MC stands for minimum cost of travel and is the shortest path among all chosen stores. There might be many routes to travel through the selected stores, however, consumer agents in this model optimize their travel cost by selecting the shortest path among the stores from which they choose to buy goods. Thus, for any suite of stores that a consumer would choose to visit, the Floyd-warshall algorithm can be used to find the shortest path. The genetic algorithm then sorts chromosomes based on the total benefit minus the total cost, which includes the minimum travel costs. It is this convention that makes the solution tractable.

Although it may seem overly simple at first, anecdotally, most people do most of their shopping within an area that they know well and have a high degree of knowledge about the travel costs of different routes between stores. Even people who move to a new area will identify the quickest routes after some period of learning. It is possible that this learning process would be path dependent—that is, consumers may not explore all routes, particularly if they are satisficing and therefore their set of routes may depend on where they searched first. However, that is a question for a subsequent model that would combine some form of learning algorithm over the best routes with the genetic algorithm described here. Before adding this additional level of complexity, we solve the problem of deciding on both the basket of goods and the travel costs using the minimum travel cost as calculated by the Floyd-warshall algorithm. The utility of the chromosome is calculated as follows:

$$Utility = TotalBenefits - TotalCosts \tag{7}$$

We also apply the consumer needs as another influential factor on the consumer decision process. There are three possibilities 1) a consumer needs an exact number of each item (as when following a recipe), 2) a consumer needs a minimum number of each item (as when buying dry goods or other consumables with a long shelf-life), and 3) a consumer needs a maximum number of each item (as when buying goods that have a short shelf-life). Therefore, we have three vectors according to the strategy that we are going to choose:

$$Need_{exact} =< e_{11,}e_{12}, \dots, e_{1k1}, \dots, e_{i1,}e_{i2}, \dots, e_{iki}, \dots, e_{n1,}e_{n2}, \dots, e_{nkn} > \tag{8}$$

In which e_{iki} shows the exact number of items ki from store i that a consumer needs. Similarly, we define the minimum and maximum needs on each item as follows:

$$Need_{min} =< m_{11,}m_{12}, \dots, m_{1k1}, \dots, m_{i1,}m_{i2}, \dots, m_{iki}, \dots, m_{n1,}m_{n2}, \dots, m_{nkn} > \quad (9)$$

$$Need_{max} =< ma_{11,}ma_{12}, \dots, ma_{1k1}, \dots, ma_{i1,}ma_{i2}, \dots, ma_{iki}, \dots, ma_{n1,}ma_{n2}, \dots, ma_{nkn} > \quad (10)$$

Therefore, for strategy 1, we use the exact needs vector, for the 2nd strategy we use minimum needs vector and strategy 3 uses maximum needs vector. These vectors control the value for each item in the chromosome.

The key functions of the genetic algorithm are crossover and mutation The main idea of proposed genetic algorithm comes from (Roozmand and Webster, 2014). To do the crossover, all chromosomes are sorted based on their utilities and are paired as parents. The crossover operation is applied on each store of paired chromosomes separately. Assuming that there are k1 items in store 1, the crossover point, which is a randomly chosen value between 1 and k1-1, is selected. Then the selected items of store 1 of two parent chromosomes are substituted based on the crossover point. This operation is applied for all other stores of these two chromosomes and finally two new chromosomes are generated. The crossover function is applied on all other paired chromosomes.

The mutation function is applied on all chromosomes with probability p including parents and offspring. The mechanism for choosing mutation point is like a crossover point and is selected separately for each store. Assuming that the mutation point refers to $item_{ij}$ and the number of $item_{ij}$ at the selected point is v_{ij}. The changes of the $item_{ij}$ at the selected point is randomly chosen in the ranges [0, v_{ij}] for reducing the number of $item_{ij}$ and [0, Avaibale_Budget / p_{ij}] for increasing the number of $item_{ij}$.The equation Avaibale_Budget / p_{ij} guarantees that the cost of item does not exceed the budget. A random binary variable is used to decide to reduce or increase the number of items in mutation function.

After applying the crossover and mutation functions on chromosomes, the chromosomes with highest utility are selected and substituted with initial population. This process is repeated until a satisficing chromosome is found or the agent reaches the limitation for the total number of iterations.

2.1. Example

Let's consider an example. Assume that we have 3 stores with the following items that are connected to each other as shown in Figure 3. As in our first example, the large dot represents the agent's start-point.

$$S_1 = \{i_{11}, i_{12}, i_{13}\} \qquad S_2 = \{i_{21}, i_{22}\} \qquad S_3 = \{i_{31}, i_{32}\}$$

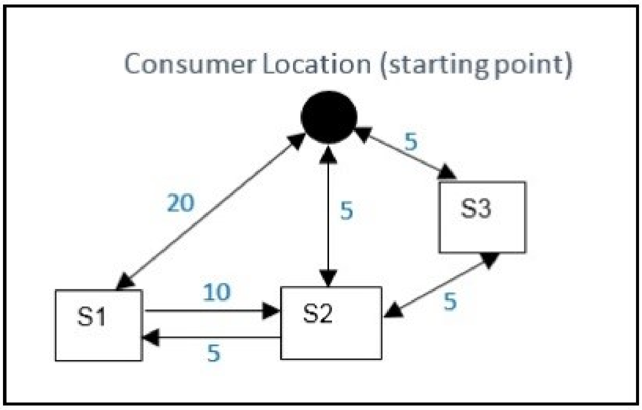

Figure 13. Market example for showing how the algorithm works

Lines with arrows represent one-way routes. Lines with two arrows show bidirectional route. The quality and price of items are as follows:

Table 2. Items used in three stores

Stores	Items	Quality	Price
S_1	i_{11}	10	5
	i_{12}	20	15
	i_{13}	30	25
S_2	i_{21}	15	15
	i_{22}	30	20
S_3	i_{31}	30	25
	i_{32}	50	40

First, let's consider what would happen without travel costs. Assume that we have the following chromosome CH:

Table 3. Structure of a chromosome

CH	1	2	3	4	5	6	7		8	9	10
Items	i11	i12	i13	i21	i22	i31	i32	Store name	S1	S2	S3
Number of item ij	5	2	4	0	0	7	1		1	0	1
	Store 1			Store 2		Store 3			Selected Stores		

This chromosome shows that, in this basket of goods there are 5 of item1, 2 of item2, and 4 of item3 from store 1, there are no items from store 2, and there are 7 of item1 and one of item2 from store 3. The last three cells show which stores would be visited if the agent selects this basket. Number 1 below the name of a store in selected store section indicates that store would be selected and 0 the store would not be selected. Here, stores 1 and 3 would be selected. Total benefits without travel costs for this chromosome is calculated as follows:

$$\text{Total Benefits} = [5*10+2*20+4*30] + [0*15+0*30] + [7*30+1*50] = 470 \quad (11)$$

To calculate the cost of this chromosome we need to add the distance cost to the cost of items. In this example, only stores 1 and 3 would be chosen. Therefore, there are three possible routes for the consumer. The first route is to move to store 1, then go to store 3 and lastly return to the starting location (note that this method could also accommodate an end point that is different from the starting location). Considering the place 0 (zero) for the consumer agent, it needs to follow the route [0, 1, 3, 0] to buy the items contained in the chromosome. Alternatively, the consumer can choose the route [0, 3, 1, 0]. Each of the above routes have different costs. In this example, the agent cannot move from location 1 to 3 directly (or vice versa), but rather must pass through location 2 or location 0. Therefore, we use Floyd-Warshall (Neapolitan and Naimipour, 2004) algorithm to find the shortest path between any two nodes in this weighted graph. This then gives us the value of MC for this specific chromosome.

In this example, we have two paths as follows:

$$MC_1 = Floyd[0,1] + \text{Floyd}[1,3] + \text{Floyd}[3,0] = 10+15+5 = 30 \quad (12)$$

Floyd [0,1] shows the shortest path from consumer location to store 1. There are three ways to get there including routes [0,1], [0,2,1] and [0,3,2,1]. The first route costs 20, the second 10, and the third route 15. Therefore, Floyd algorithm chooses the second route as the shortest path from the consumer location to store 1. Although, consumer passes store 2 to get store 1, it does not buy anything from store 2. The route [0, 3, 1, 0] is another possibility. Therefore, we have:

$$MC_2 = Floyd[0,3] + \text{Floyd}[3,1] + \text{Floyd}[1,0] = 5+10+10 = 25 \quad (13)$$

Finally the MC is calculated as the minimum of MC1 and MC2, min(30, 25) = 25. MC should be added to the total price as part of cost of purchasing this basket of goods. In this example the cost is calculated as follows:

$$\text{Total Cost} = [[5*5+2*15+4*25] + [0*15+0*20] + [7*25+1*40]] + [MC=25] = 395 \quad (14)$$

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Therefore, the total cost is 395 for this chromosome. If the Cost≤budget then this chromosome is feasible and acceptable by consumer. It means that consumer can afford this basket of items, including costs of travel among the stores.

We can then calculate the total utility of the chromosome by subtracting the costs from the benefits:

$$\text{Utility} = 470-395 = 75 \tag{15}$$

This is the value that is assessed by the genetic algorithm as it searches for the best possible combination of goods from all three stores, given travel costs.

3. Results

This section is divided into two subsections. In the subsection 3-1 we use four scenarios to show how the model works, and in subsection 3-2 we utilize the utility and indifference curve based on budget constraint to test the model based on theories in economics.

3.1. Working mechanism

The first scenario is used to test the genetic algorithm to find the optimal or satisfactory basket of goods when all items have the same quality and price, but are located in different stores. Figure 4 shows how the stores are connected to each other.

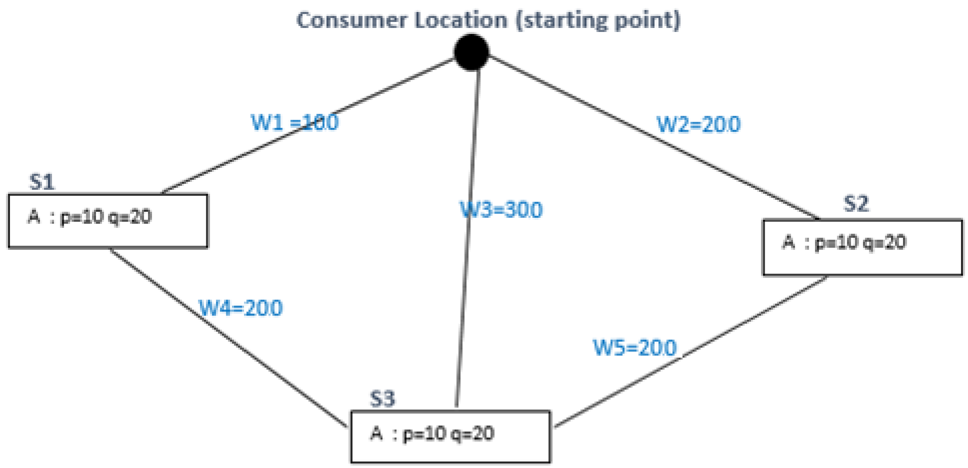

Figure 14. Market situation for scenario 1

As seen in Figure 4, all items in three stores have the same quality and price. The only difference is the distance between the consumer and the store. In fact, Figure 4 indicates that the best store for the consumer is store 1 (S1) which is the closest store to him/her. The consumer's budget is set to 3000 and the algorithm starts with 200 initial chromosomes and runs for 1000 times (Our experience shows that 1000 runs is a good number for finding optimum or near-optimum solution). We've provided the results based on three factors: fitness (utility) improvement, store selection, and route selection.

Figure 5 shows how the fitness or utility of chromosomes are improved to get the near-optimal solutions within a reasonable amount of time.

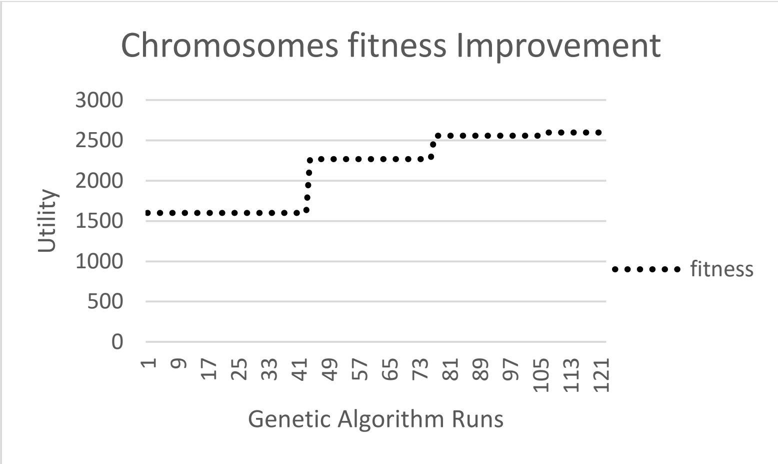

Figure 15. Fitness improvement with the increase of genetic algorithm runs

As we can see in above figure, the fitness of the selected chromosomes generally improves as the algorithm progresses. Each point shows the value of the best chromosomes' fitness. The fitness value is constant for many stages of algorithm's runs. This is because the algorithm does not produce a better solution on those runs. The best fitness value at run 1 is 1600 which belongs to a chromosome in the initial population. Finally, the algorithm ends with a fitness (Utility) of 2600 for the best chromosome, which according to this case, is the highest possible fitness. The algorithm finds the near-optimal solutions after 106 runs. Figure 6 shows how many items are selected from different stores on each run.

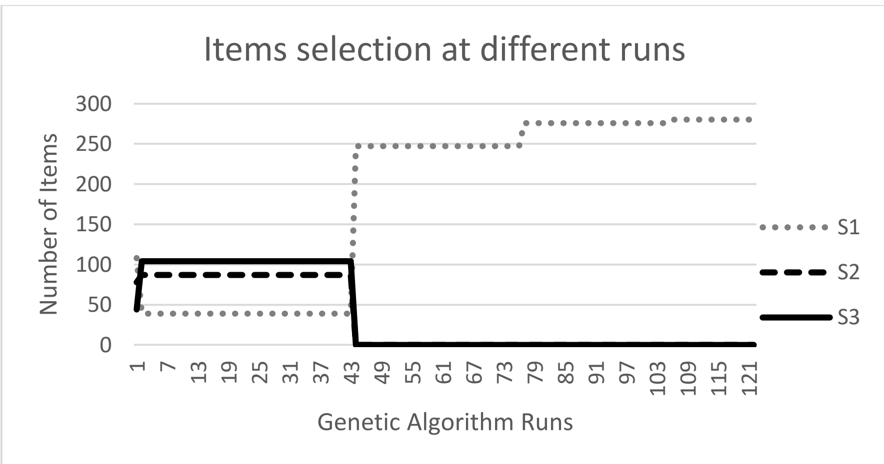

Figure 16. Item selection with the increase of genetic algorithm runs

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Items are selected randomly from all three stores in the beginning. According to the effect of crossover and mutation operations on chromosomes, we see the increase in the selection of item A from store 1 (S1) which is 280 and consequently 2600 (280*20 – 280*10-200) fitness or utility (see figure 5) and 2800 for the cost of items. There is no item selection from stores 2 and 3. Considering the movement cost for the consumer, 100 for going to the store 1 and 100 for going back, we have 200 for the travel cost. At run 44, the consumer agent has 330 units of budget unused. Finally, the algorithm selects 29 more units of item A from store 1 at run 77 and more 4 items at run 106. The more allow the algorithm to run, the more it turns from a satisficer strategy to a maximizer strategy. At this run, 280 items of good A have been selected and the result is 2600 for the utility and 3000 for the costs (2800 for the cost of items and 200 for the travel cost). The consumer agent has spent all of his/her available budget and reached the highest possible utility.

We should note here that the consumer appears to receive negative utility from the transaction because we assume price and utility are equal, ignoring the well-known concept of consumer surplus in economics. Consumer surplus refers to the utility that consumer receives above the amount paid for the good or service. In any market, there will be people who are willing and able to pay more than the equilibrium price. The difference between what they are willing to and able to pay what they actually pay is the consumer surplus (Turnovsky, Shalit and Schmitz, 1980). However, it does simplify the explanation somewhat and has no significant implications for the functioning of the model itself. In other words, the model would work just as well with consumer surplus included, it would just make it a bit more difficult to explain how the system operates.

We also examined the best chromosomes at runs in which there is a change in the fitness of the best chromosome (1, 2, 44, 77, and 106). Table 3 tracks the routes selected at each of these runs as well as the fitness, item costs, and route cost.

Table 4. Traveled stores, fitness, items' costs, and route cost

Run	**Route**	**S1's items**	**S2's items**	**S3's items**	**Fitness**	**Items' cost**	**Route cost**
1	0-S1-S2-S3-0	108	78	44	1600	2300	700
2	0-S1-S2-S3-0	39	87	104	1600	2300	700
44	0-S1-0	247	0	0	2270	2470	200
77	0-S1-0	276	0	0	2560	2760	200
106	0-S1-0	280	0	0	2600	2800	200

We also would like to see the behavior of the algorithm when high quality items are located at a further store. To do this, we changed the quality of item C in store 3. In other words, we substituted item C's attributes from <price = 10, quality = 20> to <price = 10, quality = 100>. The final result of the algorithm is shown in the table 4. It shows that our proposed genetic algorithm leads to store 3 for selecting item C, as it has the highest quality.

Table 5. Maximizing the basket of items by choosing only store 3

Route	S1's items	S2's items	S3's items	Fitness	Items' cost	Route cost
0-S3-0	0	0	240	21000	2400	600

Although store 3 is the furthest store from consumer location, it has the highest quality item (item C), so the consumer agent prefers to buy his/her items from this store in order to maximize its utility (fitness = 8400). In other words, the cost of traveling to the most distant store is outweighed by the improved utility from access to a higher quality item.

Scenario 3: In this scenario we altered scenario 1 by adding two more items to each store with the quality 100 and price 10. If this was the only change, the outcome would not be different. However, we also changed the consumer agent's needs. In scenario 1, there was no limitation on the number of items selected by the consumer agent, so it was able to maximize its utility based on any combination of items. In this scenario, we assume that consumer agent looks for specific amounts of item A and B and has no limitation on item C.

Needs = < A = 55, B=38, C = -1>

The above vector indicates that consumer agent needs 55 units of items A, 38 units of items B, and there is no limitation on item C. Therefore, the consumer agent should exactly buy 55 and 38 items of A and B respectively. The following graph shows that all items A, B, and C are available in all three stores with the same quality and price. Therefore, what matters in this scenario are the distance to each store and the consumer's needs.

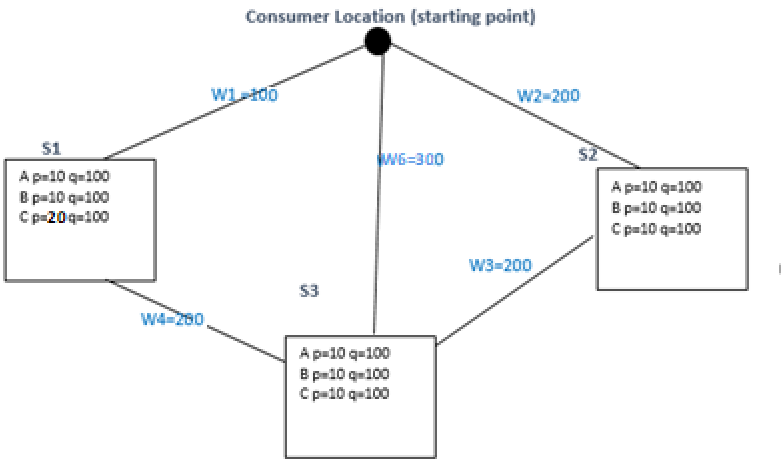

Figure 17. Market structure for scenario 3

The following Figure 8 shows how costs for route and items change over time as the algorithm progresses.

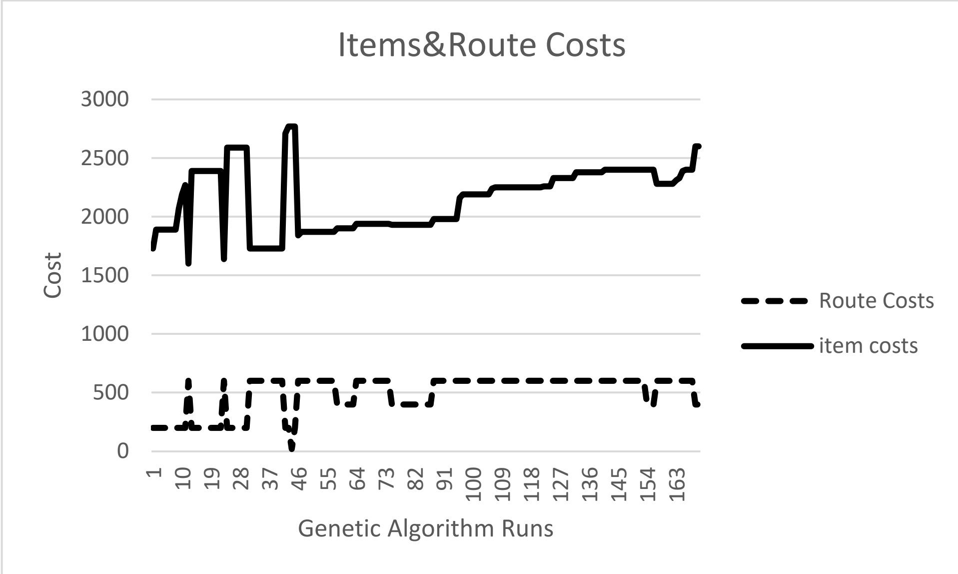

Figure 18. Items cost vs. route cost

As we see in Figure 8, the route cost decreases at the points where the algorithm finds a chromosome with higher fitness. As we described earlier, the chromosome chosen at each run is the best chromosome at that run. There might be some other chromosomes with high fitness that simply are ignored since a chromosome with better fitness exists. The following figure confirms improvement in chromosomes' fitness.

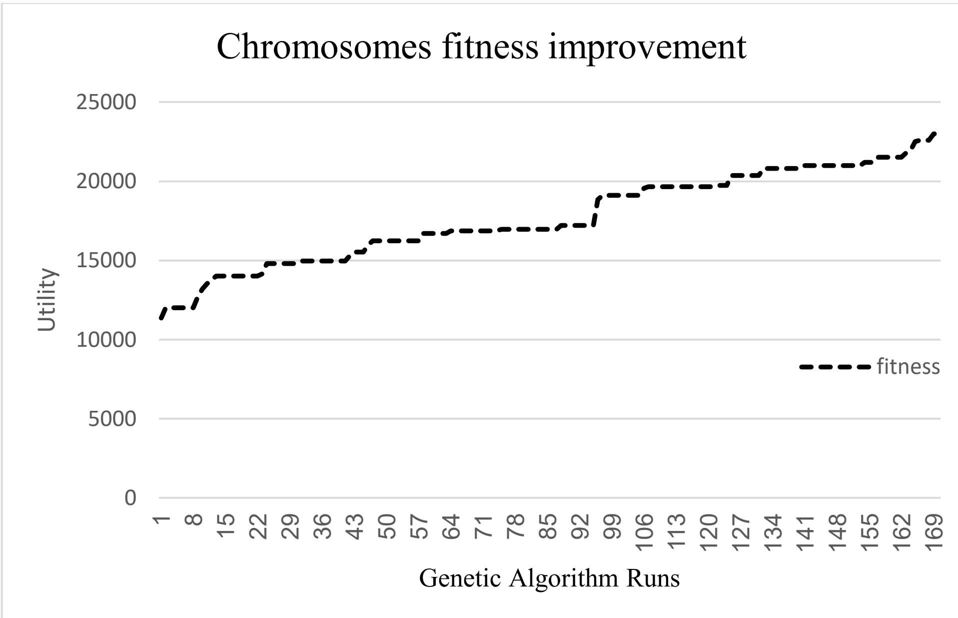

Figure 19. Fitness improvement with the increase of genetic algorithm runs

We see two improvements in the chromosomes. In this scenario, at run 169 the near-optimal solutions is found. This is 63 (169-106) runs longer than it took to find the best chromosome in scenario 1, which makes sense given the changes in scenario 3. In the first scenario, chromosomes can take any number of items, however, in this scenario many chromosomes are disqualified as they produce more than the limitations for items A and B. This consequently reduces the chance for higher fitness chromosomes. At the same time, the total number of chromosomes has increased substantially because now each store can have any combination of the three items instead of just one item. As shown in Figure 10, the result is that the agent quickly learns to purchase large amounts of C from Store 1, while fulfilling its more restricted needs for A and B from different stores, gradually learning which combination of stores provides the highest utility given travel costs.

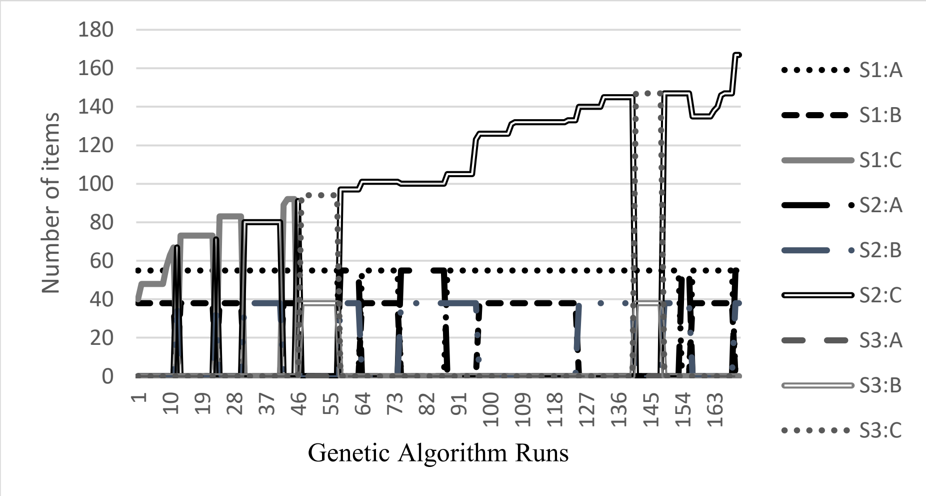

Figure 20. Items selection with the increase of genetic algorithm runs

Also, table 5 shows how the route is modified at each run where there is a change in chromosome fitness. The algorithm exactly chooses 55 units of item A, 38 units of item B, and 167 units of C from store 2 which is the closest store to the consumer. The reason for choosing store 1 and 3 is that all prices and qualities of all goods are the same in all stores. Therefore, it is quite reasonable to choose store 1 for purchasing all items as it is the closest one. Thus, this test scenario shows that algorithm is also able to consider the consumers' limitations for specific number of items.

Table 6. Results for when consumers have limitations on exact number of items

Run	Route	Store 1			Store 2			Store 3			Fitness	Items cost	Route cost
		A	B	C	A	B	C	A	B	C			
1	0-S1 -0	55	38	40	0	0	0	0	0	0	11370	1730	200
42	0-S1-0	55	38	89	0	0	0	0	0	0	15290	2710	200
141	0-S1-S3-0	55	0	0	0	0	0	0	38	147	21600	2400	600
166	0-S1-0-S2-0	55	38	0	0	0	147	0	0	0	22600	2400	600
169	0-S2-0	0	0	0	55	38	167	0	0	0	23000	2600	400

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Scenario 4: In this scenario we would like to test strategies 3 and 4. Therefore, we added item D = <price = 10, quality = 150> to store 3 in the above scenario. Also, we define the consumer needs for both strategies as follows:

Strategy 3: $Needs_{min}$ = <A = -1, B = -1, C= -1, D_{min} = 3>

Strategy 4: $Needs_{max}$ = <A = -1, B = -1, C= -1, D_{max} = 3>

These two needs vectors indicate that there is no limitation on items A, B, and C. However, in strategy 3 the consumer needs at least 3 units of item D. It may choose to buy more than 3 units of item D but cannot choose to by fewer. Based on this strategy, the algorithm finds the following combination of items.

Table 7.Results for when consumers have limitations on minimum number of items

Route	**Store 1**			**Store 2**			**Store 3**				**Fitness**	**Items cost**	**Route cost**
	A	B	C	A	B	C	A	B	C	D			
0-S3-0	0	0	0	0	0	0	0	0	0	240	33000	2400	600

Although it is furthest from the consumer's start location (cost = 600), the consumer must visit store 3 since it is the only store which sells item D. It will also buy all other items from that store since there is no difference in the quality and price of A, B, and C in any of the stores. The genetic algorithm has chosen 240 units of item D. There is no contradiction with the problem definition since consumer has bought at least 3 units. In this execution of the algorithm, it has selected 0 of A, 0 of B, 0 of C, and 240 of D, but it could have selected any other combination of items with D >=3 and still achieved optimum fitness.

We see a different behavior of our genetic algorithm in the maximum strategy (#4). The consumer does not have purchase any of item D so it also does not have to pay the high travel cost to visit store 3. If consumer happens to buy item D, it cannot buy more than 3 units but given the location of the item, it is not likely that the algorithm will select a chromosome that contains item D. Table 7 shows the result with this strategy:

Table 8. Results for when consumers have limitations on maximum number of items

Route	**Store 1**			**Store 2**			**Store 3**				**Fitness**	**Items cost**	**Route cost**
	A	B	C	A	B	C	A	B	C	D			
0-S1-0	177	18	85	0	0	0	0	0	0	0	25000	2800	200

As expected, the consumer only visits store 1 and buys only items A, B, and C. As we compare results in table 7 and table6, consumer gains 8000 units of utility which is more than the 25000 units that result from strategy 3.

3.2. Aggregated results for utility and indifference curves

Since it is hard to validate the model based on real data, we instead rely on well-established economic theories. In the next two scenarios, we show how our model produces believable utility and indifference curves based on budget constraint for a set of consumers (100 agents). This includes examining differences in model behavior depending on whether or not we assume agents are maximizing or satisficing.

Before moving on to this analysis, we transition to a generalized version of the model used in the examples above. For this, we use a simple complete graph including four nodes: consumer location, store 1, store 2, and store 3. It is possible to use more complicated graphs but a simpler set up makes it easier to interpret the behavior of the agents and the model.

Figure 11 shows the stores with different distances. All nodes are connected to each other with edges d1 to d6 as shown in this figure. Each node indicates a store, and each edge shows the distance between two stores. This generalized model will also allow us to complete sensitivity analysis as described in later sections.

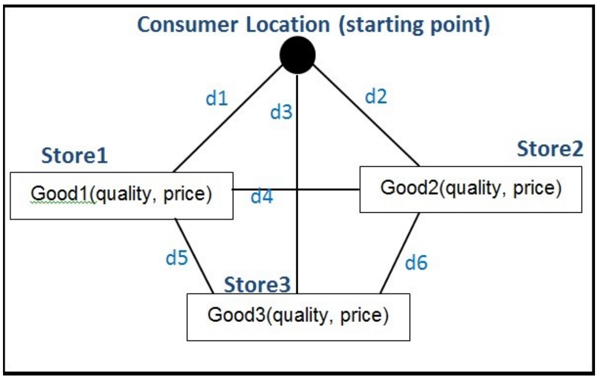

Figure 21. Market structure for validation

3.2.1. Utility

In this section, we test the effects of income (budget constraint), item quality, and price on aggregate utility. First, we consider the effects of price changes and budget constraints, holding item quality and distances constant. Our base values for item attributes and distances can be view in Table 8. We start with a skewed quality structure similar to scenario 2 above, where one store has an item of very high quality but low price and the other two stores have two lower-quality items at the same price. Note that the travel costs in this model are lower, reflecting relative proximity to stores (e.g., living in an urban or suburban environment) and allowing us to focus more on other factors in the decision process.

Table 9. Results for when one item's utility dominates other items and there is no substitution

Stores	Quality	Price	Distances					
			d1	d2	d3	d4	d5	d6
Store1 (Good1)	100	10	5	10	15	10	5	5
Store2 (Good2)	40	10						
Store3 (Good3)	40	10						

We generate 100 agents, each with budget of 1000 units. Because the distances are similar and the net benefit of good1 is so high, all agents decide to spend all of their budget on good1 and therefore only shop at store1. Next, we run the model multiple times, increasing the price for good1 5 units at each run; that is 15, 20, 25, and 30, respectively. Then, we run the model again with the same price variations but with a lower budget constraint of 500 units per agent. Figure 12 shows the resulting changes in aggregate utility.

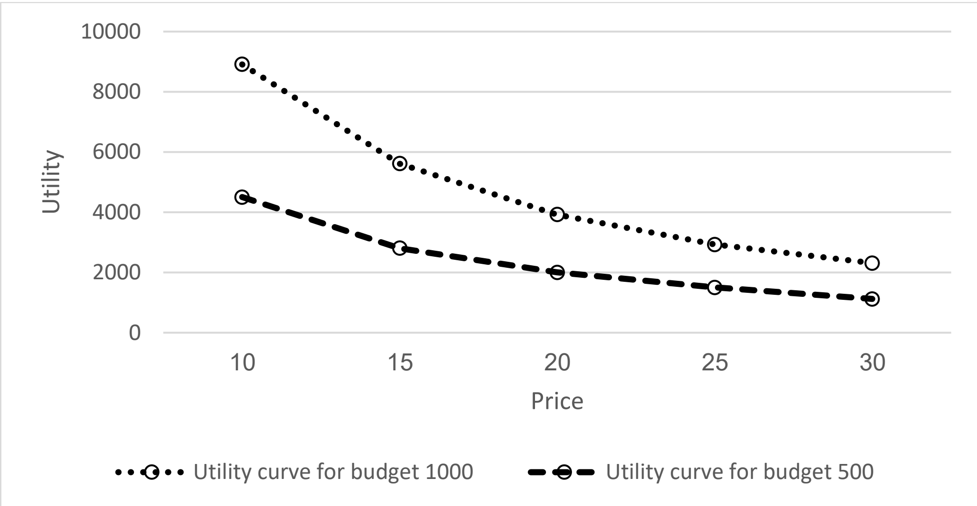

Figure 22. Obtained utility for budget 1000 and 500

The outcome is not surprising since there are no substitutes for good 1. As the price increases, agents can buy less of good1 but they do not switch to other goods because the net benefit for good1 is still higher than for goods 2 and 3. When we lower the budget constrain, the utility curve shifts down and flattens somewhat, demonstrating the expected effect of lower incomes on consumer purchasing decisions.

The results above assume that consumers are maximisers, but most consumers are satisficers. Instead of spending considerable time and effort seeking out a basket of goods with maximum utility, they select any affordable basket of items with utility larger than their satisfaction threshold (Roozmand and Webster, 2014). In this test we aim to show that how satisficing behavior can change the purchasing choices of consumers when goods vary by price, quality, and costs of travel. The following goods were generated for this test.

Table 10. Items attributes for testing satisficing behavior

Stores	Quality	Price	Distances					
			d1	d2	d3	d4	d5	d6
Store1 (Good1)	11	10						
Store2 (Good2)	12	10	5	10	15	10	5	5
Store3 (Good3)	11	15						

Given that travel costs are negligible, store 2/good 2 clearly can provide consumer agents with the highest utility when they spend their entire 500-unit budget. To investigate the effects of satisficing, we vary the satisfaction threshold by specifying it as a percentage of the maximum possible utility available. As shown in Table 10, we tested three satisfaction thresholds (82%, 46%, and 30% of maximum respectively.

Table 11. Results for testing satisficing behavior

Run time	Visited stores	Basket	Distance cost	Utility	Satisficing threshold	Budget
Run 1	0- 2 - 0	Good2=48	20	76	Maximizer	**500**
Run 2	0-1-2-0	Good1=6 Good2=41 Good3=0	25	63	82% of Max Utility	**500**
Run 3	0-1-2-3-0	Good1=12 Good2=32 Good3=2	25	35	46% of Max Utility	**500**
Run 4	0-1-2-3-0	Good1=4 Good2=34 Good3=6	25	23	30% of Max Utility	**500**

In the maximizing scenario (Run 1), the consumer selects the best basket of items including good 2 from store 2, and it gets a total utility of 76, which is the highest possible utility. Store 2 is farther away than store 1, but the consumer prefers to purchase from store 2 since the higher utility cancels out the higher travel cost. If we instead allow the consumer to satisfice at 82% of highest utility, it will select the first basket of goods that it finds which has a total utility of 63 or higher. In this case, the agent chooses both stores 1 and 2 for its purchases. It buys 6 of good 1 and 41 of good 2, reducing utility both by buying lower-utility items and by traveling more than necessary. As we decrease the satisfaction threshold to 46% and 30% in Run 3 and 4, respectively, we see that the consumer agent chooses even low quality items from other stores with lower quality. As expected, total utility decreases as the satisfaction threshold decreases, reflecting consumers' real-world preferences for convenience and minimizing transaction costs.

3.2.2. Indifference curve based on budget constraint

Consumers can get the same utility from different combinations of goods. Economists use indifference curves to represent these tradeoffs using two representative goods. In this section, we aim to check the purchasing behavior of consumer agent encountering two goods where different combinations of goods hold the same utility. To maintain tractability, we limit this analysis to only two goods: Good 1 with quality 10 and price 10, and Good 2 with quality 5 and price 5 (see Table 11). We do not test the goods in other stores, as it is difficult to interpret results with so many variables.

Table 12. Item's attributes for testing indifference curve

Stores	Quality	Price	Distances					
			d1	d2	d3	d4	d5	d6
Store1	Good1(10) Good2(5)	Good1(10) Good2(5)	5	10	15	10	5	5
Store2	-	-						
Store3	-	-						

In this test setting, purchasing two items of Good2 has the same utility as purchasing one item of Good1. Therefore, there are many combinations which have the same utility for the consumer agent. We have tested the model for 100 times with budgets 1000 and 500. The results are shown in Figure 14.

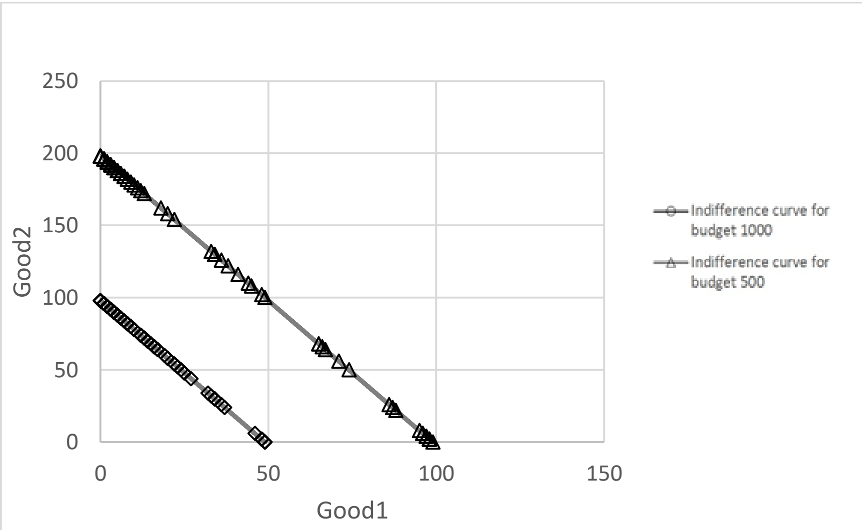

Figure 23. Indifference curve based on budget constraint for good1 and good2

With a budget constraint of 1000, and travel cost of 10 units, the consumer can use 990 units of its budget for purchasing goods. The indifference curve shows a clear 2-to-1 tradeoff between good 1 and good 2, with each combination maintaining the maximum utility at of 188 at this budget constraint. Lowering the budget constraint to 500 shifts the indifference curve to the left but does not alter the slope of the curve. Traditionally, indifference curves tend to be convex to the origin, reflecting diminishing marginal utility, but adding this dimension to our agent's behavior is a task for future work.

4. Conclusion and future work

In this paper, we propose a genetic algorithm equipped with the Floyd-warshall algorithm to simulate satisficing or maximizing consumer behavior. We applied a chromosome structure including items, utilities, and routes' costs to show a basket of items selected from different stores and calculate the total cost. The Floyd-Warshall algorithm helped find the shortest route among all possible routes from selected stores. The main novelty of this paper is that it proposes a genetic algorithm with a specific structure of chromosomes to solve this complex problem in economics. We simulated the model, showed how the model works in different scenarios, and presented that the model reproduces results compatible with theories in economics.

Although we believe that the model is well-designed and works reasonably well for this problem, it has two main weaknesses. First, the proposed algorithm is slow for a large and complex graph, including stores and their distances, so it is not suitable for modelling a big city with a large number of stores. Finding a more efficient approach would be a good next step in model development. Second, as the number of nodes and items increases, it becomes more and more difficult to assess the effects of changes in the model's parameters on model outcomes. More in-depth analysis is needed to fully understand how the model works, and then it should be possible to make the model more realistic by adding cultural knowledge, more diverse personal preferences, and other determinants of consumer behavior.

Disclosure statement

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The Application of Strategic Choice Approach (Case Study: Electricity Shortage Problem Caused by Cryptocurrency Mining in Iran)

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ABSTRACT

The continuous and round-the-clock operation of cryptocurrency mining devices generates significant heat that requires powerful cooling systems. Therefore, the main problem of mining is its high electricity consumption and energy usage. Unfortunately, due to the lack of planning by the country's officials, we are facing the problem of electricity shortage, which the growing digital currencies have exacerbated. Since decision-making in the real world (including the electricity shortage problem caused by mining) is complex and uncertain due to various influential factors, this research aims to apply a strategic selection approach to decision-making and provide solutions to solve the electricity shortage problem caused by cryptocurrency mining in Iran. In this study, the Strategic Choice Approach (SCA), one of the soft operational research methods, has been used for analysis, structuring, and decision tree development. For this purpose, four methods (styles) of SCA, which include ten steps, have been implemented. A working group consisting of twelve experts and stakeholders in digital currencies, facilitated by the researchers of this study, has been formed, and specific flowcharts and labels have been used. According to the SCA method, decision-making areas, decision options, areas of uncertainty, exploratory options, and decision trees have been designed. Finally, a ″commitment package″ (″improvement package″) has been proposed to provide practical solutions. This article provides solutions for solving the electricity shortage problem caused by cryptocurrency mining through the SCA. For this purpose, specific tasks have been assigned to the Islamic Consultative Assembly, the Ministry of Economy, the Ministry of Energy and Foreign Affairs, and the government, excluding the mentioned ministries and some key players in digital currencies, which should be carried out in the present and future. By structuring the research problem through the SCA method as one of the soft operations research methods, the readers and users of this research will learn more details and dimensions of the mentioned method, contributing to expanding their knowledge of soft operations research. Although the SCA method has been implemented in Iran and other countries for a long time in various social and organizational issues, the diagrams, shapes, and tables used to implement SCA in this research contribute more to the readers' knowledge. It also helps to localize this method and other research done in the country.

Keywords

Keywords: Cryptocurrency mining, Strategic choice approach, Decision making, Uncertainties.

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1. Introduction

The introduction of cryptocurrencies as a new form of money has attracted tremendous attention in recent years. This new financial paradigm relies on miners to validate transactions by running their Cryptocurrency Mining Devices (CMDs). Nowadays, the mining business's significant profitability has tempted many private players in the electrical industry to employ their renewable energy resources to mine digital currency (Hajipour et al.,2022). Cryptocurrency miners consume much electrical energy to run their CMDs. These CMDs have a powerful computational capability to solve a complicated mathematical problem that validates the transactions between the digital currency's holders (Ghaebi Panah et al., 2022). In response, they are rewarded in digital currency to compensate for their expenditures. Therefore, one can simply deduce that cryptocurrency miners convert electrical energy to digital currency by running their CMDs (Hajipour et al.,2022). In other words, "miners" of cryptocurrencies are electromagnetic alchemists whose activity rapidly increases the consumption of each megawatthour of electricity.

The intensive calculations of their devices (miners) form the encrypted virtual currency and create new coins as payment. This work uses a staggering amount of electrical energy (Fairly. 2017). Along with the rapid growth of cryptocurrency mining worldwide, the number of digital currency miners in Iran is also increasing. Especially due to low electricity prices in Iran, the footprints of foreign miners can also be seen, in addition to the cheapness of electricity miners' feet on cattle ranches. Agricultural lands and fields have been opened, and underground home mining has caused growth. Electricity supply in Iran is faced with the problem of reducing the production of hydroelectric power plants due to the decrease in rainfall and the lack of planning for more electricity production. Electricity supply in Iran with the problem of reducing the production of power plants water has been faced due to the decrease in rainfall and lack of planning to generate more electricity.

Also, this rapid growth of cryptocurrency mining, which requires significant electricity generation, worsens the already bad electricity shortage. Lack of electricity and its frequent blackouts. It has become a disturbance in citizens’ daily life processes, from home power outages to power cuts in the offices, the postponement of the client's work, and the closure of factories and companies that add to the country's problems. Then, the increase in electricity consumption due to the extraction of cryptocurrency, even in a situation where the country has limited direct electricity production, will put additional problems on the shoulders of the people and the country.

Now, the question arises: What is the solution? And how should this problem be solved? Answering these questions becomes more difficult when it is known that many stakeholders have faced problems, conflicts, and uncertainties. For example, some stakeholders are 100% in favor of cryptocurrency mining and say that the government should produce more electricity. But some ordinary people are seriously opposed because of the problems caused by blackouts. Also, questions such as: Why is the government's policy unclear about digital currencies? Why have the country's main custodians of digital currencies not been identified yet? There are some doubts and uncertainties about the issue. To better understand the many stakeholders of cryptocurrencies and analyze conflicts and uncertainties. It is necessary to know what factors have caused the rapid growth of cryptocurrency mining in Iran. The skyrocketing inflation rate in recent years has caused many people to maintain the value of their money. They engage in some speculative activities, which causes liquidity to wander occasionally in currency, coin, and car markets, and the stock market increases. They seek not to lose the value of their capital. There were other markets where they could make more profit. It was here that much from money; people moved towards digital currencies, of course, speed. The spread of digital currencies worldwide and its impact on the people of Iran should not be underestimated. Remember, maybe the low price of electricity in Iran sometimes causes the opening of rejection. The presence of foreigners was introduced in the country as another influencing factor.

Now, the main question of this research is, what is the solution? In a country facing a shortage of electricity and, on the other hand, people are involved in the emerging phenomenon of cryptocurrency mining (which consumes a lot of electricity), how can people address the problem and provide solutions to improve the situation? Should people legalize cryptocurrency mining like people in many other countries? Should people increase their electricity production capacity? and so on. Many people see the harsh confrontation of law enforcement and the judiciary as not a solution but also an additional cost on the shoulders of the courts and law enforcement. Some economists argue that cryptocurrency mining can be the best source of income for the government in the conditions of the country's sanctions. Several solutions are proposed, none of which can provide a comprehensive solution. Solving these problems and providing practical solutions have been the main reasons for the formation of this research. Therefore, considering the structure and position of the problem, it seems that the best option is to use the SCA as one of the research methods in soft operations.

Every science relies on philosophical foundations and has a special methodology based on the assumptions of ontology and epistemology. Based on different philosophical assumptions, our attitude toward the world and reality, the problems in the real world, and the prescriptions prescribed to solve these problems are different (Hosseinzadeh and Mehrgan, 2012). Therefore, according to the situation of cryptocurrencies in Iran, to improve its situation, it is better to use the science of operations research because in operations research, by adopting a special attitude to organizational and social issues, the way to solve problems will be completely different. But which paradigm should authors use in operations research? Authors definitely cannot say that the life of classical operations research (hard operations research) has ended, and are these methods not capable of being used in complex problems involving people with different attitudes and interests, as soft and critical researchers claim (Hosseinzadeh and Mehrgan, 2012). However, nowadays, authors see much use of research techniques in classical operations, and according to its basics, authors may be able to use hard operations research to solve the research problem. But why do the researchers in this study use soft operations research to implement cryptocurrency mining? In order to answer this question, authors must express some concepts and basics of soft operations research in order to reveal their compatibility and validity to solve the research problem:

Soft operations research, or problem structuring methods, is a systematic approach to dealing with problematic situations. This approach provides a framework for managing and managing poorly structured issues or issues that cannot be easily quantified (Definition of the Operations Research Society of South Africa (ORSSA).

Soft operations research methods mainly use qualitative, rational, objective, and structured methods to interpret, define, and discover different perspectives on an organization and its issues with a deeper look. This method leads to negotiation, learning, and ultimately more understanding and uses these perceptions to improve the conditions of complex issues (Hosseinzadeh et al.,2012).

Therefore, considering the many stakeholders of cryptocurrency miners, the emergence of many conflicts of interest between them, and the many uncertainties that exist in the issue of cryptocurrency mining in the condition of electricity shortage, we need to structure the research problem with soft operations research. In other words, since we need to identify the conflicts and uncertainties of the stakeholders in making better decisions with some research topics in soft operations, by examining and explaining them, the researchers will make a better implementation and, as a result, provide a more appropriate solution.

Among the various paradigms of soft operations, the SCA is due to the look and structure, qualities required for managing various uncertainties are selected for further study and investigation (Ram et al., 2011). The SCA is chosen for further study and investigation due to its special view and structure for managing various types of uncertainty (Hosseinzadeh et al., 2012). SCA is used to tackle the decision problem in terms of structuring the problem and defining scenarios (Lami and Todella, 2023). The main goal of the SCA is to deal with complex decision issues and make decisions by considering different methods of uncertainty management and dealing with each type of uncertainty differently (Azar et al., 2016). The paper proposes using the SCA to structure the decisions and provide a solution to the lack of electricity caused by the cryptocurrency mining process, which is done by individuals and partly supported by meetings and interviews with DMs, experts, and stakeholders. The method is employed as a design tool to provide alternative transformation scenarios. It represents a way of approaching the challenge of planning in an uncertain world, eliciting guidelines and strategies.

Furthermore, it produces an actual project or transformation in a physical sense. By investigating what occurs during the different micro-processes with the interviewees, we focus on some behavioral issues and effects of the context, the models of the application, and the different entities involved in the interventions (Todella et al.,2018). The main objective of the SCA is to deal with complex decision-making issues and decision-making by considering different methods of managing uncertainty and dealing with different types of uncertainties differently. According to the stated contents, it seems that using the SCA is the best option for deciding on the current research problem. The present research is important and innovative due to its contribution to expanding the knowledge of soft operations research. In this way, it has been tried to describe the SCA as one of the soft research methods.

It should be noted that the current research has frequent validation due to the fact that it is evaluated and validated by the opinion of experts and stakeholders (Hosseinzadeh and Mehrgan, 2012). In this research, prominent books in this field, domestic and foreign articles, official statistics, magazines and reliable domestic and foreign websites have been used to collect data.

This research uses the SCA of four methods (style) that includes ten steps. It can be implemented. Also, a working group consisting of twelve experts and the beneficiaries of digital currencies has been formed with the facilitation of the researcher of this research. The end of the "commitment package" (improvement) is proposed in order to provide a practical solution.

2. A review of literature and research background

Problem Structuring Methods (PSMs) belong to the family of facilitated modeling approaches, a term that some soft OR scholars and consultants use to define approaches that combine group dialogue, facilitation, and participatory modeling (e.g., Franco and Montibeller, 2010; Franco and Rouwette, 2011). The application of PSMs involves a group of stakeholders who seek to address a complex and uncertain problem situation of common (Lami and Tavella,2019). The SCA is one of the types of problem structuring methods that we will explain:

The origin of the SCA can be found in the experience gained from two research projects in the 1960s. These are two projects, and several researchers have many records. They cooperated differently to understand the behavior of strategic decision-makers while making decisions and studied and talked with them about the dilemmas they constantly face. SCAes were discussed. One of these projects related to communication in the industry (Crichton, 1966), and another related to the policy of city administration (Friend and Jessop, 1977). Both projects were carried out by research teams from the Operational Research and Sociotechnical Institute that was named ″Tavistak″. The perspective gained during the implementation of these two projects later became the foundation for developing operational methods used in decision-making processes. One of the scientists involved in these research projects is ″John Friend″. He researched policy-making in municipal governments and was one of the pioneers of the SCA in planning under uncertainty. Friend, with the collaboration of ″Allan Hikling″, published his experiences with the workshops of the SCA in his book “Planning Under Pressure” (Friend and Hickling, 2005). Gradually, these methods became widespread, and today, they are used to solve decision-making problems in many parts of the world and various organizational and inter-organizational environments. However, this approach is very effective and can be implemented quickly and informally, even at lower decision-making levels.

In SCA, to manage the complexities, contradictions, and uncertainties of the decision-making process, the four complementary states of “shaping”, “design”, “comparison”, and “choosing” are definitions. It has been shown that they are connected in dynamic ways (Figure 1). The inputs to this process are multiple problems, and the outputs are multiple decisions. The formulation (shaping) of the structuring of the fields of authority and relationships between them is done, and in the state of design of possible solutions according to the compatibility between the options of the fields, different options are designed in the situation of comparing these solutions in terms of consequences. Their predictability is compared by considering the range of related uncertainty. In the state of discretion about conscious management and uncertainty over time, how moving forward by balancing flexibility against commitment in a closed format progress is determined in the first two situations, the field of discretion is open to decision-makers, and in the two final situations of this field in order to reach an action agreement is limited. Formulation situations, political authority over design situations, and technical comparison are considered during decision-making. Through circulation or changing the state, decision-makers can move from one state to another.

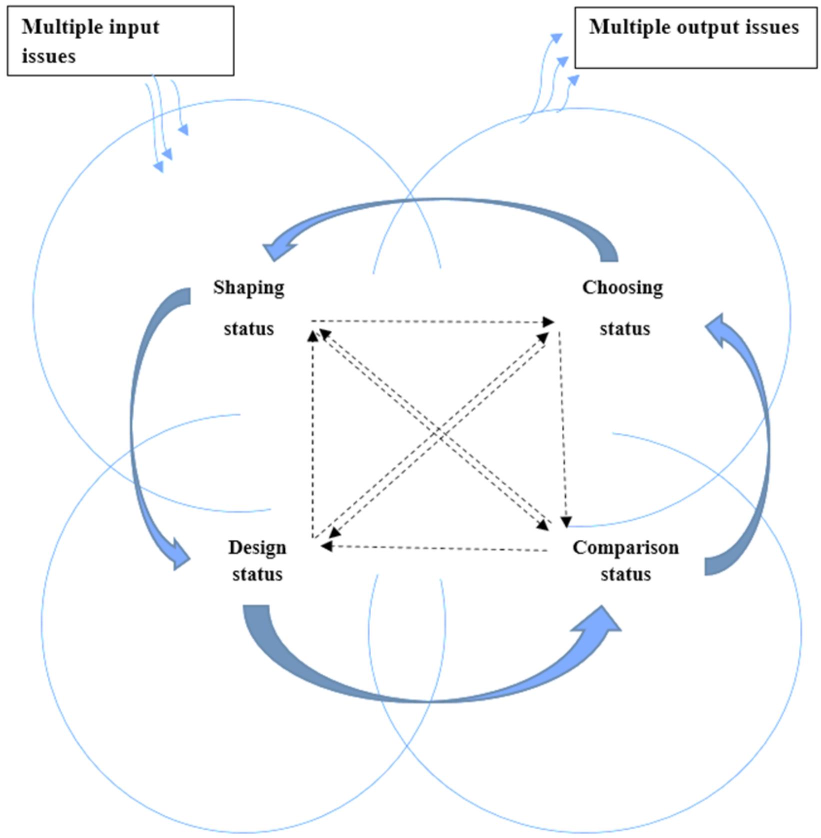

Figure 24. Input and output status SCA

Decisions are always faced with different. According to the strategic approach, different uncertainties should be dealt with differently. There are three general categories of uncertainties:

A. Uncertainties about our working environment(UE): This type of uncertainty can be managed through relatively technical responses, such as exploration, scientific research, and cost prediction.

B. Uncertainties about our Guiding values (UV): This type of uncertainty requires a political response. Such a response can take the form of a request from a higher authority for policy guidance, a structured exercise to clarify stated goals, or a program of consultation.

C. Uncertainties about choices on related agendas (UR): This type of uncertainty arises from the consequences of a decision.

Figure 2 summarizes the three initial types of uncertainties, each requiring a different kind of response. This image represents a snapshot of the overall view at any given moment when one or more decision-makers or a level of difficulty in decision-making are present. Therefore, the image may appear static, but it actually has a significant impact on the dynamic movement of any complex decision-making process.

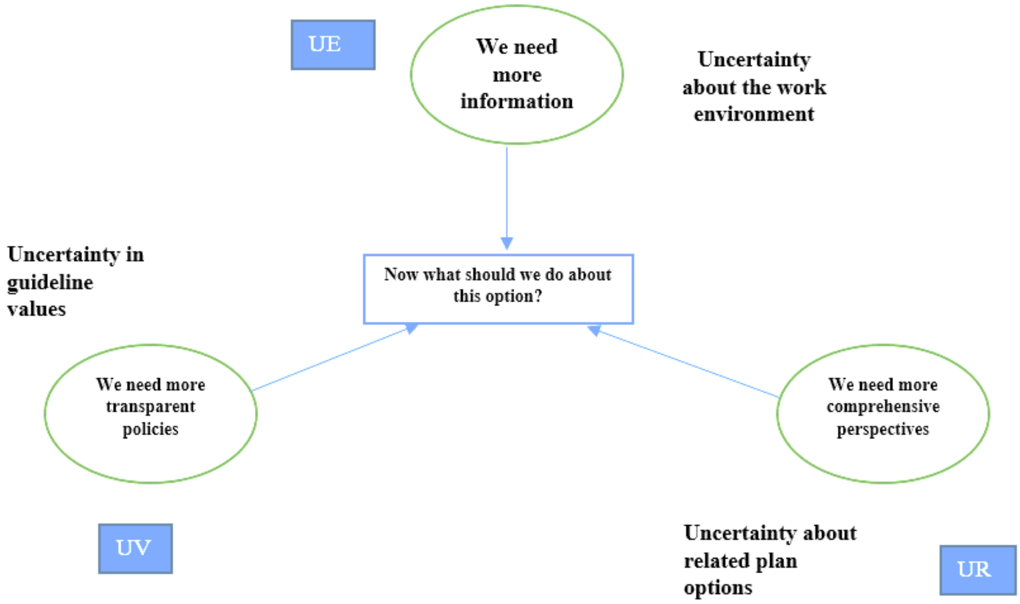

Figure 25. Three types of uncertainty in decision-making

Based on studies conducted, the strategic decision-making approach has been used in various researches, such as decision-making in economic issues (Collins and Zhu, 2005), public projects (Rolando, 2015), design and architecture (Todella et al., 2018), a multi-methodological combination of the SCA and the analytic network process (Lami and Todella, 2023), and so on.

3. Stages of implementing the SCA

3.1. Methods of shaping

Step 1: Determining decision-making areas

SCA allows actions of detection through the shaping mode (Friend and Hickling, 2005; Gomes Júnior and Schramm, 2021; Smith and Shaw, 2019). The set of decision areas enables consideration of the main concerns that the irruption of a new problem implies and makes them visible: through the shaping mode, it is possible to have a clearer representation of the problematic situation. The shaping mode in SCA relates to the "perplexity" phase, where the problem comes to the fore. This first mode of SCA aims to support detecting all the issues related to the problem (Lami and Todella, 2023).

In a conventional strategic decision-making workshop, the facilitator begins the program by creating a common understanding of the main decision-making areas. This process can lead to extensive discussions, enabling participants to learn from other perspectives. This study chose a group of 12 stakeholders and digital asset experts for the workshop. In this workshop, participants were arranged in a semi-circle facing the facilitators. The researchers of this article were introduced as the facilitators of the workshop. The session starts with the facilitators establishing a baseline concept of "decision areas" regarding cryptocurrencies. During the sessions, some issues lightly influenced by participants' input are better recorded in a separate list called "Uncertainty Areas." It is necessary to identify different types of uncertainties. To better identify decision-making areas and understand the issues, their root causes were explored and presented in Table 1. It should be noted that in all SCA stages, shortened titles of decision areas are used instead of using abbreviations for each decision area. Additionally, a question mark (?) is placed before each decision area's title for identification purposes.

Table 13. Problem, root causes, and decision areas (Nejati et al.,2018)

Problem	The root causes of the problem	Decision-making areas	The title of the areas - decision-making
The need for fundamental transformation in the field of digital currencies	-In recent years, with the increase in popularity and public interest in digital currencies, the speed of approval and implementation of regulatory laws has not increased -The government and parliament have not looked at it as a new industry -In recent years, the lack of electricity caused by the growth of cryptocurrency mining has created problems close to a crisis for the country	What are the most important transformative measures in the country's field of cryptocurrencies?	Transformational actions?
So far, the government has focused more on mining and has not paid attention to other aspects of blockchain.	-The problem of lack of electricity caused by the growth of underground mining -He does not consider blockchain as a transformative technology that pays attention to its other dimensions -The abandonment and uncertainty of cryptocurrency exchange and payment platforms inside the country	What solutions exist for the government to comprehensively focus on all aspects of the blockchain, not just mining?	The government's focus on all aspects of the blockchain?
Unreasonable growth of illegal (underground) mining	-Increasing home extraction -Prohibition of legal mining and reduction of issuing mining licenses by the government increases illegal mining -Low electricity prices in Iran -Absence of an intelligent, online, and real-time monitoring system of electricity consumption at all levels of production, transmission, and distribution	What are the optimal and basic solutions to prevent illegal extraction?	What are the basic and optimal ways to prevent illegal mining?
	- Subsidies paid by the government		

Problem	The root causes of the problem	Decision-making areas	The title of the areas - decision-making
There is not enough electricity to mine cryptocurrencies, and the low electricity tariff encourages people, including foreigners, to mine in Iran.	- So far, no proper planning has been done to provide electricity through renewable sources such as solar, wind, and nuclear. - The electricity tariff is not different for mining in the cold and hot seasons - The power of the private sector has not been used to produce electricity	What work method should we use to supply the required electricity and create a suitable and optimal tariff system?	Appropriate and optimal electricity supply and price solutions?
The threat-oriented, passive, mandated, negative, and permission-oriented view of the field of cryptocurrencies by the government	-So far, the government has not reached a consensus on cryptocurrencies -Lack of appropriate and codified laws -Failure to pay attention to the concerns of the private sector in the field of digital currencies	How will the threat-oriented, passive, mandated cryptocurrency change to an opportunity-oriented, active governance system and new regulatory methods?	Changing the government's view of the state of cryptocurrencies?
Weakness in macro-management of crypto-currencies, the existence of disturbances in the field of the mining industry	-Failure to estimate the positive effects of the digital currency industry, especially from the aspects of macroeconomics, energy, and environment -Lack of preparation of legal, software, and hardware infrastructures for the implementation of macro policies regarding cryptocurrencies. -Illegal entry of mining equipment and devices, or counterfeit, scrapped devices and equipment -Absence of appropriate and codified laws in the field of extraction, which is a sign of the government's lack of planning	What solutions can people use to address the weaknesses in the macro management of cryptocurrencies and solve the country's problems?	Appropriate solutions to cover the weakness in the macro management of crypto-currencies and solve the mining problems ?
The inappropriateness of the government's regulatory policies in asset management and asset maintenance has created risks for people's activities in the cryptocurrency market.	-Service infrastructures, relevant technologies, investment funds, and supporting institutions have not been established in this case -There is no proper insurance and tax mechanism in this case -It is not clear whether cryptocurrencies are currency or assets (if it is a currency, it is related to the central bank, and if it is an asset, it is related to the stock exchange) -Lack of development of institutional capacities and capital market tools	What solution is suggested for improper regulation of asset management policies and the keeping of cryptocurrencies, which currently creates risks for people's activities in this field?	Appropriate regulation in the field of cryptocurrency management policies?
The government has not taken valuable measures in the fields of consensus algorithms, blockchain, functional tokens, personal wallets, and the conversion of metal assets into digital assets	-Lack of awareness of their benefits, which can improve the economic and political situation of the country -Academic research has not been optimally used either in software or hardware -Considering the scope of the issue, and the large volume of transactions, and its users, people need advanced and expensive technologies	What measures should the government take regarding consensus algorithms, blockchain, utility tokens, personal wallets, and converting metal	Necessary measures in the field of cryptocurrencies?

Problem	The root causes of the problem	Decision-making areas	The title of the areas - decision-making
(necessities of cryptocurrencies).		assets into digital assets?	
The need for quality and suitable devices and equipment for extraction	-Prohibiting or reducing the issuance of mining licenses and the growth of illegal mining causes smuggled, scrapped, counterfeit, and low-quality devices and equipment to enter the country. -Blockchain, creation of functional tokens, cryptocurrency, etc., due to the large volume of users and their transactions, in order to verify the identity and the possibility of public participation, needs new technologies to build devices and equipment, which currently these technologies are There is no complete in the country - lack of attention to the features of each device according to the type of extraction	What is the solution in manufacturing or buying suitable and high-quality extraction devices and equipment?	Making or buying suitable and quality devices and equipment?
Missed opportunities in exploiting the strategic capacities of cryptocurrencies in the field of payment and exchange	-The necessary standards for exchanging cryptocurrencies have not been developed with an emphasis on customer recognition, maintenance rules, and validation. -Prohibition of direct exchange of cryptocurrencies with goods and services inside the country and lack of monitoring, supervision, and control of payment and settlement tools in goods and services transactions by creating an integrated technical infrastructure -Failure to create or strengthen internal cryptocurrency exchanges.	How can people compensate for the lost opportunities by exploiting cryptocurrencies' strategic capacities in payment and exchange?	Compensation for lost opportunities in using the capacities of payment and exchange?
Lack of serious involvement of the executive branch and the legislative branch regarding cryptocurrency mining	-Maybe they are unaware of the problem, which is that the problems caused by blackouts affected by cryptocurrency mining may cause the country to have a crisis.	How can the government and parliament help to organize the cryptocurrency mining situation?	Organization of the mining situation by the government and parliament?
Failure to determine the duties of businesses in the field of digital currencies	-Ignorance that it can generate income for the people and the country -Due to the sanctions, Iranians cannot operate in all foreign exchanges, or the capital of Iranian users may be blocked due to the sanctions.	What are the suggestions for digital currency businesses to help improve the power shortage situation?	What is the status of businesses in the field of digital currencies?
Development or non-development and participation or non-participation with foreigners in the creation and development of mining fields in the country	-Although the development of mining farms can be a source of income for the country, industries and factories, manufacturing and service companies and organizations, and ordinary people suffer due to blackouts caused by mining. -Unfortunately, no effective action has been taken by the government in this case	Should mining farms be developed or banned, given the country's current situation? Moreover, should we cooperate with	Development or non-development, participation or non-participation with foreigners in establishing mining fields?

Problem	The root causes of the problem	Decision-making areas	The title of the areas - decision-making
		foreigners in this field?	
Using cryptocurrency mining (digital currencies in general) to earn income for the country	-Cryptocurrency mining is a major source of income that has not been used in Iran - Cryptocurrencies can be used instead of dollars in business transactions	How can cryptocurrency mining (digital currencies in general) be used to earn income for the country?	Earning income from cryptocurrency mining (digital currencies)?
Non-cooperation of the general public regarding rational extraction and helping to solve the problem of electricity shortage	-Lack of education and awareness of the issue -Some unpleasant characteristics of Iranians, such as personal profiteering, make them not accept that the profit or loss resulting from the extraction goes to themselves in the first stage.	How can people promote rational extraction to the country's public and help solve the electricity shortage problem?	Promoting ordinary people to avoid illegal mining?

Second and third steps: relationship between decision areas and determining the center of focus

In the next stage, the "decision-making" diagram is created, in which certain decision areas are connected by straight lines, usually referred to as "decision relationships." It is worth mentioning that, unlike other methods, the strategic option approach does not use arrows to indicate causal or sequential relationships between decision areas. A decision diagram or graph provides a broader view of the problem structure. A decision graph is a two-dimensional map that shows a collection of decision areas, connections, and disconnections between decision areas. Figure 3 illustrates the type of decision-making diagram in this workshop, which has been approved after some discussion and conversation among the participants. Some conventions used in this stage to construct Figure 3 are described as follows:

- Different line drawing styles (dashed line and dotted line) are used to record the relationships between elements where there is disagreement or uncertainty.
- Decision areas with high importance or urgency are indicated by a circle with a solid line around them.
- The group must choose a center of focus after examining**.**

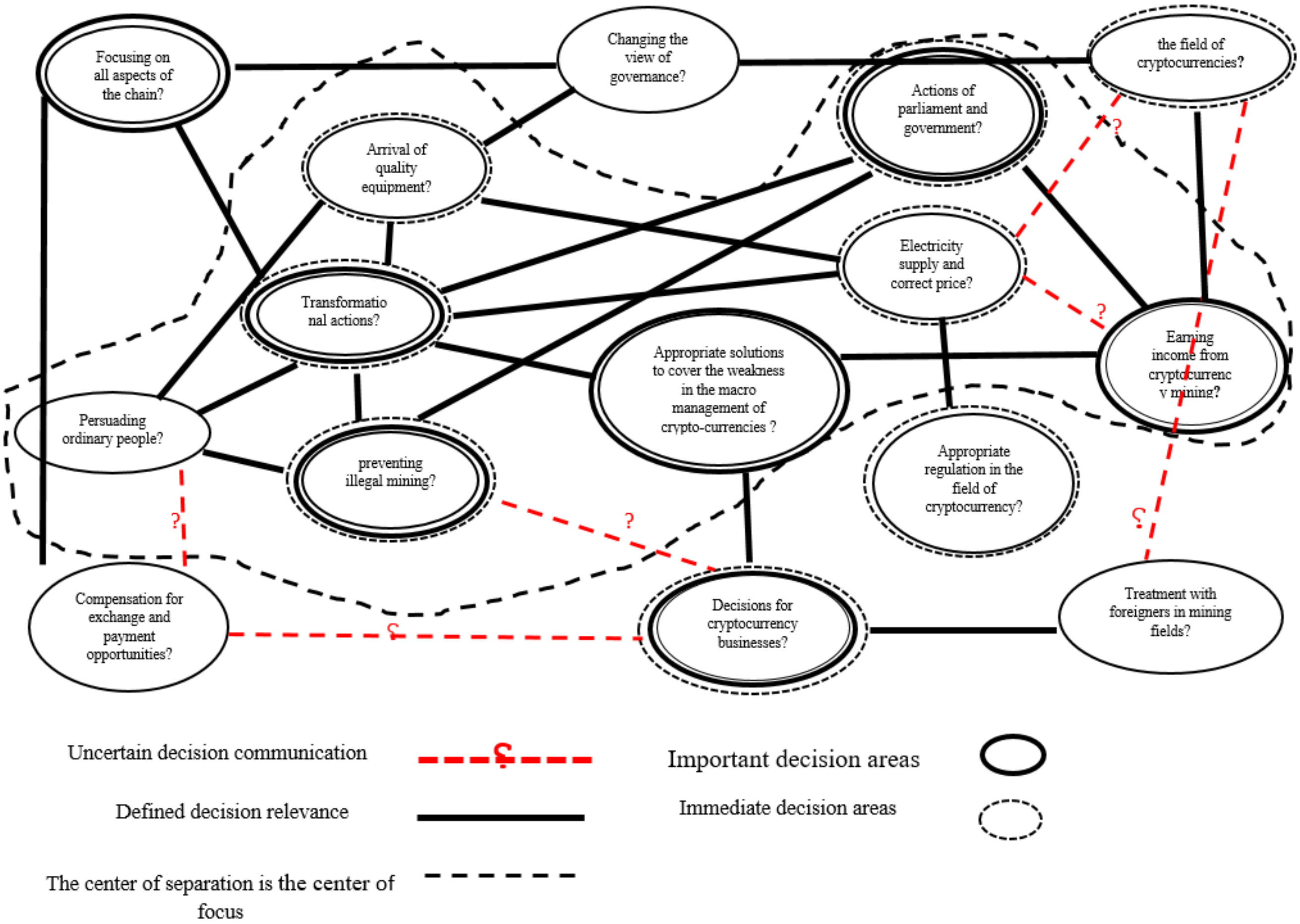

Figure 26. Decision-making diagram and Focus Center

Since the number of areas present in the decision-making diagram and the complex relationships between them seem difficult, in this step, a subset of these decision areas is selected based on "importance and significance," "need for immediate action," and the decision relationship "defined" and "uncertain" with other decision areas, as the focal point of the issue. Regarding the decision areas that are set aside, it does not mean that they do not require immediate and significant action, but rather that decision-making about these decision areas can be done almost independently and does not require additional resources in the decision-making process due to the complexity of the process. However, as a principle, it should be known that the final choice of the focus center lies with the users (facilitators) because the choice of the focus center is not a technical issue but a matter that should be entrusted to the judgments of the participants' values.

3.2. Design methods

Fourth step: determining decision options

The designing mode in SCA can be likened to the "consultation" phase, in which each aspect of a defined problem is articulated. This second mode of SCA aims to develop several alternatives and scenarios, which include the whole range of entities and aspects involved in the process (Lami and Todella,2023). When a problem focus center is selected with a reasonable number of decision areas and is approved, the next step is to agree on the options within each decision area. Table 2 - The options identified within each decision area are displayed.

Table 14. Creating options for decision areas within the focus center

Row	The title of decision-making areas	Decision making options
1	Persuading ordinary people? (Advocating the general public of the country to avoid illegal mining?)	-Cultivation and education -The electricity tariff should be different in the electricity consumption time. It should be divided into three parts: critical, limited, and normal, for which extraction should be prohibited entirely in critical conditions.
2	Transformational actions?	-From the threat-oriented, passive, directive, negative, and license-oriented governance system of cryptocurrencies to the opportunity-oriented, active, and positive governance system with a risk management approach and modern regulatory methods; -From focusing only on the cryptocurrency mining industry to the comprehensive attention of all dimensions of blockchain technology and from services based on centralized reference bases to distributed services based on distributed ledger (strengthening all three fields of extraction (mining), maintenance (holding) and transaction (trading)) and, as a result, creating functional tokens, national cryptocurrencies, and converting and exchanging physical assets into digital currencies -Both methods
3	Preventing illegal mining? (Prohibition of unauthorized extraction (underground)?)	-Creating a smart and online monitoring system for electricity consumption at all levels of production, transmission, and distribution, using the capacity of public reports, reforming the energy subsidy system and currency policies and increasing the popularity and public interest in cryptocurrencies, the speed of legislation, and monitoring of laws should also be increased, and it is necessary for governing institutions to look at it as a new industry -In the field of cryptocurrency mining, it has been emphasized the development of the production of products with optimal efficiency and increasing the export of electricity along with consumption management and promoting the consumption of domestic goods along with planning to improve quality and competitiveness in production
4	The arrival of quality equipment? (Making and buying quality equipment?)	-Manufacturing or importing quality devices and equipment, depending on the type of cryptocurrency and the more profitable the device, the higher its price, and also legalizing the import of devices and equipment in order to prevent the entry of smuggled and counterfeit devices -Using academic and academic capacity to build devices and equipment -Allocating part of the income of cryptocurrency producers to the import of mining devices and equipment
5	What are the solutions to compensate for the weakness in the macro management of cryptocurrencies and solve the existing problems?	-Creating cryptocurrency-tradable investment funds in the stock market requires the development of institutional capacity and capital market tools to manage investment risks in the cryptocurrency market. -Formation of digital assets depository institution and cryptocurrency deposit company

		-Developing the infrastructure of cryptocurrency custody services of the stock exchange and cryptocurrency investment advisory services with an emphasis on increasing the production capacity of cryptocurrencies in the country and adopting appropriate tax and insurance measures
6	Electricity supply and correct price?	-Using the power of the private sector to produce electricity and to supply cryptocurrency miners with the electricity they need, as well as connecting cryptocurrency miners to the power grid and purchasing the required electricity -The Ministry of Energy should use renewable sources, including solar, water, geothermal, and especially nuclear, to supply electricity to mining farms and home miners and supply energy from the place of increasing productivity, such as generating electricity from flare gas and reducing electricity losses. Production in the transmission network
7	Actions of parliament and government?	-To resolve the uncertainty in the field of blockchain in the field of exchange, tariffs, and the activity of foreign platforms and, in general, the uncertain situation, to introduce cryptocurrencies as assets and be included in the field of capital market supervision (not that they are presented as currencies and in the field of be supervised by the central bank) -Creation and strengthening of cryptocurrency exchanges with Iranian platforms in the country and in the short term by forming the National Headquarters of Cryptocurrencies with the mission of recognition, explanation, policy-making, division of duties between the ministries and related institutions, and supervision of the proper implementation of assigned duties and activation of all capacities of this To improve the current situation.
8	Earning income from cryptocurrency mining (digital currencies)?	-Big investment in constructing and purchasing devices and equipment needed for digital currencies and forming support and investment funds. - to expand trade exchanges with other countries, new policies on digital currencies and the development of international discourse are needed. -Development of technological infrastructures and websters and use of appropriate and efficient tax and insurance system

Step 5: Examining compatibility between options and creating compatible plans

When a set of two or more options is agreed upon in each decision-making area, the next step is to examine the compatibility of these options between different decision-making areas within the problem's focus. The selected options from different decision-making areas, which are within a focal point, are examined and judged in pairs to what extent they can be combined.

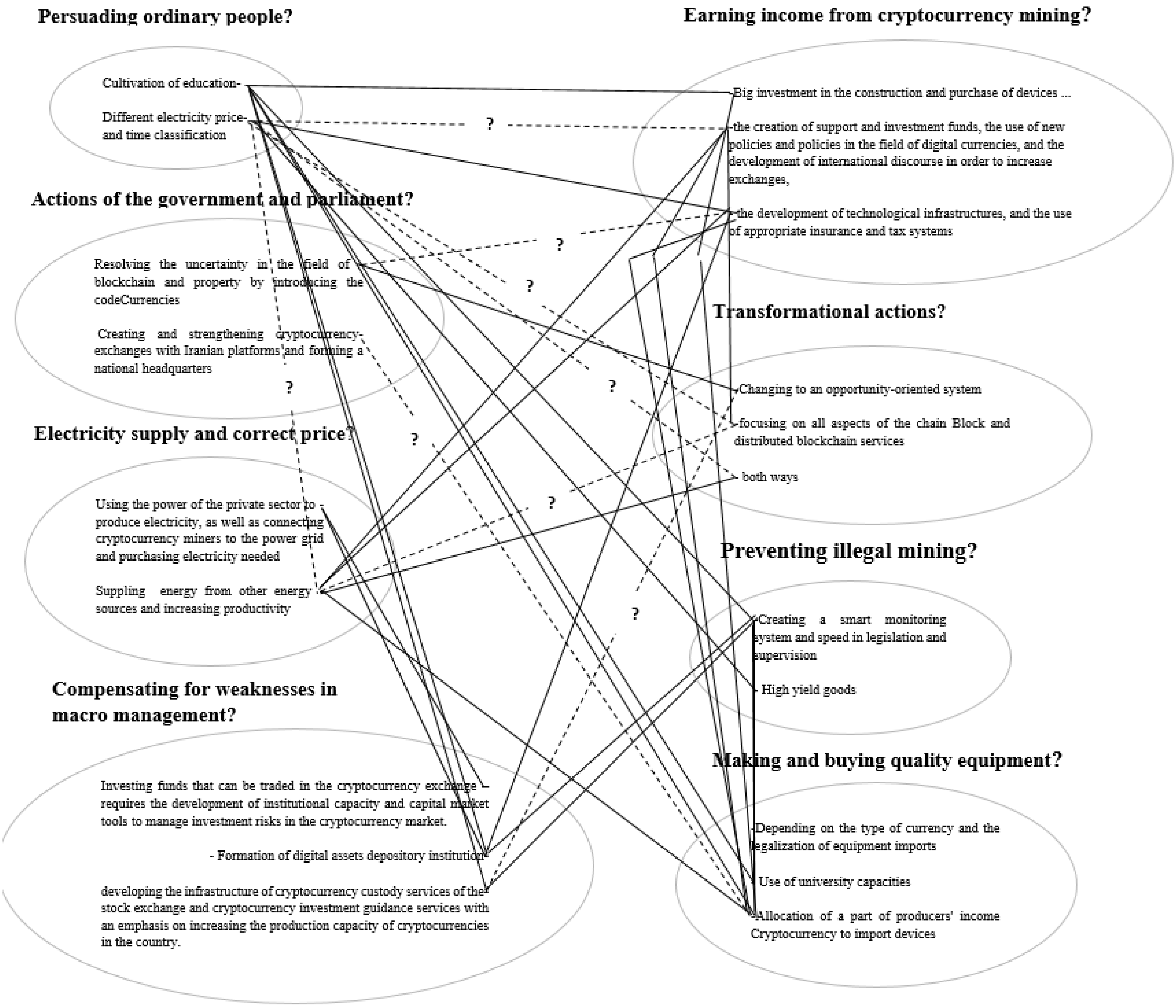

Figure 27. Represents a graphical view of the compatibility between options (Nejati et al.,2018)

It may seem strange that the lines connecting the options in the graph, instead of showing the compatibility relationship between the two options, actually show their incompatibility. In any case, experience shows that the number of incompatible relationships is often less than that of compatible relationships, and a simpler graph is always drawn by using this. By expanding each part of the decision diagram and turning it into an option diagram, the decision relationship is replaced by a binary options pair. Binary option pairs are formed when two combined options are incompatible and present a conflicting situation when combined. Incompatibility can arise due to logical inconsistency or judgmental inconsistency (such as the high cost of option combination or unacceptable consequences). This process is done by drawing a compatibility network or a compatibility matrix. In Figure 4, the decision areas within the focus are shown in the compatibility network. For the sake of simplicity and ease of concept transfer, the following symbols are used:

- (x) denotes an incompatible, conflicting combination (binary option pair).
- (?) denotes questionable compatibility.
- (*) indicates a compatible combination.

It may seem strange that the connecting lines between options in the graph represent their incompatibility instead of showing the relationship between the two options. However, experience shows that the number of incompatible relationships is usually smaller than the number of compatible relationships, and following this rule, a simpler graph can always be drawn. The best way to obtain an accurate count of combinations is to consider decision areas in agreement and sequentially, then systematically assess the probability of each relationship occurring until all possible combinations are reached. Moreover, the feasibility of each combination should be controlled at each stage. The logic of this method is explained in Figure 5.

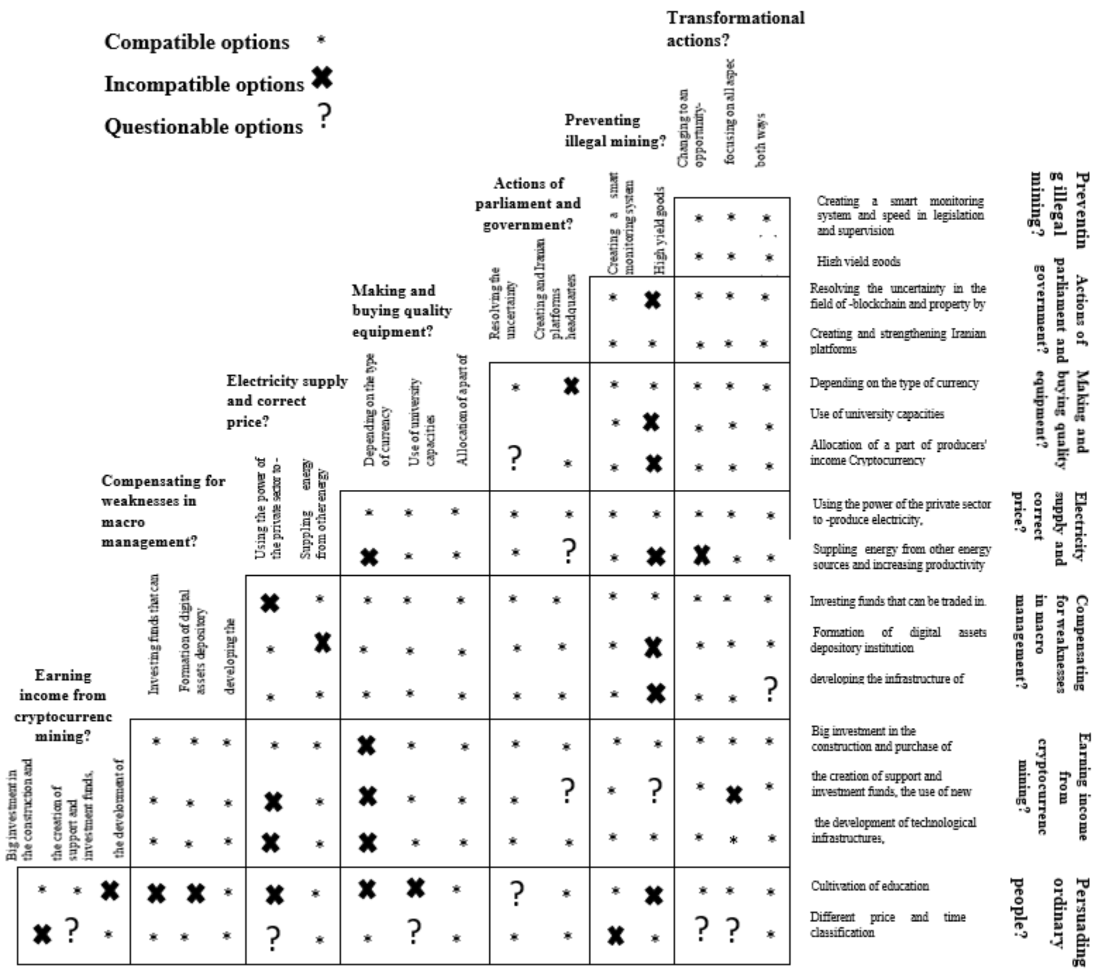

Figure 28. Compatibility and incompatibility network of decision areas in the center of focus (Adaptability Matrix) (Nejati et al.,2018)

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According to Figure 5, the decision areas in the center of focus are listed in a specific order from left to right; in this case, the order of Table 2 (Figure 3) is used. Then, the option is individually analyzed so that the last option's compatibility with the previous options in the chain is examined at each point. The result of implementing this procedure reduces the number of possible combinations to 10 cases (Figure 6). To explain the method in detail, all possible branches are individually examined. In this chart, referred to as the "decision tree", whenever we reach a binary options pair, we draw a multiplication sign at the end of the branch. Any combination that does not result in a binary option pair is considered a possible decision pattern. The branches with a multiplication sign are eliminated as closed or dead branches.

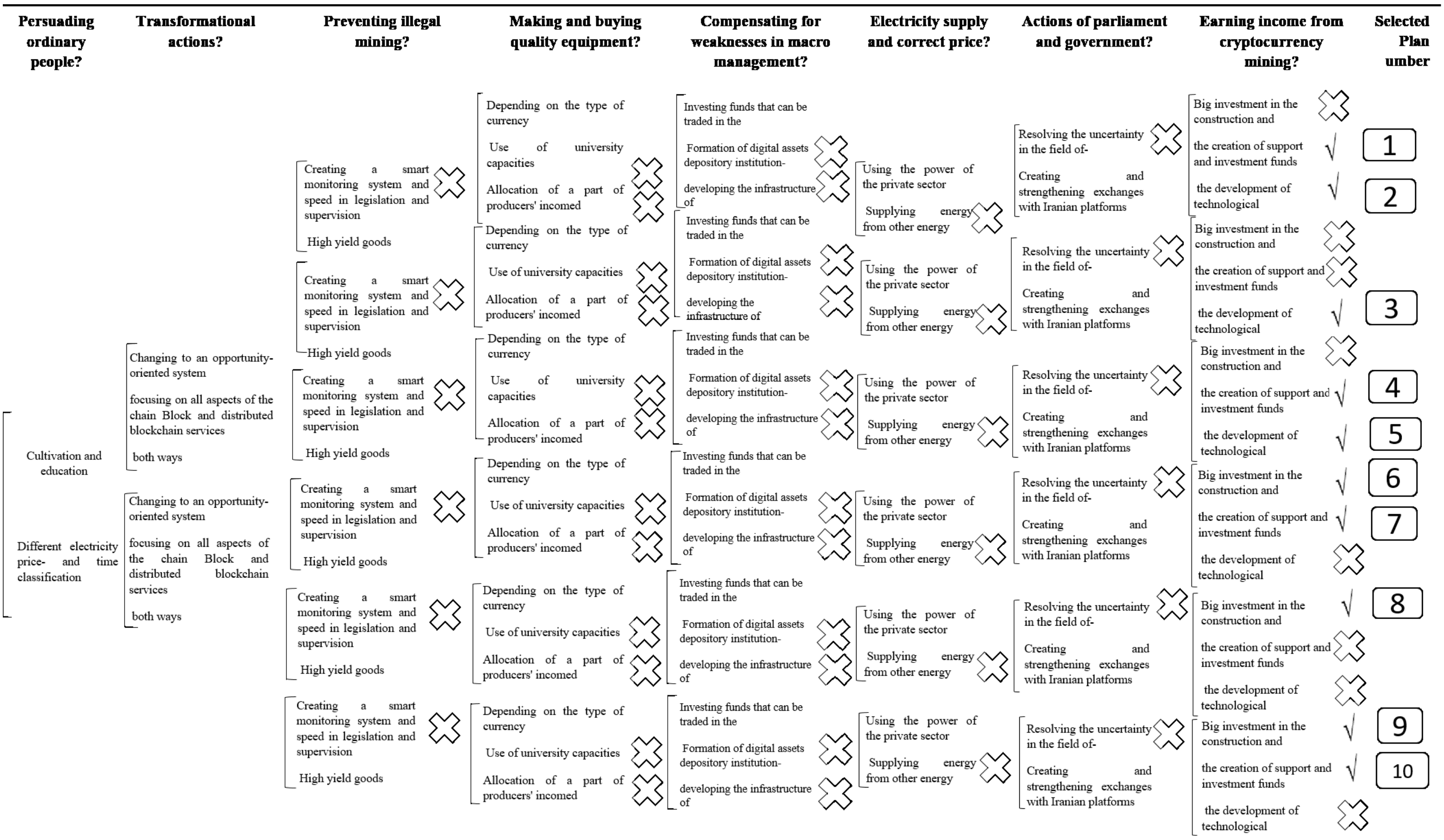

Figure 29. Production of practical decision-making Plans through selection trees (Nejati et al.,2018)

As discussed in the identification of options within a decision area, it is natural for different participants to have different perspectives on combining options, considering some as possible and others as impossible. Such differences can be a starting point for working towards clearer shared perspectives on the structure of the decision problem for the decision-maker. In this section, after eliminating plans that have resulted in dead ends, ten potential plans are shown in Figure 7. It should be noted that according to the consensus in this study, even disputed combinations have been considered as compatible combinations.

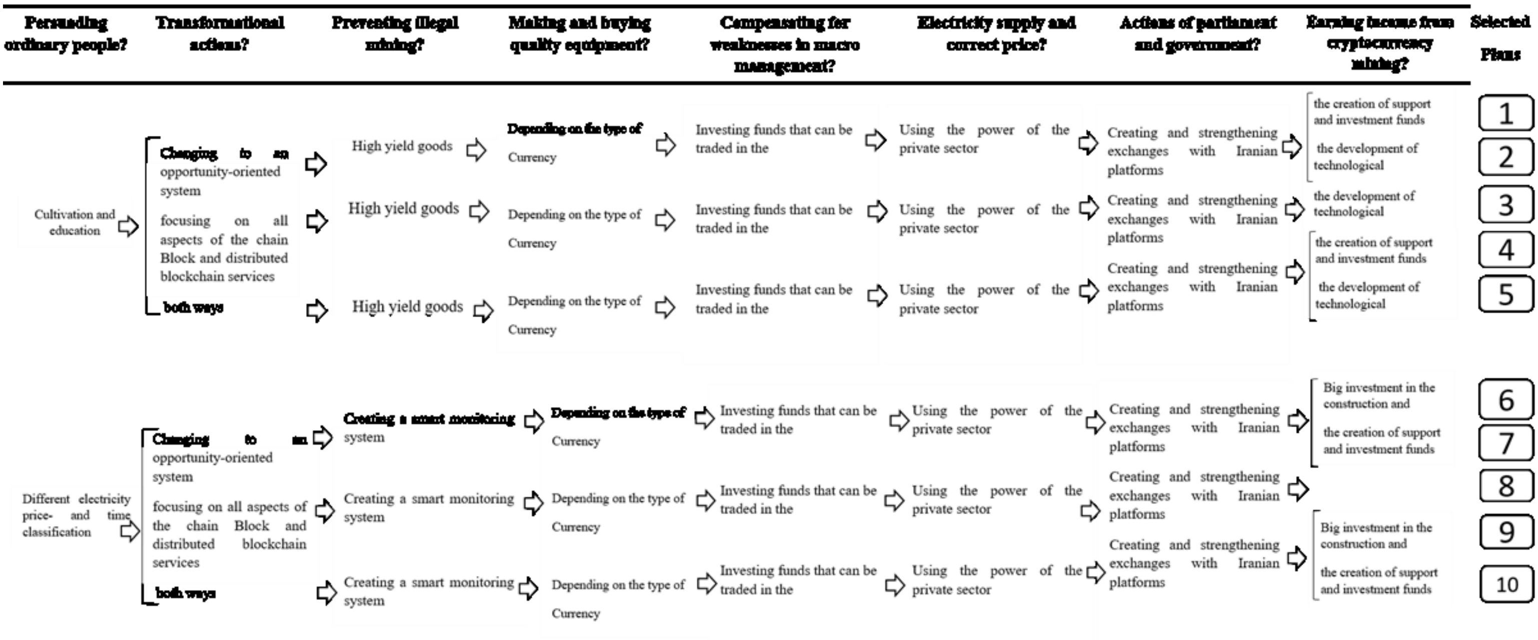

Figure 30. Selected plans (Nejati et al.,2018)

3.3. *Methods used in comparative style*

Step 6: Identifying the areas of comparison

Only one dimension is rarely considered in a decision. In addition, in a decision problem, many individuals usually participate, each having their criteria. Essentially, a comparison area can be considered as several important areas in terms of participants' involvement in the decision-making process, in which participants are interested in knowing the consequences of alternative paths and options. Table 3 shows an example of four comparison areas agreed upon by the members in this section. This list has been obtained through discussion and exchange of views among participants.

Table 15. Comparison areas

Comparison title	The field of comparison
Implementation costs and resources	The cost, financial, human and technological resources of project implementation
Execution time	Project implementation time
Possible result	The possibility of achieving the plan
Income (output)	Income (output) of the plan

Step 7: Comparing different plans

When many decision plans are created, especially if the goal is to extract important information about areas of process uncertainty, comparing all of these plans simultaneously based on all agreed-upon criteria is difficult. A set of ten decision plans has been created and presented in Figure 7, and to be simultaneously assessed based on the four comparison areas, it will be a large set. In practical workshops, a rotational approach is often used when comparing decision plans to deal with the diversity problem. For example, comparing plans three and six (pairwise comparisons and elimination to reduce the number of feasible plans) is shown in Figure 8.

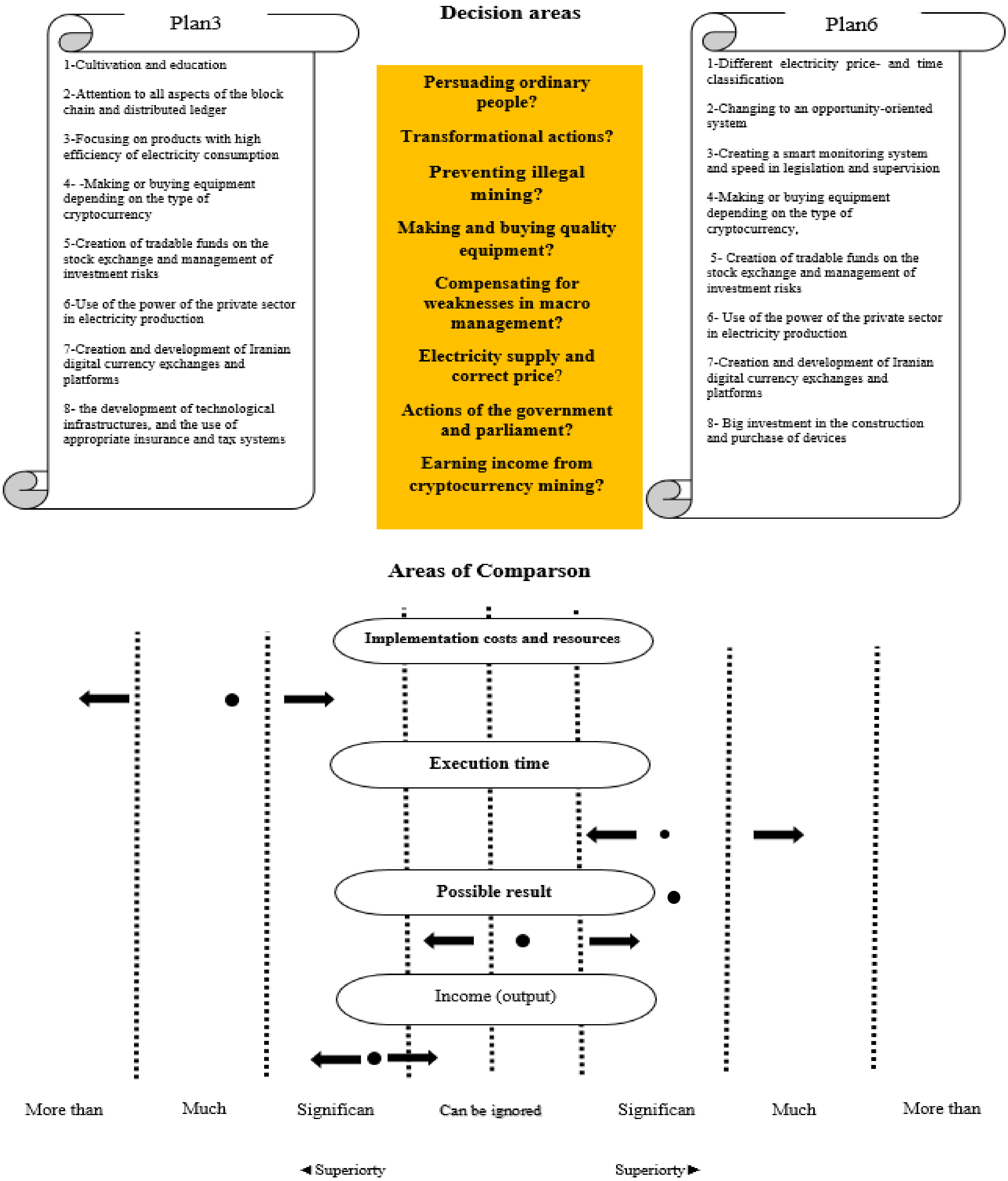

Figure 31. A network comparison chart between plan 3 and 6 (Nejati et al., 2018)

In Figure 8, the network diagram is divided by vertical lines, which represent the superiority of the "More than," "Much," "Significan," and "Can be ignored" options attached to the right or left. The vertical line in the center of the diagram indicates the superiority (Can be ignored) of one option over the other. Therefore, judgments can be made regarding the superiority level of one option on the right or left side of this diagram, such as judging comparison areas. Figure 8 shows that judgments can be made based on each comparison area regarding the superiority level of each option compared to another option, as well as judgments about the range of uncertainty surrounding this point. Since flip charts are used in this study, small labels are used to place a dot indicator (●) to show the level of superiority and two range indicators (🡄or🡆) to represent the spectrum on the row of each comparison area. These indicators can be easily changed during discussions among participants.

3.4. Methods used in the selection style

Step 8: Identifying approaches for dealing with uncertainties

When transitioning from the comparison style to the selection style, the issue of managing uncertainties arises. All three uncertainties (Figure 2) can hinder the agreement on priority options for key decision areas. The unique characteristic of the strategic option approach is that it provides a framework for managing various uncertainties in the selection style. After presenting the list of uncertainties, the type of uncertainty must be determined. Sometimes, the type is ambiguous, and a combination of classifications needs to be used. As shown in Table 4, decision areas are listed, and each uncertainty area is given a specific title. In the next step, the relative importance of uncertainties is determined. To prevent confusion between the decision areas and the uncertainty areas, a question mark (?) is placed before the label of the uncertainty areas. Table 4 presents a four-point scale for grading uncertainty areas based on their relative importance or superiority compared to the focal point of the comparison process.

Table 16. A set of uncertainty areas

Score	Type	The title of the field	Areas of uncertainty
**	UE	?Definition and recognition of the customer and expert	?Accurate definition and recognition of customers or beneficiaries and specialists or experts
***	UV/UR	?The value of the mental image	?The value of the mental image created after solving the problem, for each of the stakeholders
**	UV	?Development of nuclear energy	?Development of peaceful nuclear activities for electricity production according to the conditions of the country
****	UE/UV	?The nature of cryptocurrencies	?Today's nature of digital currencies that are under the supervision of the central bank as a currency or an asset under the supervision of the stock exchange
*	UE	?Islamic and customary jurisprudential limitations	?The limitations of mining and digital currencies in general from the point of view of jurisprudence (Islamic discussions of halal and haram) and custom
****	UV	?Agreement on the JCPOA	?Agreeing with 5+1 and reaching the conclusion of JCPOA
****	UR	?The growth of the gold and stock market and...	?Potential growth of gold, coin, dollar and stock markets
***	UV	? Iran's Sanctioners strategies	?Iran's Sanctioners strategies to Earning income through cryptocurrencies or digital currencies
***	UE/UR	?The level of environmental destruction	?The amount of destruction and cost that mining can have on the environment or the planet

The next issue is what actions can reduce uncertainty in key areas. Any action taken to address doubts and uncertainties within an area of uncertainty is called an "exploratory option". Identifying each exploratory option can be in response to a specific area of uncertainty. Table 5 provides a framework for encouraging discussion and exchange of ideas on this issue. One option for dealing with uncertainty is always "Failure to take action" (meaning it is a neutral option but visually emphasized since reducing uncertainty can sometimes be so difficult that taking no action may be the best choice). It should also be noted that every exploratory effort in investment leads to a reduction in uncertainties within each area of uncertainty, or not (at what cost and when?).

Table 17. Compares options for further research and investigation in areas of uncertainty

Profit	Delay	Cost	Options for further research (exploratory)	Areas of uncertainty
... ++	... **	... #	Failure to take action Negotiating and consulting with the government for the rapid implementation of the digital transformation document, as well as preparing a comprehensive plan to be submitted to the parliament for approval	?Today's nature of digital currencies that are under the supervision of the central bank as a currency or an asset under the supervision of the stock exchange
++ ...	** ...	## ...	Negotiating with relevant government officials and managers Failure to take action	?Agreeing with 5+1 and reaching the conclusion of JCPOA
++ ... +	* ... ***	# ... ###	Consultation for the formation of an economic expert team in the Ministry of Economy, specializing in cryptocurrencies Failure to take action Putting the issue on the agenda of the government	?Potential growth of gold, coin, dollar and stock markets
++ ++ ...	** * ...	### # ...	Negotiation with key and effective managers Simulation of the problem with software Failure to take action	?The value of the mental image created after solving the problem for each of the stakeholders
... + ++	... *** **	... ## #	Failure to take action Open negotiations Consultation and clarification meeting with the country's ambassadors	?Iran's Sanctions strategies for Earning income through cryptocurrencies or digital currencies
... ++ +	... * ***	... # ###	Failure to take action Negotiation to be included in the agenda of the government board Consultation with miners	?The amount of destruction and cost that mining can have on the environment or the planet

In Table 5, different symbols have been used in the left column for each criterion to evaluate the options under consideration relative to the reference point (non-action). The cost of an option is measured by its component or opportunity cost. The delay caused by an option may lead to immediate decision-making, and the benefit obtained due to increased certainty and reduced uncertainty in a particular area.

Step 9: Prioritizing decision areas and presenting confidence-building plans

The author has now reached a point where the author can express the relative advantage of options in decision areas with a higher priority based on their relative flexibility in determining the future of other decision areas. It is done by retrieving the decision plan layout based on the priority level, as shown in Figure 9. Decision areas with higher priority are moved to the beginning of the list. Here, the option tree's structure is the same as presented in Figure 7, with the difference that the areas with high priority have been moved to the beginning of the decision areas list of the center of focus. Here, the option decision area "Transformational actions?" has the highest priority compared to other areas.

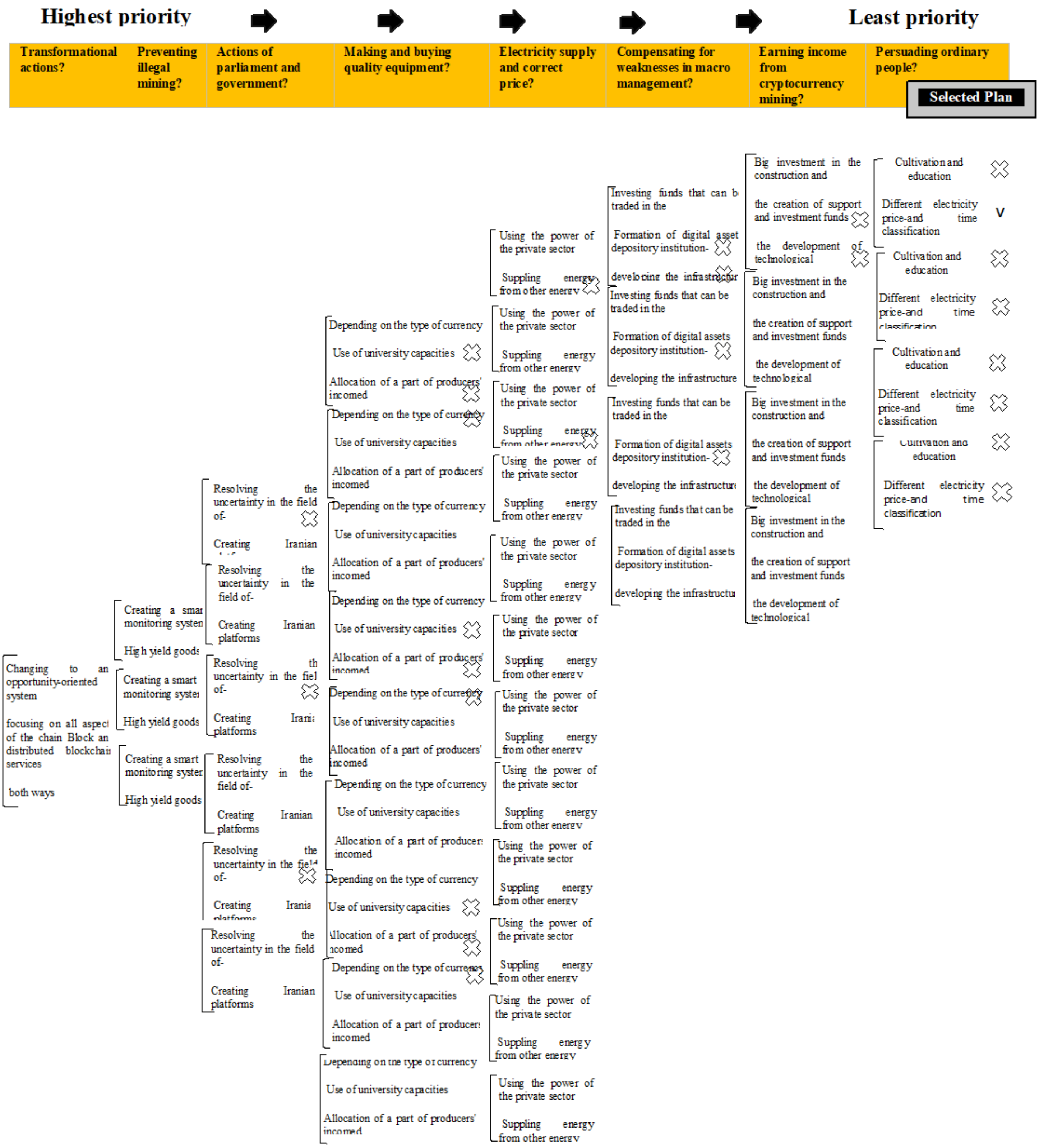

Figure 32. Comparison of options in terms of priority for determining flexibility in future choices (Nejati et al., 2018)

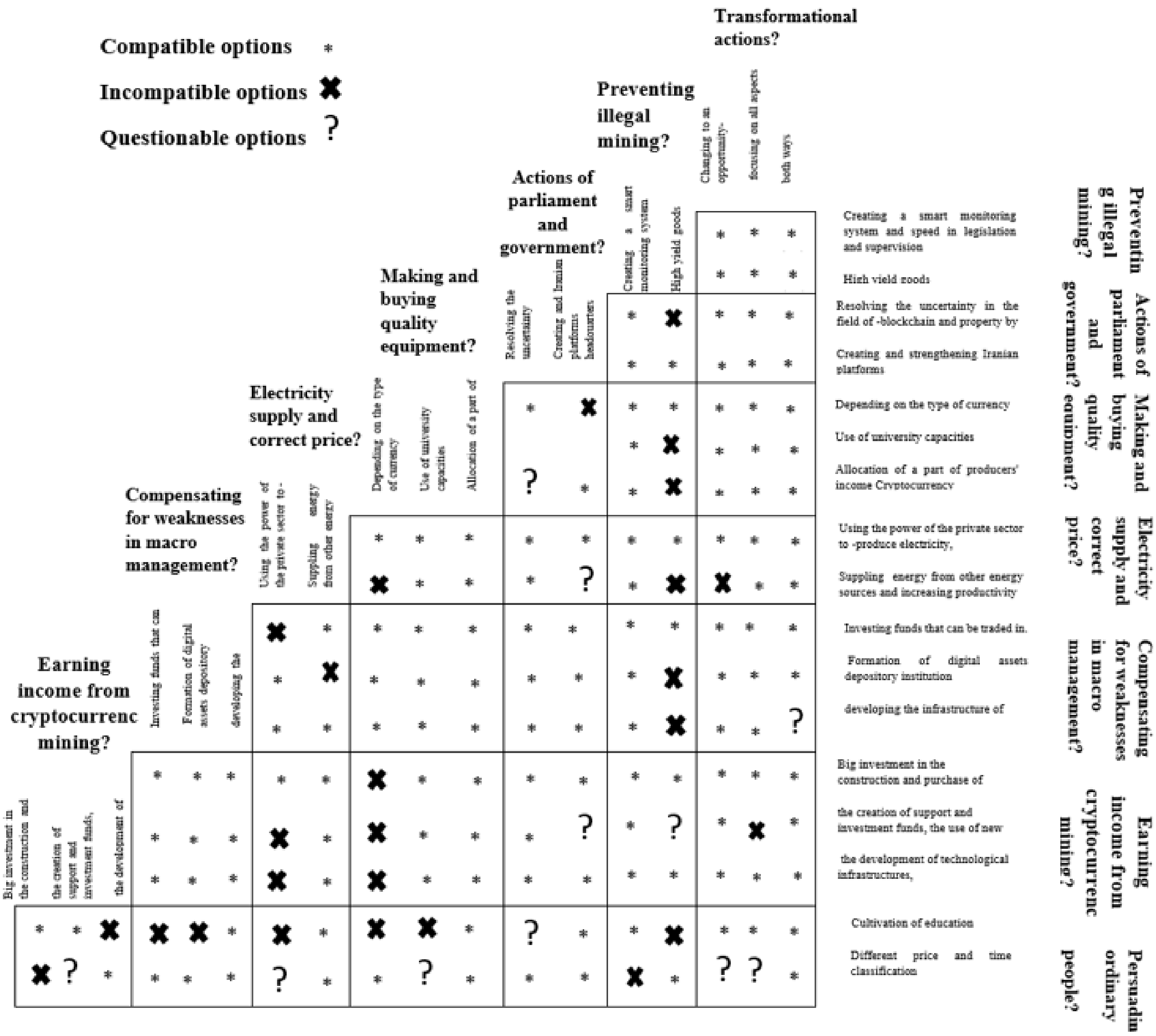

Figure 33. Adaptability matrix in new form (Nejati et al., 2018)

Among the 13 proposed plans listed in Figure 11, seven more probable and superior decision plans have been extracted. These plans have been selected based on several more important comparative areas. If the number of superior and more reliable decision plans has already been prepared from all or some of the decision areas that are easily selected, but in cases where analysis and investigation are required, the problem differs. At this stage, participants focused on analyzing new aspects of the problem situation to select more reliable plans; ultimately, these seven plans were chosen. However, as mentioned before, this study also considers questionable plans compatible.

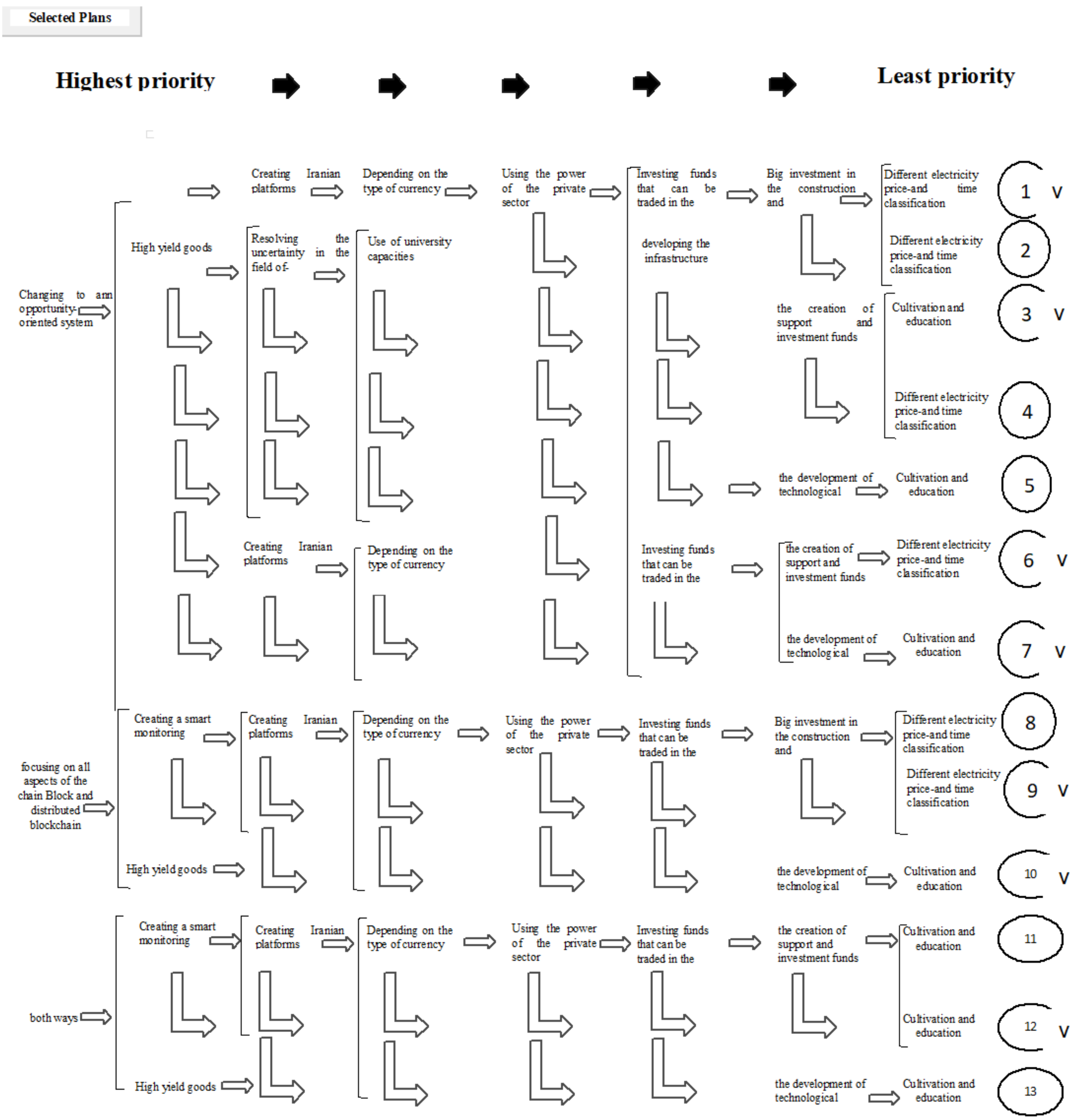

Figure 34. Selected plans (Nejati et al., 2018)

Step 10: Providing commitment package(improvement package)

Now, attention must be paid simultaneously to making initial decisions and managing uncertainty. Usually, a network diagram is used as a framework and infrastructure for the integration process, which has gained popularity as a commitment package or abbreviated as an improvement package. As shown in Tables 6 and 7, each commitment package includes a set of proposals for how to move towards a commitment over time. In the "Present" column, immediate decisions or actions and an exploratory option are considered for each decision area. In the "Future" column, decisions that need to be made in the future for exploratory options and necessary contingency planning for decisions that have immediate action for them are specified for each decision area. Finally, after examining and analyzing the problem, facilitators presented the commitment package with the help of the commitment package working group in Tables 6 and 7.

Table 18. Commitment package in the present time

	Actions to be taken in the present	
	Decision areas- Actions	**Areas of uncertainty -further research and investigation**
Some of the main players in the field of digital currency include basic companies such as banks, accounting and legal companies, technology companies, and startups.	Deciding on businesses in the field of cryptocurrencies? (setting up a two-year plan)	?The value of mental image (Problem simulation with software)
Parliament and the government, except the Ministry of Economy, Ministry of Energy, and Ministry of Foreign Affairs	Transformational actions? (Change to an opportunity-based system)	?Potential growth of gold, coin, dollar, stock markets, and so on (Consultation for the formation of an economic expert team in the Ministry of Economy, specializing in cryptocurrencies)
Ministry of Economy, Central Bank and Stock Exchange	Making appropriate decisions about cryptocurrency policies? (providing infrastructure and funds)	?The nature of cryptocurrencies (negotiations and consultations with the government for the rapid implementation of the digital transformation document and also the preparation of a comprehensive plan to be submitted to the parliament for approval)
Ministry of Power	Preventing illegal mining? (Creating a smart monitoring system and High-yield Goods)	?The amount of environmental destruction (negotiation to be included in the agenda of the government board)
Ministry of Foreign Affairs		?Iran's Sanctions strategies for Earning income through cryptocurrencies or digital currencies (consultation and explanation meetings with the country's ambassadors)

Table 19. Commitment package in the future

	Actions that have been postponed until some time in the future	
	decision areas	**Areas of uncertainty**
Some of the main players in the field of digital currency include basic companies such as banks, accounting and legal companies, technology companies, and startups.	Compensating the weakness in macro management of cryptocurrencies? Compensation for lost opportunities in exploiting the capacities of exchange and payment?	
Parliament and the government, except the Ministry of Economy, Ministry of Energy, and Ministry of Foreign Affairs	Actions of parliament and government? Cooperation or noncooperation with foreigners in creating and developing mining fields?	?Legal, Islamic and customary restrictions
Ministry of Economy, Central Bank and Stock Exchange	Making and Buying quality mining equipment and devices? Necessary actions in the field of requirements and requirements of cryptocurrencies?	?Definition and recognition of customers and experts
Ministry of Power	Persuading ordinary people not to extract illegally/Supply? Supply of electricity required for extraction and proper electricity tariff?	?Development of nuclear energy for electricity generation
Ministry of Foreign Affairs	Earning income through cryptocurrencies?	?Agreement on the JCPOA

4. Research findings

The blockchain, a part of digitalization, can promote competition and provide transparency between power companies and their customers. Iran is known as a country with excessive electricity consumption and an undeniable share of total energy consumption. According to the Iranian Ministry of Energy report, Iran's most significant electricity consumption sectors are industrial, residential, agriculture, and public (Esmaeili and Rafei , 2021). Statistical information published by Tavanir Co. shows that electricity consumption for these sectors in 2019 was 97,081 million kWh, 88.500 million kWh, 38,764 million kWh, and 25,589 million kWh. The general results of this research show that cryptocurrency mining does not greatly impact Iran's electricity shortage (about ten percent). The benefits of the cryptocurrency mining industry should not be ignored due to the lack of electricity. However, one should consider providing more energy through renewable energies, such as nuclear energy.

According to the above tables, the proposed solutions for solving the problem of electricity shortage caused by mining are shown in two decision areas and areas of uncertainty in present and future times. In the decision areas, according to Figure 9, the decision area "Transformational actions?" with the decision option " Change to an opportunity-based system" and the decision area "Preventing illegal mining?" with the options "Creating a smart monitoring system and speed in legislation and supervision" and "High-yield Goods" have the highest priority that should be pursued and implemented by the Parliament, the government, and the Ministry of Energy. Regarding the six decision areas in the center of focus, in the future, delayed and fundamental actions should be taken through the relevant ministries or organizations. These decision areas are displayed in red and bold font. Among the decision areas that were not in the center of focus, the two decision areas, " Deciding on businesses in the field of cryptocurrencies?" and "Making appropriate decisions about cryptocurrency policies?" have considerable priority according to Figure 3, and three decision areas "Compensation for lost opportunities in exploiting the capacities of exchange and payment?", "Cooperation or noncooperation with foreigners in the creation and development of mining fields?", and "Necessary actions in the field of requirements and requirements of cryptocurrencies?" have been selected by the working group members without official analysis and agreement. They should be pursued and implemented in the future.

According to Table 5, five areas of uncertainty along with the option for further research and investigation are: "?Value of mental imagery" (simulating the problem with software), ?Potential growth of gold, coin, dollar, and stock market" (Consultation for forming an economic expert team in the Ministry of Economy, specialized in cryptocurrencies), "?The nature of cryptocurrencies" (negotiating and consulting with the government for the rapid implementation of the digital document transformation and preparing a comprehensive plan for approval by the Parliament), "?The amount of environmental destruction" (negotiation to be included in the agenda of the government board), and ″?Strategies of sanctions to earning income through digital currencies" (consultation and explanation meetings with the country's ambassadors). The relevant ministries and organizations should pursue and act upon these areas to help solve the electricity shortage problem. These areas are displayed in green font and bold. One area of uncertainty, "?Agreement on the JCPOA", that is not mentioned in the mentioned table requires action, along with three areas of uncertainty "?Legal, Islamic and customary restrictions", "?Definition and recognition of customers and experts?", and ?Development of nuclear energy for electricity generation", should also be followed up and acted upon in the future.

It should be noted that constructing a commitment package does not necessarily mean the end point of the SCA process, as all delayed options must be examined according to predetermined procedures and specific orders. Additionally, new decision areas may unexpectedly emerge, new areas of uncertainty may arise, and new participants may enter the process. These factors contribute to the continuation of the SCA process and the cycle of lightweight shaping, design, and comparison. The more complex the subject under investigation, the more illogical it is to assume that the process of SCA reaches its endpoint .

5. Conclusion

The SCA is one of the problem structuring methods to deal with complex and not properly structured problems, which is rooted in the experience of observing and supporting the groups involved in the developing decision-making processes, and its development has been related to the philosophy of practical research (Nejati et al., 2018). In this research, using the SCA to improve the situation of the problem (problems of lack of electricity due to the mining of cryptocurrencies), decision-making and solutions have been presented in such a way that the measures taken by Iran's government organizations and institutions to reduce uncertainties and improve the fields the decisions of cryptocurrencies, have to do, has predicted. But the most important result of this research, which results during the implementation of SCA, is that:

The cryptocurrency industry and digital currencies have many advantages and should not be ignored due to the lack of electricity. However, government institutions should take measures to supply the required electricity and organize the status of digital currencies.

The use of the SCA method for structuring and deciding many social and organizational issues has become common in Iran, and its further implementation helps to localize this knowledge in the country, so it is suggested to use this method in other issues that are important for the country in future research. It is very important to use. Of course, SCA is one of the soft operations research methods, and researchers can implement the same issue of digital currencies with other soft methods such as SSM and SODA.

Ethical Approval

All surveys, interviews or focus groups, etc. conducted in this research according to Ethics approval is by the Human Research Ethics Committee (HREC), duly constituted All subjects gave their informed consent before participating in the study..and Important ethical concerns were considered. During the manuscript, the ethical principles of writing, including ethics, fraudulent publication, plagiarism, duplicate publication, authorship and possible conflict of interest, have been observed. All experts and interviewees have participated in this research with their consent and all scientific principles and rules have been correctly implemented in these interviews. Also, all the authors are fully satisfied with the publication of the information of this article

Availability of data and materials

The main data of this research was obtained through interviews with twelve experts who have complete knowledge of digital currencies and cryptocurrency mining. This data is freely available to the public. The authors provide a data availability statement indicating that the data, the methods used in the analysis, the code and the materials used to conduct the research can be made available to any researcher for the purposes of reproducing the results or replicating the method.

Disclosure statement

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

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Exploring Chaos Theory in Economic Growth and Energy Price Dynamics: A Numerical Simulation Approach

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ABSTRACT

Chaos theory offers a unique lens to understand the intricate relationships between economic growth and energy supply pricing. Existing economic theories often emphasize energy prices' inherent randomness, unpredictability, and economic growth. A deeper comprehension can be achieved by applying chaos theory to this complex system. Developing a dynamic model that captures the causal relationships among the various variables impacting economic growth, energy supply, and pricing is crucial for unraveling this complexity. This study aims to delve into the chaotic nature of the energy economy system within the context of economic growth. The research methodology is rooted in a fundamental-applied approach. By employing numerical simulation techniques, specifically utilizing the Simulink MATLAB toolbox, the study seeks to explore and potentially control chaos within the system. The findings highlight the system's nonlinear dynamics, showcasing its sensitivity to initial conditions and exhibiting chaotic behavior, limit cycles, and stable equilibrium points across varying initial values. This research endeavor contributes to a more nuanced understanding of the interplay between energy economics, economic growth, and pricing dynamics.

Keywords

Keywords: Chaos theory, Energy economy, Economic growth, Numerical simulation.

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1. Introduction

Conducted studies and extensive applications of chaos in various sciences, such as electrical engineering, telecommunications, medicine, meteorology, management, and economics, show that this phenomenon and its control are significant. One of the notable reasons for this nonlinear phenomenon is its inherent and individual characteristics, including extreme sensitivity to minimal changes in the initial conditions (Jia, 2007). The research presented on chaos can be divided into two categories in a general classification. The first category includes articles that focus on investigating the nature of the chaos phenomenon, its inherent characteristics, the introduction of new chaos systems, and practical and physical applications of chaos (Jia, 2007; Ge and Yang, 2009; Karawanich and Prommee, 2022). The second category includes articles focusing on chaos control and developing control methods that can be applied to chaotic systems. Carefully, this category of articles explains that one of the main goals of chaos control is to remove the chaotic system from its chaotic state and converge it towards the equilibrium point or a limit cycle (Ott, Grebogi, and Yorke, 1990; Qazza et al., 2023).

On the other hand, studying the behavior of economic, social, and management systems that have high complexity is an important issue (Xue et al., 2023; Banovetz and Oprea, 2023). In the field of energy economy, energy price assessment includes various information on the energy market. Energy prices play an important role in the global economy. With the growth of the economy, the issue of energy prices has attracted widespread global attention. Such issues as the relationship between energy supply, economic growth, and energy price, how to investigate the mechanism of energy price fluctuations, and how to investigate the effects of energy price on economic growth and energy supply have become important topics of academic research. The energy market, control laws, and government policy have played a strategic role in its development. Therefore, optimizing energy price performance indicates the importance of the energy market impact and the better use of control laws and policies to ensure the sustainable development and health of the energy market (Bhadoria and Marwaha, 2023).

Energy price systems, energy supply, and economic growth include many factors, such as energy price, demand, supply, economic growth, and energy efficiency; therefore, they are very complex. How to research this system with nonlinear dynamic models is an important question. Most previous studies on energy prices mainly focused on empirical analysis with a statistical approach and systematic theoretical analysis (Tang and Tan, 2013; Lin and Du, 2014; Bhadoria and Marwaha, 2023; Chen et al., 2022).

At the beginning of the 19th century, mathematicians first noticed chaos theory. In the 1970s, biological researchers applied this theory to population models. In economics, researchers who studied stability and instability in the 1980s and 1990s focused on chaotic systems (Oestreicher, 2007). Zeng et al. (2014) based on energy consumption, carbon emission, and economic growth, researched a three-dimensional system in the Chinese economy. Also, Wang and Tian (2015) modeled the nonlinear dynamic system of economic growth, energy supply, and price in China and investigated the chaotic behavior of the system. Dabachi et al. (2020) investigated the relationships between environmental variables, energy price, energy intensity, and economic growth in OPEC member countries. They suggested that sustainable energy consumption should be considered by adopting appropriate policies. In this research, Pireddu (2023) showed from a mathematical point of view the existence of complex dynamics for a seasonally disturbed version of the Goodwin growth cycle model, both in its initial formulation and for the modified formulation, including the nonlinear terms of the real wage bargaining function and the investment function. The framework of associated convolution maps is introduced by using the periodic dependence on the time of that model parameter. Valid topological results in this field have made it possible to prove that the Poincaré map, related to the systems in question, is disordered, focusing on sets located in the unit field and when dealing with the original version of the Goodwin model. Accordingly, chaotic trademark features such as sensitive dependence on initial conditions and positive topological entropy follow.

Crude oil is the most important source of energy in the world, and oil price fluctuations can significantly affect investors, companies, and governments. The price of crude oil has several characteristics, including randomness, sudden structural changes, inherent nonlinearity, fluctuations, and a chaotic nature. These characteristics make accurate forecasting of crude oil prices challenging. Sun et al. (2022) proposed a hybrid forecasting model for future crude oil prices, whose accuracy and robustness have been shown through controlled experiments and sensitivity analysis. This study uses a new denoising method for data processing to improve crude oil price forecasting accuracy and stability. In addition, chaotic time series forecasting methods, neural networks, linear model forecasting methods, and deep learning methods are adopted as sub-models. The results of interval predictions with low width and high prediction accuracy are obtained by introducing a confidence interval adjustment factor. The results of the simulation experiments showed that the proposed hybrid forecasting model shows higher accuracy and efficiency as well as better robustness in forecasting than the control models. In summary, the proposed forecasting framework can derive accurate point and interval forecasts and provide a valuable reference for future crude oil price forecasting.

Therefore, it is necessary to conduct deeper research on the following aspects. Many factors in the energy market form a complex coupling relationship. For this reason, the energy market needs to clarify the relationships between the factors and then analyze them. On the other hand, there is a huge increase in the emission of greenhouse gases in Iran and the eighty percent share of the energy sector in their emission. Also, the high energy intensity and the lack of use of innovative technologies in industries show the importance of research in this field. In this nonlinear dynamic model, three variables of energy price, energy supply and economic growth are considered as system state variables. State variables are considered auxiliary variables if other factors influence them. This nonlinear dynamic method can analyze this system theoretically and numerically.

This research explores the intricate relationship between energy prices, supply, and economic growth using a novel approach: nonlinear dynamic systems modeling. Unlike conventional studies that primarily focus on linear models, this research delves into the complexities of nonlinear dynamics, emphasizing the importance of stability analysis. By employing the Vensim software environment, a causal model is developed to simulate the complex interactions between variables. This model is further enhanced through a chaos model implemented in MATLAB, providing a deeper understanding of the system's behavior. The research aims to align the energy market with the strategic goal of achieving sustainable economic growth while adapting to evolving energy structures and environmental considerations.

The study's key contributions include: 1) Exploring the stability of nonlinear dynamic systems: This research goes beyond simply modeling the system; it investigates the it’s stability, analyzing concepts like stable equilibrium points, chaos, and limit cycles. 2) Utilizing advanced modeling tools: Vensim and MATLAB allow for a comprehensive and robust analysis of the complex relationships within the energy-economy nexus. 3) Providing insights for sustainable development: By understanding the dynamic interplay between energy supply, prices, and economic growth, this research provides valuable insights for developing sustainable energy policies and strategies. This research represents a significant advancement in understanding the energy market dynamics. Incorporating nonlinear dynamic systems theory offers a more accurate and nuanced perspective on the complex relationships within the energy-economy nexus, ultimately contributing to developing more effective and sustainable energy policies.

2. Literature review

In this section, information about linear dynamic systems and non-linear dynamic systems (chaos) is provided.

2.1. Linear dynamic system

The performance of linear systems does not depend on their state and is only related to their initial point and does not depend on their state and position at different times; that is, by having the initial point of movement, it can be known all its future positions. The gradual evolution of linear dynamic systems is also a linear process, and the sum of two solutions in the system is another solution in the system. Also, linear systems can be analyzed by breaking down the problem into smaller components, and then by summarizing the results, they can be analyzed as a whole, and this is one of the things that makes the analysis of linear systems easy. Create (such as Fourier analysis and superposition topics). Finally, the analysis of equations related to these systems is known.

Linear dynamical systems are dynamical systems where the evaluation functions are linear. Dynamical systems generally do not have closed-form solutions, but linear dynamical systems have a rich set of exact mathematical properties. Linear systems can also be used to understand the qualitative behavior of general dynamical systems by calculating the equilibrium points of the system and approximating it as a linear system around each point. Linear dynamical systems can be solved more accurately than nonlinear systems. In addition, any nonlinear system's (approximate) solutions of can be well approximated using an equivalent linear system close to its fixed points (Zhurabok, et al., 2017).

2-2. Nonlinear dynamic systems (chaos)

Chaos comes via Latin chaos from the Greek chaos, "the first state of the universe, the formless state of primordial matter, (personified) the parent of Darkness and Night, infinite and empty space, the expanse of air." The original Greek meaning of cháos was "hole, empty, yawning opening," from an unrecorded cháwos and related to the adjective chaûnos, "loose, spongy, having holes. "The first meaning in English was "an immeasurable and formless void, infinite darkness," especially about the state that preceded God's universe creation. The current

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meaning, "a state of utter confusion and disorder (resembling the primordial state)" first appeared about 1533 (Kolo and Adepoju, 2015).

Historically, after Newton's laws of motion were presented, many people, relying on the intrinsic certainty of these laws, called them God's calculator and considered them sufficient for predicting the future based on current values. In general, it was believed that if the current situation was known with high accuracy, the future could be predicted with the same accuracy. This belief was still in place until the end of the 19th century "Henri Poincaré" in his investigation and effort to solve the three-body problem realized that in some cases, if the accuracy in the initial conditions is high, the uncertainty in the final results is not necessarily insignificant. By reducing the uncertainty in the initial conditions, the uncertainty does not necessarily decrease. This issue was a manifestation of chaotic behavior that was not recognized then. Almost the first numerical research that led to the comprehensive introduction of chaos was presented by "Edward Lorentz" (Sato and Murakami, 1991).

Chaos is a long-term, non-periodic behavior in a deterministic system that shows a sensitive dependence on the initial conditions. The meaning of long-term non-periodic behavior in dynamic systems is that there are paths that do not lead to fixed points, periodic orbits, or quasi-periodic orbits when time tends to infinity. Determinism means that the system does not have stochastic parameters or inputs, but the disordered behavior of these systems is caused by non-linearity. This term is used in contrast to stochastic, which means that the system’s behavior is irregular, stochastic, uncertain, and unpredictable. Being sensitive to the initial conditions in dynamic systems means that adjacent paths are rapidly and exponentially separated. This feature is the main difference between chaotic and non-chaotic dynamic systems. In non-chaotic dynamic systems, the initial small difference in two paths is a measurement error. It increases linearly with time, while the difference between two paths with a very small distance increases exponentially in chaotic dynamic systems.

Nonlinear dynamic systems and even discrete linear systems can exhibit completely unpredictable behavior. Such behavior may appear to be stochastic despite the fact that it is essentially certain (i.e., there is no possibility of a random state). This unpredictable behavior is called chaos.

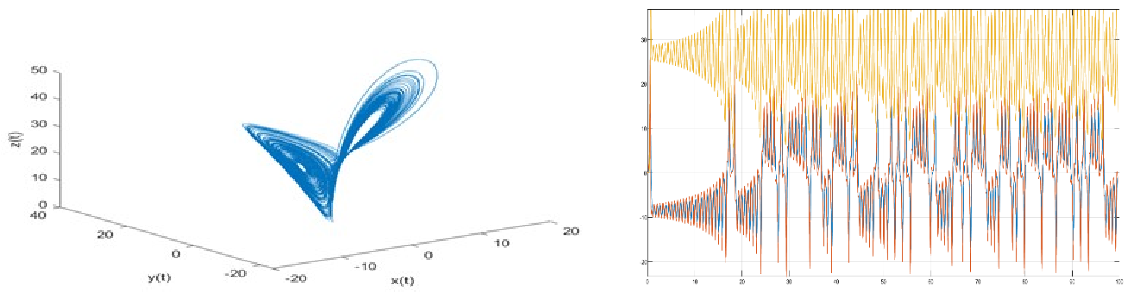
Unlike linear systems, the relationship between speed and position is nonlinear in nonlinear dynamic systems. In such a system, if there are two answers, the sum of them is not the answer of the other system, and the system cannot be divided into smaller components; each can be solved separately, but the whole system must be studied together. Therefore, the equations related to transformation in these systems do not have an analytical solution, or their analytical solution is very difficult (Wang *et al.*, 2019).

One of the characteristics of chaos theory is the butterfly effect introduced by Lorentz. Lorentz published the results of his research in the form of a system of nonlinear differential equations. The calculation results showed the extreme sensitivity of the Lorentz model to the initial values. This property is called the butterfly effect and became the cornerstone of chaos theory. This feature indicates if the variables have a chaotic process. Predicting them in the long run will take much work and effort. In this regard, economic, social, and political systems have a butterfly effect. The butterfly effect is a valid and complete reason for the appropriate and low-cost decisions of a creative and successful manager, which causes a tremendous transformation in his organization.

Lorentz's differential equation system is in the form of equation (1).

$$\begin{cases} \dot{x} = \sigma(y - x) \\ \dot{y} = x(\rho - z) - y \\ \dot{z} = xy - \beta z \end{cases} \tag{1}$$

Lorentz model for initials $(x_0, y_0, z_0) = (0.1,0,0)$, Parameters $(\sigma, \rho, \beta) = (10,28,8.3)$ is simulated in Simulink MATLAB toolbox and the software outputs are shown It will be given. given. In Figure 1. a, the system is drawn in three dimensions. It can be seen that the system has two absorbing points and the continuously moves around these two points from one to the other. Figure 1.b shows three simultaneous systems, and the system can be seen as pseudo-random and chaotic.



a: Three-dimensional Lorentz diagram b: Diagram of three variables of the system

Figure 35. Lorentz diagram and diagram of three variables of the system according to time

Three two-dimensional figures of the system in terms of changes in x, y; x, z and y, z are shown in Figure 2, and in Figure 3, System change is shown separately in time.

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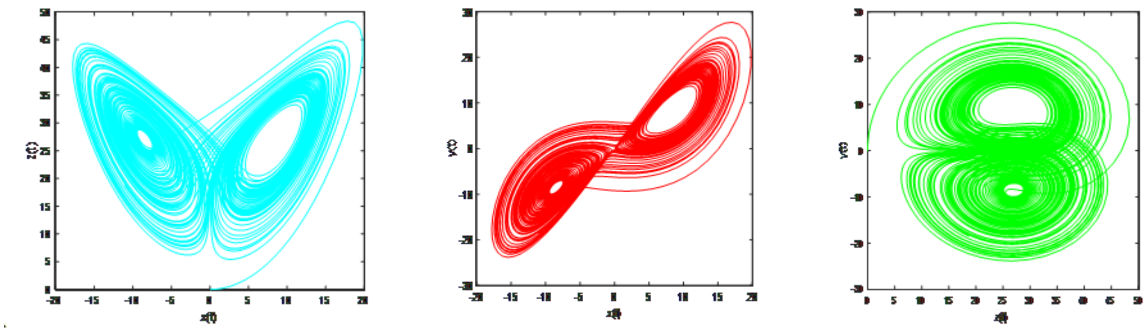

Figure 36. Two-dimensional diagrams of the lorentz

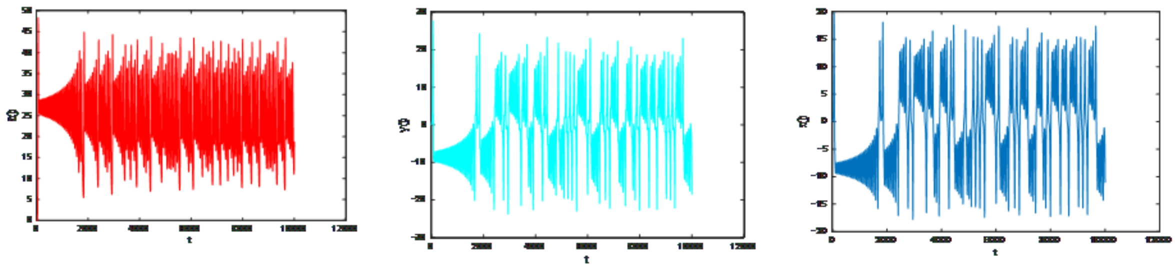

Figure 37. Diagrams of system variables according to time

3. Research method

First, the system's conceptual model is defined based on direct and indirect causal relationships between energy prices, energy supply, and economic growth and the factors affecting them. Then, a non-linear system of energy price dynamics, energy supply, and economic growth is obtained based on the complex relationship between all system factors. Using this system, the dynamic evaluation of these factors was done using numerical simulation. The conceptual model is drawn using Vensim software. Then, the non-linear dynamic system, which has high complexity, is simulated and analyzed by the Simulink MATLAB toolbox.

3.1. Cause and effect model of energy supply system, energy price and economic growth

The studied model drawn in Vensim software includes 71 cause and effect loops, which shows the high complexity of this system. In Figure 4, (adapted from (Wang and Tian, 2015)) "+" indicates positive correlation and "-" indicates negative correlation and $k_i; i = 1,2,\dots,36$indicates the relationship between both elements.

For example, according to Figure 4, energy prices are variable and go up and down; some factors, such as energy consumption and lack of energy supply in the market, will increase energy prices. Increasing energy production will increase energy supply. So, the lack of energy supply is reduced. As a result, the price of energy will also decrease. Meanwhile, with the increase in energy production and consumption in the market, carbon emissions will increase. Then, the government will adjust the energy structure accordingly. These settings will reduce energy intensity and increase energy efficiency. After that, the economy may develop rapidly, increasing energy consumption and increasing energy supply shortages.

Meanwhile, rapid economic development can help promote the advancement of science and technology. Innovative technologies can help us use more energy and increase energy production. Technological development can help exploit new energies, such as solar energy, which can reduce carbon emissions. Similarly, it can improve energy use efficiency and reduce energy intensity effectively; therefore, the economy will develop. As a result, there are some non-linear relationships, direct or indirect, between energy prices, supply, and economic growth.

Therefore, in order to analyze the behavior of the system, it is a system of non-linear differential Equations (2) in terms of state variables depending on the time of energy supply x(t), energy price y(t), and the growth of the gross national product z(t) (measure of size economic growth) and the relationships presented in the cause and effect figure are written; And by using MATLAB software, the model has been simulated and its behavior has been checked.

$$\begin{cases} \dot{x} = a_1 x + a_2(c - y) + a_3(z - d_1) \\ \dot{y} = -b_1 y + b_2 x - b_3 z\left(1 - \frac{z}{d_2}\right) \\ \dot{z} = C_1 z\left(1 - \frac{z}{L}\right) + C_2 yz \end{cases} \quad (2)$$

That,

$$\begin{cases} a_1 = f(k_1.k_2.k_3.k_5.k_6) \\ a_2 = f(k_1.k_8.k_{12}.k_{16}.k_{36}.k_{36}) \\ a_3 = f(k_1.k_{11}.k_{28}.k_{30}.k_{31}.k_{12}) \\ b_1 = f(k_{21}.k_{22}.k_{23}.k_9) \\ b_2 = f(k_{24}.k_{22}.k_7.k_{14}.k_{17}.k_{20}.k_{24}) \\ b_3 = f(k_{11}.k_9.k_3.k_{18}.k_{17}.k_{24}.k_{20}.k_{23}.k_{28}.k_{29}.k_{27}.k_{34}.k_{22}.k_{21}.k_{33}) \\ c_1 = f(k_{10}.k_{11}.k_{13}.k_{25}.k_{16}.k_{34}.k_{28}.k_{17}.k_{18}.k_{30}.k_{31}) \\ c_2 = f(k_{13}.k_{14}.k_{15}.k_{17}.k_{18}.k_{20}.k_{26}.k_{32}.k_{35}.k_{31}.k_{36}) \end{cases} \quad (3)$$

In differential equations device (3):

a_i ; $i = 1,2,3$: parameters related to energy supply x(t)

parameters related to energy price y(t): b_i ; $i = 1,2,3$

c_i ; $i = 1,2,3$: parameters related to the growth of the national gross product z(t)

k_i ; $i = 1,2, \ldots ,36$: Relationship between variables

d_1, d_2, c, l are positive constants that respectively express the degree of flexibility of the economy, the tolerance threshold of energy supply in relation to energy price and the tolerance threshold of economic growth in relation to energy price and energy supply.

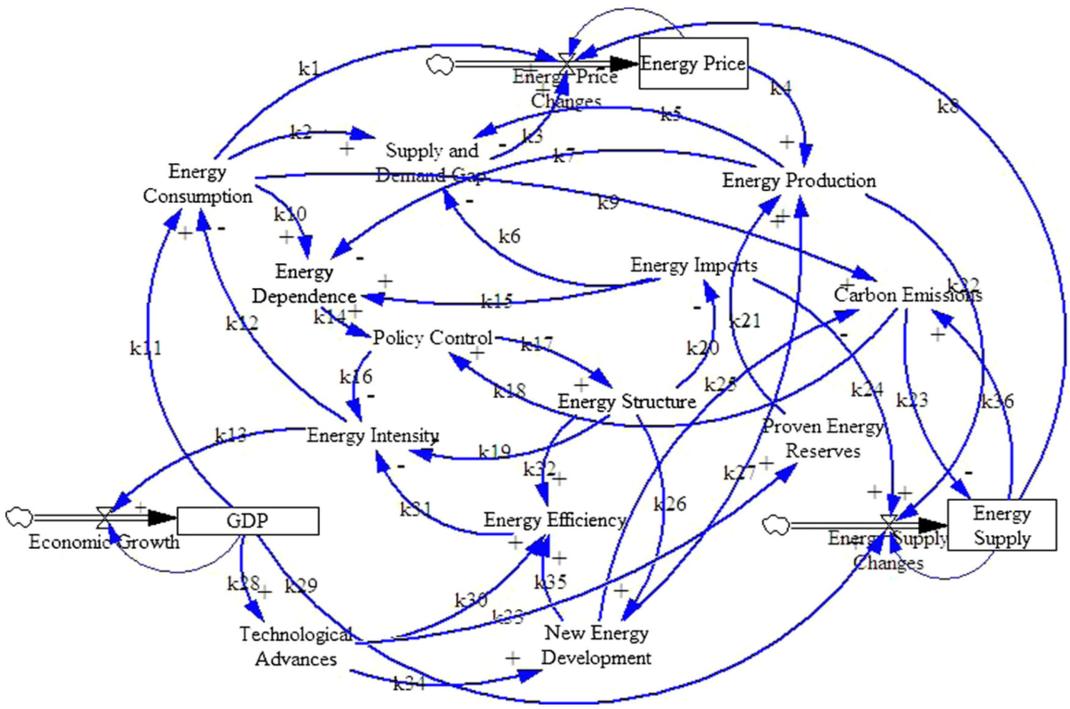

Figure 38. Cause and effect relationships of the system

3.2. Examining model parameters

a_1: The intrinsic growth factor is the price of energy, which by (k_1) shows the effect of energy consumption on energy price ($k_2.k_5.k_6$), respectively shows the effect of energy consumption, energy production, and energy import due to lack of energy supply on the energy market, and (k_3) the effect of a lack of energy supply on energy price approved.

a_2: The effect coefficient of energy changes on the price of energy. By (k_8) the direct effect of energy supply on the price, ($k_1, k_{12}, k_{18}, k_{36}$) confirms the indirect effect of energy supply factors such as carbon emissions, government policies, and energy consumption on the price of energy is confirmed.

a_3: The effect coefficient of economic growth on the price of energy. Since economic growth can increase energy consumption (k_1), and contribute to the advancement of science and technology (k_{28}), the efficiency of using those energies increases (k_{30}) and energy intensity decreases (k_{31}). Therefore, energy consumption is reduced (k_{12}). Changes in energy consumption will lead to energy price fluctuations (k_1). Therefore, the influence factor a_3 is confirmed by the mentioned parameters.

b_1: The emission coefficient of energy supply growth, which is determined by (k_{21}) energy sources that can lead to energy production, (k_{22}) the effect of energy consumption on energy supply, (k_{23}) the effect of carbon emissions on energy supply, and (k_9) the effect of energy consumption Carbon emissions confirmed.

b_2: The impact factor of energy price changes in line with energy supply. In this way, energy price affects energy production (k_4), expands energy production and supply (k_{22}), or reduces energy dependence (k_7). This reduction will lead to regulating energy policies (k_{14}) and then the energy structure (k_{17}). This setting can change energy import (k_{20}) and supply (k_{24}). The stated items confirm b_2.

b_3: The coefficient of economic growth on energy supply. Economic growth can help increase energy consumption (k_{17}), and carbon emissions (k_9) will increase accordingly. Due to the protection of the environment, the increase in carbon emissions prevents the increase in energy production (k_{23}). Economic growth will force the government to adjust its policies (k_{18}) and the energy structure (k_{17}). Energy import (k_{20}) and energy supply (k_{24}) will change. In addition, economic growth will directly increase the exploitation of new energies (k_{34}) and available energy resources (k_{33}). New energies and the development of existing energy sources can promote the production of new energies and energy sources (k_{21}) and (k_{27}) and finally increase the total energy supply. Therefore, the mentioned factors confirm b_3.

c_1 shows the effect of economic growth on itself. Economic growth will lead to technological progress (k_{28}). Then, it will improve the efficiency of energy use (k_{30}) or the exploitation of new energy, (k_{34}) the exploitation of new energy will change carbon emissions, and (k_{18}) the regulation of policies. Accordingly, the energy structure will change (k_{17}). The two mentioned paths reduce energy intensity ($k_{31}.k_{19}$) and will change the economy's growth (k_{13}). Economic growth increases energy consumption directly (k_{11}) and changes energy dependence (k_{10}), and then policies are set (k_{14}) that lead to energy intensity reduction (k_{16}) and economic growth (k_{13}); therefore, c_1 is confirmed.

c_2: indicates the coefficient of impact of energy supply on economic growth. Energy supply causes changes in carbon emissions (k_{36}) that lead to policy adjustments (k_{18}); these adjustments can help change the energy structure (k_{17}) and energy imports (k_{20}). Based on these cases, energy dependence will change (k_{16}), and the economy will develop (k_{13}). Meanwhile, adjusting the energy structure will increase energy utilization (k_{26}) and help improve energy use efficiency (k_{35}). The goal of reducing energy intensity can be achieved (k_{16}), and therefore, the economy will develop (k_{13}). The stated items are in favor of c_2.

3.3. *Numerical simulation of the model*

The following methods are used to determine the stability of the non-linear dynamic system:

1- Solving the system of differential equations by numerical methods (simulation) and studying the behavior of the solution
2- Linearization of the non-linear system in several points where this method is prone to linearization errors.
3- Defining a Lyapunov function and studying the behavior of the function

In this research, the simulation approach and the ODE45 command in MATLAB, which has high accuracy, have been used.

The economic growth system of energy price and its supply shows the interactive relationships between economic growth, energy price, and energy supply. In the evolutionary process of the system, there are complex dynamic features between the system variables and parameters. We discuss the dynamic characteristics of the system using numerical simulation methods.

Some models have an analytical solution with one or two variables, in which case the values of the variables are easily obtained. However, models with higher dimensions and high complexity that do not have an analytical solution can be analyzed numerically. For this purpose, the model is simulated using MATLAB software and the Simulink toolbox. In order to check the behavior of the system, by selecting the initial parameters and values in Table 1, the simulation is performed with the time horizon of 1000 and the step length of 0.0001, and it is executed with the ODE45 solver that uses the fourth and fifth order Rang Kuta. The numerical solutions obtained by this solver are highly accurate in most cases. Many differential equations cannot be easily solved analytically, but solving them numerically is relatively simple. Hence, a numerical approach is, in general, more applicable.

4. Simulation results

In this section, simulations were performed using MATLAB software. The simulation results are displayed as three-dimensional, two-dimensional, and one-dimensional graphs. The system's behavior has been analyzed for each case.

Table 20. Parameters and initial values of the model for four simulation cases

Case	Z_0	Y_0	X_0	a_1	a_2	a_3	b_1	b_2	b_3	c_1	c_2	d_1	d_2	c	l

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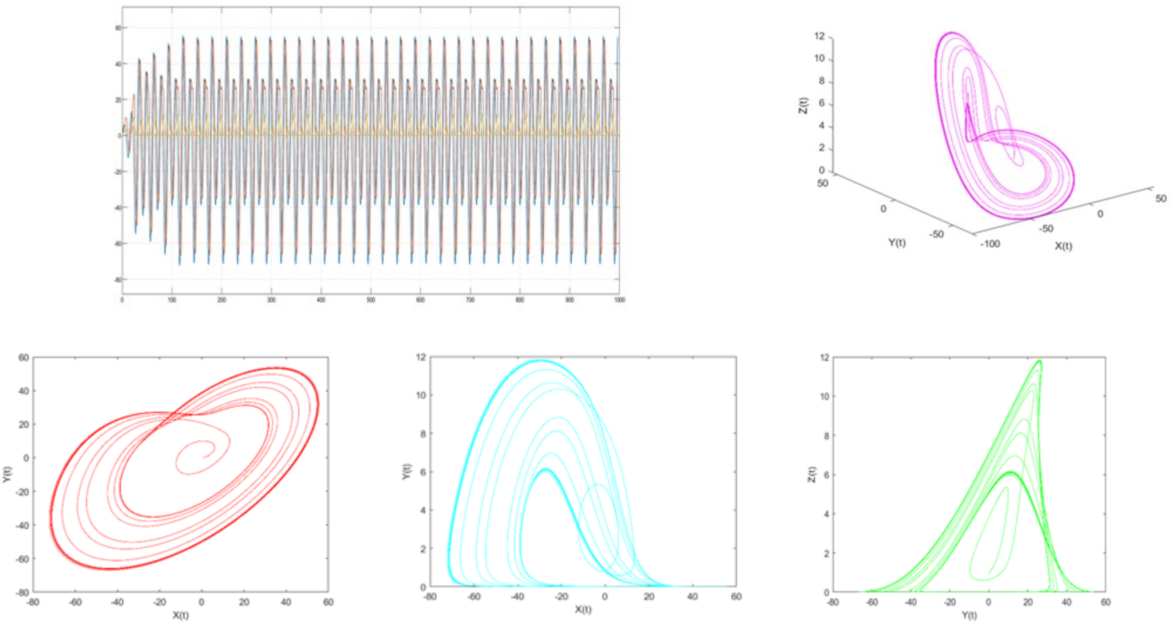
1	0.09	0.05	0.8	0.3	0.5563	0.15	0.4	0.6073	0.3	0.3	0.06	1.5	1.5	2.7	1.9
2	0.8	0.2	0.1	0.3	0.5563	0.15	0.4	0.6073	0.3	0.3	0.06	1.5	1.5	2.7	1.9
3	0.9	0.8	0.5	0.3	0.5563	0.15	0.4	0.6073	0.3	0.3	0.06	1.7	1.8	2.7	1.9
4				0.3	0.5563	0.15	0.4	0.6073	0.3	0.3	0.06	1.7	1.8	2.7	1.9

The first case, as depicted in the figure, presents a system exhibiting random behavior. However, this apparent randomness is deceptive. This system is fundamentally deterministic, meaning its future states can be predicted accurately given its mathematical equation and initial conditions. This characteristic classifies it as a chaotic system. Despite the apparent disorder, chaotic systems possess a hidden order that manifests as recurring patterns over time. A crucial aspect of chaotic systems is the sensitivity to initial conditions, often called the "butterfly effect." Even minute changes in starting values can lead to drastically different outcomes. This sensitivity underscores the importance of precise parameter setting in chaotic systems.

Figure 5 further illustrates the quasi-random and chaotic nature of the system. The presence of an attractor, also known as an absorbent area, is evident. This attractor represents a region in the system's phase space where the system's trajectory tends to converge over time, regardless of the initial conditions. The existence of an attractor suggests that while the system exhibits chaotic behavior, it is not entirely unpredictable. The system's dynamics are constrained within the boundaries of the attractor, providing a degree of predictability despite the apparent randomness.



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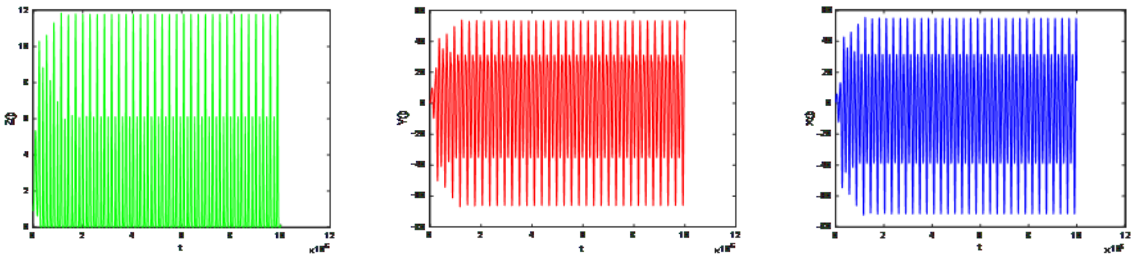

Figure 39. System diagrams for mode 1

In the second case depicted in the figure, the system may appear random at first glance. However, it is crucial to note that this system operates deterministically. It implies that possessing the mathematical model of the system at any given moment enables accurate predictions of its future behavior. The system in question exhibits chaotic characteristics, wherein an underlying order emerges amidst apparent disorder and persists over time. A key consideration in chaotic systems lies in the configuration of parameters. Furthermore, Figure 6 illustrates the system's behavior, showcasing a blend of quasi-random and chaotic tendencies. Additionally, the existence of an absorbent area is a notable feature.

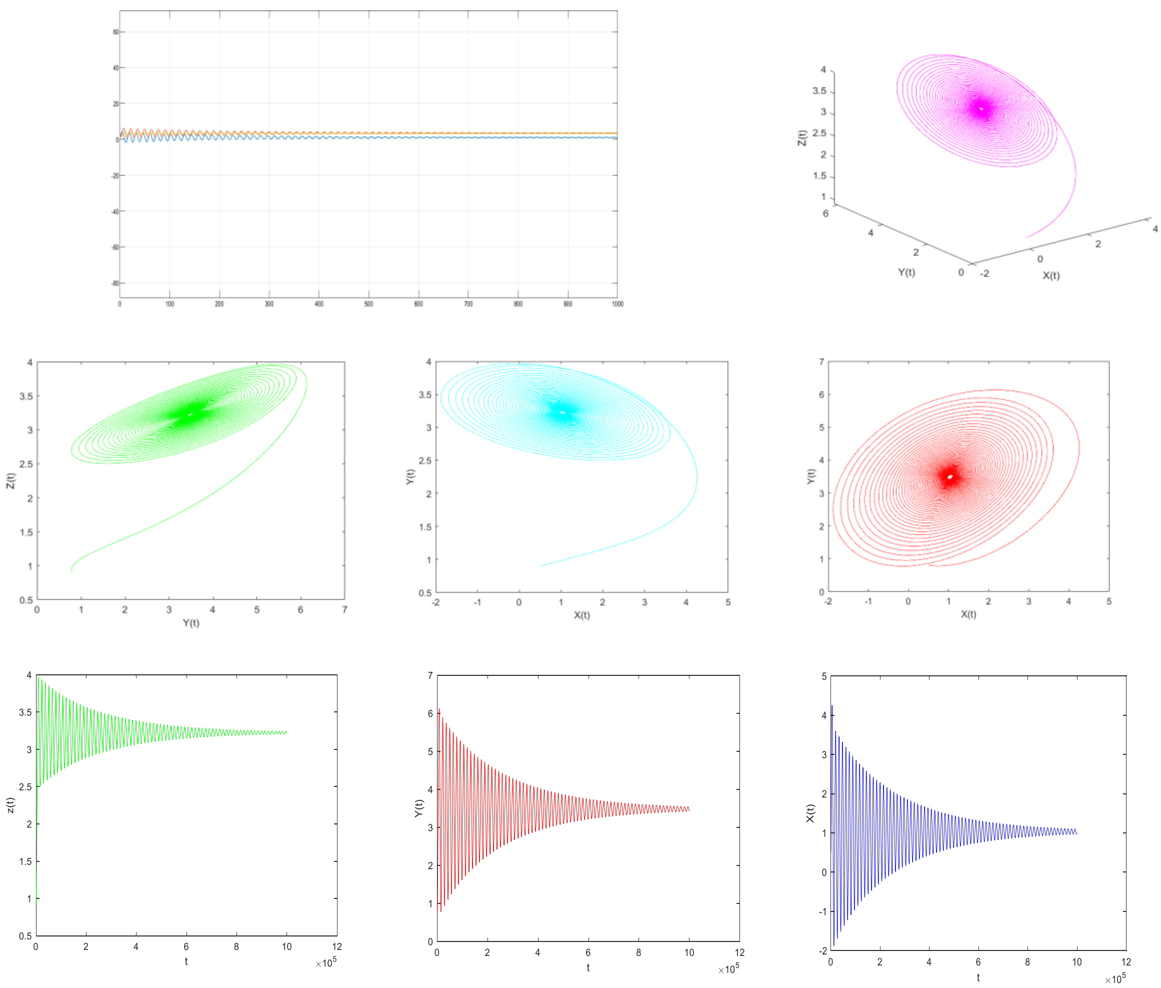

Figure 40. System diagrams for mode 2

In the third case, with the change of the initial values and the fixed values, the system has an oscillating periodicity, and therefore, the system has a limit cycle; in other words, the system has an oscillating cyclic path on which the states of the system are established. The limit cycle of the system can be used in the context of the cyclical economy, which aims to maintain products, compounds, and raw materials at the highest level of usefulness and value over time, to modify and reuse resources, and to distinguish between biological and technical cycles. Paying attention to this issue can help to recycle and thus reduce greenhouse gas emissions. The behavior of the system in this case is shown in Figure 7.

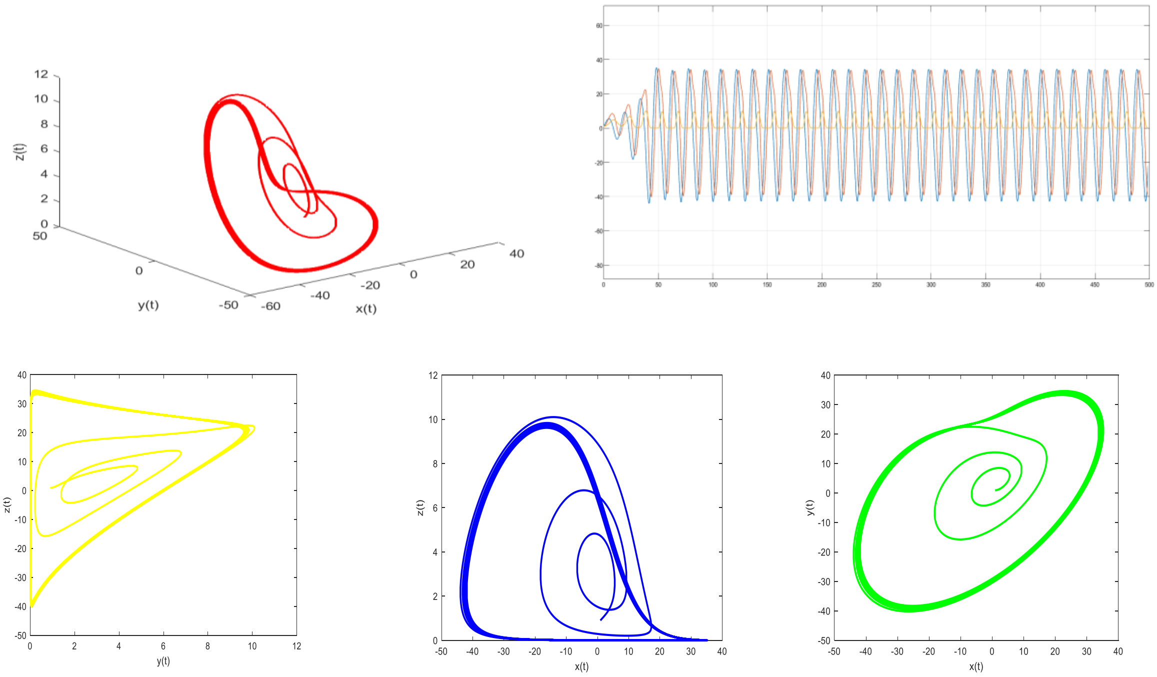

Figure 41. System diagrams for mode 3

In the fourth case, the system eventually converges to a stable equilibrium point where all three state variables stabilize and remain constant over time. This state of equilibrium signifies a balance in the system's dynamics, indicating a point where the system reaches a steady state and ceases to undergo significant changes. The attainment of this stable equilibrium holds significant implications for policy formulation. By understanding and leveraging this balance point, policymakers can design and implement strategies to reduce energy intensity. This reduction can lead to enhanced productivity, decreased environmental impacts such as lower greenhouse gas emissions, and overall improvements in sustainability. Figure 8 visually encapsulates this concept, showcasing the system's progression toward stability and the potential outcomes of achieving a balanced state. Identifying and utilizing such equilibrium

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points are crucial for guiding decision-making toward more efficient and sustainable energy practices, fostering long-term economic and environmental benefits.

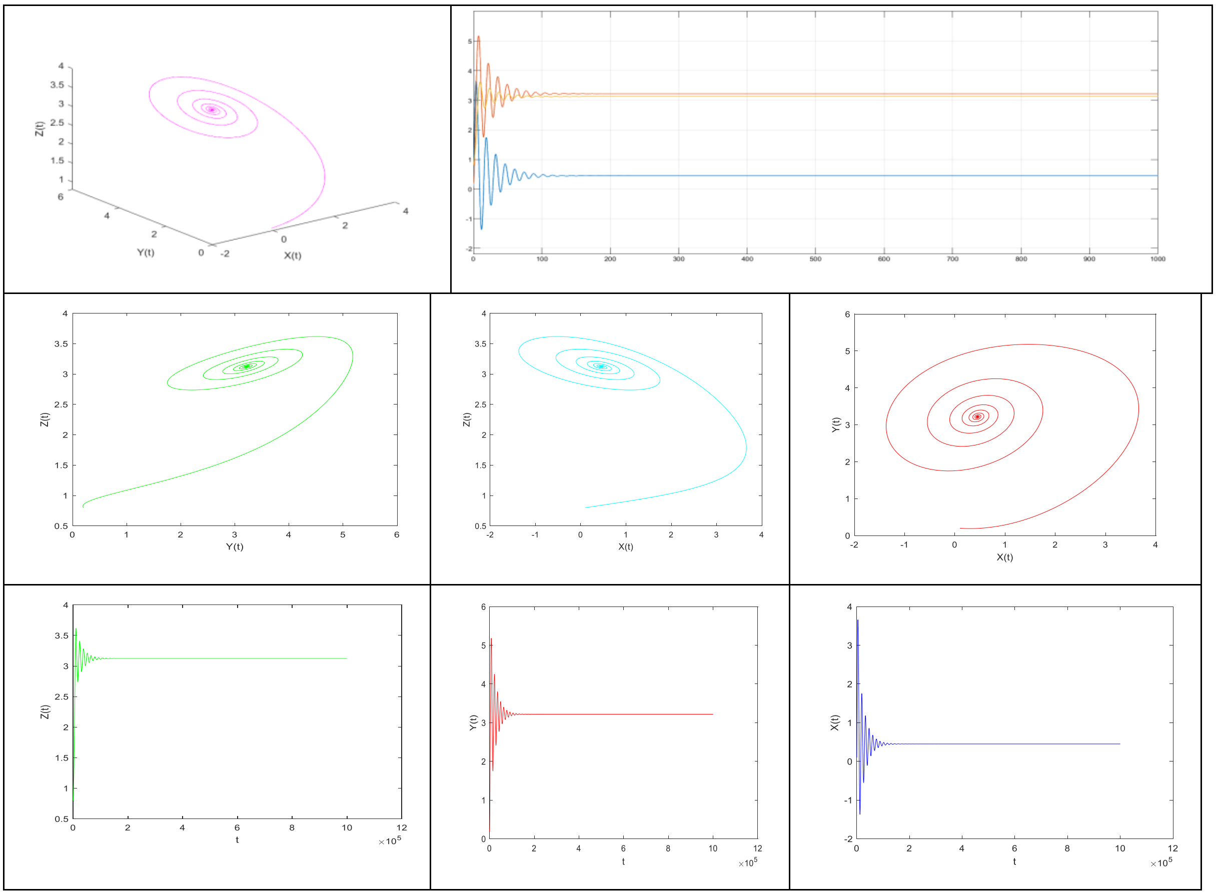

Figure 42. System diagrams for mode 4

Numerical simulation results show a complex nonlinear relationship between energy price, supply, and economic growth. The existing complexity is closely related to the parameters of the model. The model is observed for different values in different periods of the system, which leads to a stable state (Figure 8), intermittent and periodic changes (Figure 7), and a state of disorder and chaos (Figure 5). Also, according to the numerical simulation results, it can be seen that the system shows different states with the same parameters and under different initial conditions, which indicates the system's sensitivity to the initial values.

System Dynamics and Chaos Theory are both tools for studying complex systems. System Dynamics focuses on how systems change over time, especially in long-term, stable systems. Chaos Theory better analyzes systems where small changes lead to big, unpredictable effects. The choice between these approaches depends on the system's characteristics and the research question. Chaos Theory suits systems with non-linearity, emergent properties, and many unknown variables. System Dynamics works better for systems with a detailed understanding of their structure and relationships. However, these approaches can be used together for a more comprehensive understanding of complex systems.

5. Conclusions and suggestions

Most previous research has used economic models regarding energy supply, energy price, and economic growth (Mahadevan and Asafu-Adjaye, 2007; Lee and Chiu, 2011; Tang and Tan, 2013). They have either used empirical analysis (Odhiambo, 2010) (or they have used simple linear and quadratic relationships (Mumuni and Mwimba, 2023; Berk and Yetkiner, 2014). Considering the highly effective factors on the energy supply system, energy price and economic growth, and the complex and non-linear relationships between factors, it is necessary to use the theory of non-linear dynamic systems (chaos) to reduce modeling errors. In this research, after creating a non-linear dynamic model, the execution model and the behavior of the system have been investigated using numerical simulation. Small changes in the initial values change the behavior of the system drastically and the system shows high sensitivity to the initial values. Also; The numerical simulation results show that the chaos of the system is controlled. In other words, the chaotic behavior of the system reached a limit cycle and finally a stable point. Therefore, according to the findings of this research, it is recommended that future studies delve deeper into the theoretical aspects by employing the Lyapunov function to analyze the model's behavior.

Additionally, conducting bifurcation analysis to estimate parameters and establish tolerance thresholds for parameters and constant values within the model should be considered. Practically, utilizing authentic data from Iran's economy is crucial to effectively tackle the intricate challenges within the energy economy and macroeconomic variables. Furthermore, implementing diverse strategies and crafting tailored policies in the energy economy sector, which intersects with environmental, livelihood, and economic concerns, can offer viable solutions to current and future issues in these domains. By developing a novel system tailored to the economic landscape, researchers can derive detailed energy intensity calculation formulas to explore the impact of control intensity on reducing energy intensity across various control strategies. Additionally, conducting quantitative evaluations can provide valuable insights into the effectiveness of control policies in decreasing energy intensity and the time required for implementation, facilitating informed decision-making and policy formulation within the energy sector.

Disclosure statement

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

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Investigating Strategies for Implementing Resilience Based on Industry 4.0 in the Electricity Supply Chain: A Combination of Soft and Hard Operational Research

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A B S T R A C T

Resilience is one of the most crucial parameters in the electricity supply chain, and the absence of this concept can lead to various issues in service provision. One perspective that can greatly contribute to resilience is utilizing the Industry 4.0 approach. This study examines the challenges and strategies for the flexibility of the electricity supply chain in the Industry 4.0 era. A descriptive-analytical method employing library research and field studies has been employed. Subsequently, using the factors and criteria obtained from Value-Focused Thinking (VFT) from Soft Operational Research and verification by literature, a fuzzy IVIF-WASPAS-based analysis was conducted. The decision-making team comprised internal experts in the electricity supply chain in Iran, focusing on the principles of resilience in the Industry 4.0 era to analyze key issues. A case study was also conducted within the electricity supply chain, incorporating insights from academic experts and the team's experiences. Strategies like smart network systems, blockchain technology, cybersecurity, and education are fundamental to enhancing the supply chain's flexibility. This study's findings indicate a long journey in developing Industry 4.0 in Iran's electricity supply chain. However, relying on the proposed strategies can minimize existing issues and propel the system toward growth.

Keywords

Keywords: Electricity supply chain, Industry 4.0, Fuzzy IVIF-WASPAS, Value-Focused thinking, Soft operational research.

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1. Introduction

Considering incomplete information about future events, there is always a presence of risk and uncertainty. In other words, uncertainty about the future creates risks (Alamerew and Brissaud, 2020). This risk in the supply chain involves the potential occurrence of events that hinder the flow of materials and information, leading to disruptions in its performance (Borazon et al., 2022). In this regard, one of the current challenges for businesses is the management and reduction of risks arising from resilient supply chain design. Resilience has gained attention as a distinctive capability by organizations to maintain sustainability and continuity in a turbulent economic environment. From a supply chain resilience perspective, it refers to its ability to confront disturbances, provide responses, improve, and grow without interrupting customer service (Hosseini et al., 2019).

Resilience is a significant and interdisciplinary concept addressed in various fields, such as ecology, engineering, and beyond. Multiple definitions and quantitative methods for assessing resilience have been proposed, drawing much attention to this concept (Mishra et al., 2019). Facing complexities and unpredictabilities in supply chain management within disruption-prone business environments, achieving resilience capabilities to cope with or prevent disruptions is inevitable (Wang et al., 2019). Based on supply chain resilience studies, emphasis has been placed on identifying and analyzing supply chain vulnerabilities against potential disruptions and enhancing resilience capabilities to counter these vulnerabilities (Wangsa and Wee, 2019). Resilience in the electrical industry is crucial because it ensures the continuous delivery of electricity despite disruptions, whether from natural disasters, cyber-attacks, or equipment failures. This ability to anticipate, respond to, and recover from such disturbances is essential for maintaining energy security and supporting economic stability and public safety.

In 2021, the average Iranian consumed 3,160 kWh of electricity per year. It is slightly higher than the world average of 2,800 kWh per year. Iran's average electricity consumption per capita is slightly higher than the world average (Figure 1), which indicates a significant reliance on electricity for daily activities. Ranked 37th in the world for electricity consumption per capita, Iran's electricity needs are influenced by its climatic conditions, particularly the hot climate that necessitates increased energy consumption for air conditioning and cooling. Additionally, rapid urbanization has resulted in more households using energy-intensive appliances. Moreover, the government's subsidizing electricity prices has made electricity affordable for the population, further driving demand.

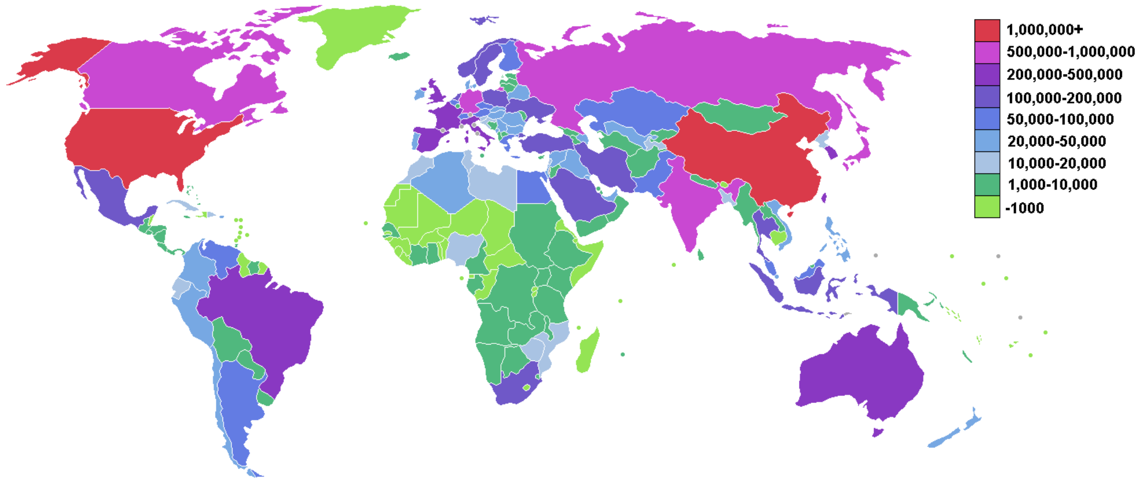

Figure 43. Average electricity consumption by countries in million kWh (CIA Factbook).

Despite being a net exporter of electricity, Iran's large installed capacity for electricity generation mainly depends on fossil fuels (Saghaei et al., 2020). It underscores the need for a robust and resilient electricity supply chain to ensure consistent power availability and stability, especially given the country's reliance on electricity for various sectors and the potential environmental impacts of fossil fuel-based generation (Hosseini et al., 2019). Ensuring the resilience of the electricity supply chain is crucial to maintaining economic activities, public services, and the overall well-being of the population, highlighting its vital significance in Iran's energy landscape (Wangsa and Wee, 2019).

With the rapid advancement toward Industry 4.0, there is a fundamental need to enhance and align the supply chain with these transformations (Mastos et al., 2021). The necessary resilience capabilities to address disruptions arising from the Fourth Industrial Revolution and ensure non-interruption of organizational activities have become essential (Lasi et al., 2014). The need to analyze supply chain vulnerabilities and strengthen resilience capabilities against them holds greater significance in supply chain management, especially in today's complex and dynamic environment (Tsaramirsis et al., 2022). Considering the significance of the electricity industry as a vital foundation for other industries and services, economic development and societal well-being are heavily dependent on a consistent power supply. Hence, ensuring a sustainable and resilient electricity supply chain has become a critical national concern (Hosseini et al., 2019; Vafadarnikjoo et al., 2022). As energy demands increase in the modern world, dependence on electricity as a primary energy source grows, and ensuring its sustainable supply becomes imperative for every country's society and economy (Richter et al., 2022; Queiroz et al., 2020). Consequently, disruptions in the electricity supply chain can lead to serious economic and societal consequences. For example, summer electricity crises can impact the production and distribution of goods and services, causing extensive economic and social damage (Paoli and Gül, 2022; Mishra et al., 2019; Chen et al., 2023).

Therefore, the concept of electricity supply chain resilience, as the ability to confront disruptions, provide rapid responses and continuously improve in today's highly risky environment, holds a significant position (Ahmad et al., 2022; Robert et al., 2022; Tsaramirsis et al., 2022; Lahtinen et al., 2017). Ultimately, the importance of electricity supply as a fundamental factor for economic development and societal welfare, coupled with the need to seriously address electricity supply chain resilience in the face of future challenges and transformations, is paramount (Hosseini et al., 2019). In this regard, research and planning efforts to ensure sustainable performance and responsiveness to disruptions in the electricity supply chain are highly crucial to providing energy services to society and industries sustainably and reliably.

In conclusion, this study makes significant contributions to the understanding and enhancement of the electricity supply chain's resilience through the lens of Industry 4.0. By investigating the challenges and strategies related to flexibility in the Industry 4.0 era (Lasi et al., 2014; Oliveira-Pinto et al., 2019; Gao et al., 2017). This study fills a critical gap in the literature surrounding the application of advanced technological paradigms in the electricity supply chain. Utilizing a descriptive-analytical approach that combines library research, field studies, and a comprehensive fuzzy IVIF-WASPAS-based analysis underscores this research’s rigor and multidimensional nature. To clarify the innovative content and methodology articulated in the problem statement, this paper introduces the Variable Flexibility Threshold (VFT) model as a novel approach to managing uncertainty and enhancing adaptability in the electricity supply chain. The VFT model leverages real-time data and adaptive decision-making processes to adjust flexibility thresholds based on prevailing market conditions and supply chain disruptions. This approach not only underpins the theoretical contributions of our study but also provides a practical framework for implementing Industry 4.0 technologies effectively. By integrating the VFT model, we offer a unique perspective on resilience and flexibility, addressing both theoretical gaps and practical challenges in the current landscape of the electricity supply chain.

Moreover, the involvement of internal experts from Iran's electricity supply chain and the integration of academic insights through a real case study further validate the practical implications of the findings. Ultimately, this research is a valuable guide for stakeholders and decision-makers in navigating the complexities of Industry 4.0 integration within the electricity supply chain, fostering resilience and sustainable development.

2. *Literature review*

The integration of Industry 4.0 concepts in the electric supply chain is a critical aspect of the fourth industrial revolution, offering the transformative potential for enhanced efficiency, innovation, and cost reduction (Mastos et al., 2021; Bressanelli et al., 2021; Alamerew and Brissaud, 2020). This integration involves advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), big data, and robotics, which enable improved processes and intelligent communication within the electricity supply chain (Zhao et al., 2021; Mishra et al., 2019; Chen and Fan, 2023). The literature highlights the considerable benefits of Industry 4.0 adoption in the electricity supply chain, including increased efficiency, cost reduction, heightened security, and innovation (Wang et al., 2019; Pamucar et al., 2022).

An essential focus in this domain is the interconnectedness and communication among equipment and devices within the electricity supply chain. Industry 4.0 facilitates data exchange between producers, distributors, and consumers using sensors and smart devices. At the same time, the IoT supports data collection related to electricity production, distribution, and consumption, contributing to efficiency enhancement and energy optimization (Paoli and Gül, 2022; Pamucar et al., 2022; Ahmad et al., 2022). Moreover, AI can address load fluctuations, workforce estimation, and energy optimization, further exemplifying the potential of Industry 4.0 in improving the electricity supply chain (Hosseini et al., 2019).

Saghaei et al. (2020) highlighted essential supply chain management concepts within the electricity sector, including collaboration, flexibility, and knowledge sharing. The principles of supply chain management in electricity, encompassing risk management, innovation, and supplier evaluation, were outlined. Hosseini-Motlagh et al. (2020) addressed uncertainty in designing a reliable and sustainable electricity supply chain network, introducing a multi-objective optimization model incorporating reliability measures and corporate social responsibility aspects. Richter et al. (2022) underscored the significance of the electricity supply chain in enhancing production, transportation, and consumption processes.

Moreover, the literature also examines specific risk and security aspects of power supply chains. Vafadarnikjoo et al. (2022) introduced a vulnerability assessment framework for evaluating risks associated with the electric power supply chain in the United Kingdom, highlighting the relationship among these risks and presenting a novel hesitant expert selection

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model. Lotfi et al. (2022) studied resilience and sustainable healthcare supply chains using a hybrid fuzzy and data-driven robust optimization approach. The findings of this study shed light on the importance of robust optimization techniques in enhancing the resilience of the healthcare supply chain. Dubey et al. (2023) explored the role of dynamic digital capabilities in enhancing supply chain resilience. Their study emphasized the significance of government effectiveness in facilitating digital capabilities that contribute to the supply chain's resilience.

Zhao et al. (2023) examined the impact of supply chain digitalization on resilience and performance. They proposed a multi-mediation model highlighting the complex interplay between digitalization, resilience, and supply chain performance. Zamani et al. (2023) conducted a systematic literature review on applying artificial intelligence and big data analytics to enhance supply chain resilience. The findings of this review underscored the potential of advanced technologies in strengthening the resilience of supply chains. Aityassine et al. (2022) investigated the effect of supply chain resilience on the performance of chemical industrial companies. Their study provided insights into the positive impact of resilience on supply chain performance.

Although the reviewed literature has provided valuable insights into Industry 4.0 integration in the electricity supply chain, a notable gap exists in understanding and addressing the specific challenges of implementing Industry 4.0 in Iran's electric supply chain. While the literature emphasizes the potential benefits and methodologies for analysis, a comprehensive investigation into the practical challenges, barriers, and strategies to overcome them within the Iranian context is lacking. Thus, a potential research direction would be to conduct a comprehensive empirical study focusing on the Iranian electricity supply chain and its readiness for Industry 4.0 integration. This research could involve qualitative and quantitative data collection to identify the unique challenges that Iranian organizations face in adopting Industry 4.0 technologies. Additionally, the study could explore potential strategies, policies, and best practices to overcome these challenges and facilitate the successful implementation of Industry 4.0 concepts in the Iranian electric supply chain. By addressing this gap, researchers can provide practical insights to policymakers, industry leaders, and practitioners to drive the effective integration of Industry 4.0 in the Iranian electricity supply chain, contributing to sustainable development and improved efficiency in the sector.

2.1. Criteria, sub-criteria, and extracted strategies from literature

In order to conduct further analyses in the methodology section, criteria and strategies for addressing the challenges of implementing a resilient electricity supply chain in the Industry 4.0 context need to be identified. Accordingly, three overarching criteria of intelligent performance, resilience performance, and environmental performance have been considered for the system, accompanied by the specified criteria, sub-criteria, and sources as presented in Table 1:

Table 21. Performance indicators of the electricity supply chain

Criteria	Sub-Criteria	Sub criteria description	References
Intelligent performance (IP)	Automation and intelligent control (IP-1)	Automating electricity supply chain processes with intelligent systems, including automatic execution of production, transmission, and distribution tasks, and adjusting parameters in response to network changes.	Richter et al., (2022), Queiroz et al., (2020), Hosseini-Motlagh et al., (2020)
	Advanced Forecasting and Analysis (IP-2)	Utilizing data analysis and AI to predict electricity supply chain events and disruptions, identifying issues through historical data and forecasts, and implementing preventive measures for performance optimization.	Richter et al., (2022), Queiroz et al., (2020), Mastos et al., (2021), Ahmad et al., (2022)
	Interaction and intelligent communication (IP-3)	Enabling communication between electricity supply chain components through smart technologies, facilitating real-time interaction among equipment, sensors, systems, and managers to enhance decision-making and manage disruptions.	Richter et al., (2022)
	Flexibility and quick response (IP-4)	Swiftly adapting the electricity supply chain to sudden changes, customer demands, and environmental shifts using smart technologies and available data to adjust electricity production, distribution, and consumption as needed.	Zhao et al., (2021), Bas, (2013), Oliveira-Pinto et al., (2019)
Resilience performance (RP)	Identification and prediction of risks (RP-1)	Detecting and analyzing advanced risks and threats in the electricity supply chain through data analysis, predictive models, and AI, allowing for early identification and application of preventive measures.	Chen et al., (2023), Chen and Fan, (2023)
	Specialized management and coordination of supply chain components (RP-2)	Integrating and coordinating electricity supply chain components during disruptions using smart technologies and connected systems to foster participation, cooperation, and specialized decision-making.	Zhao et al., (2021), Vafadarnikjoo et al., (2022)
	Preventive and Corrective Strategies (RP-3)	Developing and implementing preventive and corrective strategies for managing disturbances in the electricity supply chain, leveraging data, analytics, and predictive models for proactive actions and responsive improvements.	Chen and Fan, (2023), Urciuoli et al., (2014)
Environmental performance (EP)	Sustainable Resource Management (EP-1)	Sustainably and optimally managing electricity production resources over time using smart technologies, accurately monitoring resource consumption, and enhancing overall productivity.	Zhao et al., (2021), Gao et al., (2017), Lahtinen et al., (2017)

3. Research methodology

The present study investigates the challenges and strategies of flexibility in the electricity supply chain in the Industry 4.0 era. This study adopts a descriptive-analytical approach to examine the fundamental problems in this domain. To this end, a literature review method has been utilized to gather information and identify performance indicators of the electricity supply chain from various sources. Additionally, through field study methodology, questionnaires were distributed to industry experts and professionals, and performance indicators and strategies were evaluated. A purposive judgmental sampling technique was also employed to select the experts. VFT, as a soft operational research approach, has been incorporated as a cognitive method for a comprehensive exploration and definition of strategies, leveraging expert interviews to gather opinions and insights. This approach allows for a deep understanding of the challenges and complexities within the electricity supply chain.

Furthermore, a decision-making team of experts from within the Tehran Electric Company's supply chain has been formed, emphasizing the importance of adapting to existing challenges and variables. The insights of academic experts, including three professors and researchers, and the experiences of team members, including power system engineers, energy analysts, load dispatchers, and grid managers, have played a crucial role in enhancing the performance of the supply chain. To analyze and refine the identified strategies, the study employs Fuzzy WASPAS-IVIF, providing a robust framework for evaluating and prioritizing strategies in the dynamic landscape of the electricity supply chain.

3.1. Value-Focused thinking (VFT)

VFT, as developed by Keeney in 1992, integrates concepts from problem structuring methods and soft Operational Research (OR), serving as a pragmatic tool in operational research practices tailored to address client needs, problem owners, and stakeholders. OR involves creating simplified mathematical models of complex real-world systems, focusing on defining useful variables and relationships that guide real-world actions efficiently. This process is underpinned by problem structuring, which is essential for transforming unstructured real-world issues into manageable problems with solvable mathematical models. VFT specifically aids in mapping out stakeholders' concerns into a structured and measurable set of variables, preparing the ground for constructing formal utility models that can guide decision-making processes (Figure 2).

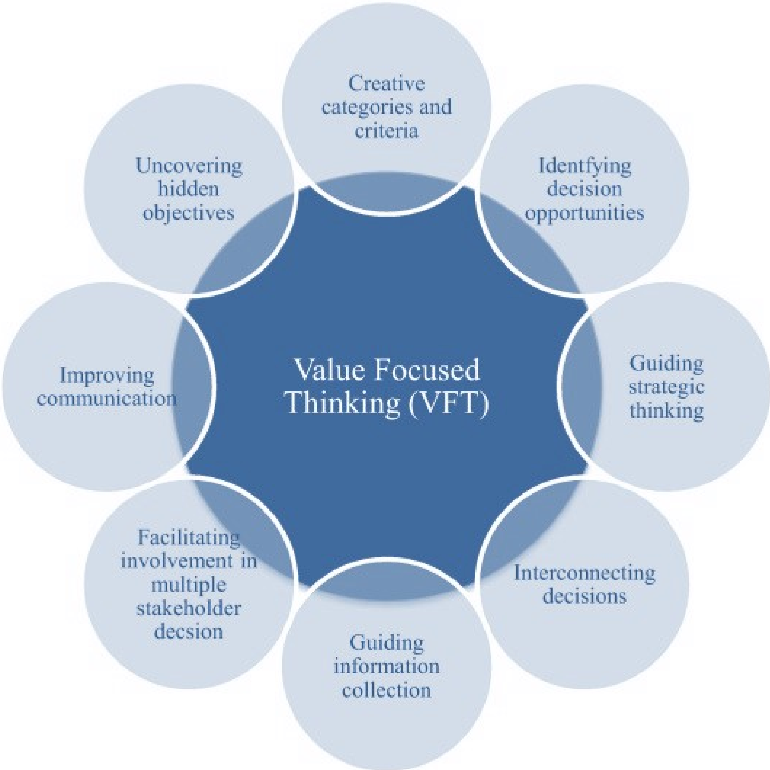

Figure 44. Value-Focused thinking process and elements

In the realm of soft OR, which uses elements of OR modeling to facilitate decision-making without necessarily arriving at a detailed formal solution, VFT plays a crucial role. It simplifies the formal OR methods to adapt to the dynamics of group and organizational processes, often culminating in qualitative decision-making by stakeholders. This approach is particularly effective in decision conferencing contexts, where VFT can be seamlessly integrated with decision analysis models to foster group interactions and facilitate consensus-building. By bridging problem structuring and decision analysis, VFT helps clarify and prioritize values and objectives within organizational processes and generates and evaluates strategic alternatives, making it a versatile tool in both structured decision analysis and broader soft OR applications.VFT application in this research

VFT represents a key application of soft operational research and systems thinking methodologies tailored to address strategic decision-making within the electricity supply chain amidst the complexities of Industry 4.0. This structured decision-making approach aligns supply chain strategies with the core organization's values and long-term objectives. Initially, the process involves identifying key stakeholders—experts, decision-makers, and other relevant parties within the electricity supply chain. A diverse team of eight experts is assembled to bring a broad range of perspectives and deep industry insights. During structured meetings, these experts engage in systems thinking to map out the interdependencies and potential impacts within the supply chain. They collaboratively work to define and prioritize the core values and strategic objectives, ensuring that the identified strategies are feasible but also integrative and systemic.

The application of VFT within this framework facilitates a holistic approach to decision-making. It emphasizes the importance of comprehensive engagement and collective intelligence, fostering a dynamic exchange of ideas underpinning robust, adaptable strategies. It is particularly crucial in navigating the rapidly evolving technological landscape of Industry 4.0, where the ability to anticipate and react to changes can significantly influence organizational resilience and adaptability. Furthermore, VFT supports operationalizing these strategies by ensuring they resonate with the organization's foundational principles and respond effectively to the current and anticipated challenges. This methodological approach not only underscores the technical feasibility of the strategies but also enhances their sustainability and relevance in the face of future developments. In summary, integrating VFT as a soft and systemic tool within the quantitative approaches provides a strategic, value-aligned approach to managing the complexities of the electricity supply chain in the era of Industry 4.0. By focusing on core values and the systemic impact of decisions, VFT helps to forge strategies that are effective in the short term and sustainable and adaptive over the long haul, thus aligning with the overarching goals and values of the electricity supply chain.

3.2. Basic concepts of intuitive fuzzy sets with interval values

Intuitive fuzzy sets are described by three functions: degree of membership, degree of non-membership, and degree of uncertainty. An intuitionistic fuzzy set A of the reference set X is defined as follows (Equation1);

$$A = \{\langle x, \mu_A(x), v_A(x)\rangle | x \epsilon X, \} \tag{1}$$

According to this definition, the degree of membership and the degree of non-membership are defined as follows (Equation 2 and 3):

$$\mu_A : X \rightarrow [0\,,1] \tag{2}$$

$$v_A : X \rightarrow [0\,,1] \tag{3}$$

And the following equation always holds (Equation 4):

$$0 \le \mu_A(X) + v_A(X) \le 1 \tag{4}$$

For each $x \epsilon X$ ، $\mu_{\tilde{A}}(x)$and $v_{\tilde{A}}(x)$are the interval values that $\mu_{AU}(x)$ ،$\mu_{AL}(x)$ ، $v_{AL}(x)$ ،$v_{AU}(x)$ form the upper limit and lower limit of this interval, respectively. The IVIF set is defined as follows in Equation. 5 and 6 (Zavadskas et al., 2014):

$$A = \{\langle x, [\mu_{AL}(x), \mu_{AU}(x)], [v_{AL}(x), v_{AU}(x)]\rangle | x \epsilon X, \} \tag{5}$$

$$0 \le \mu_{AU}(X) + v_{AU}(X) \le 1, \qquad 0 \le \mu_{AL}(X) + v_{AU}(X) \le 1 \tag{۶}$$

The interval intuitionistic fuzzy set is represented as $\tilde{A} = ([a,b],[c,d])$. If $\widetilde{A_1} = ([a_1,b_1],[c_1,d_1])$ and $\widetilde{A_2} = ([a_2,b_2],[c_2,d_2])$ are two IVIF numbers, the intuitive interval fuzzy operators are as defined below becomes (Equation 7-11):

$$\tilde{A}_1 + \tilde{A}_2 = ([a_1 + a_2 - a_1 a_2, b_1 + b_2 - b_1 b_2], [c_1 c_2, d_1 d_2]) \tag{7}$$

$$\tilde{A}_1 . \tilde{A}_2 = ([a_1, a_2, b_1 b_2], [c_1 + c_2 - c_1 c_2, d_1 + d_2 - d_1 d_2]) \tag{8}$$

$$\lambda \tilde{A} = ([1 - (1 - a_1)^{\lambda}, 1 - (1 - b_1)^{\lambda}], [c_1^{\lambda}, d_1^{\lambda}]) \qquad \lambda > 0 \tag{9}$$

$$\tilde{A}_1^{\lambda} = ([a_1^{\lambda}, b_1^{\lambda}], [1 - (1 - c_1)^{\lambda}, 1 - (1 - d_1)^{\lambda}]) \qquad \lambda > 0 \tag{10}$$

$$\frac{\tilde{A}_1}{\tilde{A}_2} = ([\min(a_1, a_2), \min(b_1, b_2)], [\max(c_1, c_2), \max(d_1, d_2)]) \tag{11}$$

To compare two IVIF numbers, the score function, $s(\tilde{A})$ is defined (Equation 12):

$$s(\tilde{A}) = \frac{1}{2}(a - c + b - d) \tag{12}$$

If $s(\tilde{A}) \in [-1,1]$, the accuracy function $h(\tilde{A})$ is used (Equation 13):

$$h(\tilde{A}) = \frac{1}{2}(a + c + b + d) \tag{13}$$

If $s(\tilde{A}_1) < s(\tilde{A}_2)$ we can conclude $(\tilde{A}_1) < (\tilde{A}_2)$؛

If $s(\tilde{A}_1) = s(\tilde{A}_2)$, then:

If $h(\tilde{A}_1) = h(\tilde{A}_2)$ we can conclude $(\tilde{A}_1) = (\tilde{A}_2)$؛

If $h(\tilde{A}_1) < h(\tilde{A}_2)$ we can conclude $(\tilde{A}_1) < (\tilde{A}_2)$.

3.3. Intuitive fuzzy WASPAS with interval values

WASPAS is one of the new decision-making techniques (Pamucar et al., 2022) and is categorized as multi-criteria decision-making methods (Khazaei et al., 2023; Zare et al., 2015; Wang et al., 2022). This method is a combination of the weighted sum model (WSM) and the weighted product model (WPM) (Putra et al., 2016; Taghipour et al., 2023). This model is highly effective in complex decision-making problems, and its results are highly accurate.

In this research, an expanded version of the WASPAS method (Zavadskas et al., 2014), namely WASPAS-IVIF, is presented (Zavadskas et al., 2014; Ilbahar, 2022), which can be applied in the environment of ambiguous decision making and uncertainty. Suppose the decision problem is a set of m number of options including $\tilde{A}_m, \dots \tilde{A}_2, \tilde{A}_1$ and n number of criteria including $\tilde{c}_n, \dots \tilde{c}_2, \tilde{c}_1$. Performance review and ranking of each option i in criterion j is done based on IVIF numbers. Also, k determines the number in relation to the importance of weight. w_j^k is k's expert's judgment about the importance of j's criterion. Table 2 decision-making variables will participate in the decision-making process. The decision maker expresses his opinions and evaluations in the language that is used to determine the weight of the criteria:

Table 22. Linguistic variable to determine the relative importance of criteria

Linguistic variable	IVIF Numbers
Very important (VI)	([0.9,0.9], [0.1,0.1])
Important (I)	([0.4,0.7625], [0 ,0.2115])
Medium (M)	([0.15,0.5125], [0.25,0.4625])
Unimportant (U)	([0 ,0.3625], [0.4,0.6125])
Very Unimportant (VU)	([0.1,0.1], [0.9,0.9])

The following formula is used to summarize the opinion of decision makers in a matrix (Equation 14):

$$w_i = \frac{1}{k}\left[\sum_{\rho=1}^{k} \widetilde{w}_i^{\rho}\right], \qquad i = 1,2,3, \dots, m \tag{14}$$

ρ represents the number of decision makers. Another element that must be calculated at this stage is the evaluation of options against the criteria according to the following matrix:

$$\tilde{X}^k = \begin{bmatrix} \tilde{x}_{11}^k & \tilde{x}_{12}^k & \cdots & \tilde{x}_{1n}^k \\ \tilde{x}_{21}^k & \tilde{x}_{22}^k & \cdots & \tilde{x}_{2n}^k \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1}^k & \tilde{x}_{m2}^k & \cdots & \tilde{x}_{mn}^k \end{bmatrix}$$

$$\tilde{x}_{ij}^k = \left(\left[\mu_{Lij}^k, \mu_{Uij}^k\right], \left[v_{Lij}^k, v_{Uij}^k\right]\right)$$

IVIF numbers, as specified in Table 3, are used to replace linguistic information to evaluate options against criteria:

Table 23. IVIFN scale for evaluating options against criteria

Linguistic variable	IVIF Numbers
Extremely Good (EG)	([1,1], [0,0])
Perfectly good (PG)	([0.9,0.9], [0.1,0.1])
Very Good (VG)	([0.7333,0.825], [0,0.125])
Good (G)	([0.6333,0.725], [0.1,0.225])
Medium Good (MG)	([0.5333,0.625], [0.2,0.325])
Medium (M)	([0.4333,0.525], [0.3,0.425])
Medium bad (MB)	([0.3333,0.425], [0.4,0.525])
Bad (B)	([0.15,0.2875], [0.42,0.6375])
Very bad (VB)	([0,0.1375], [0.6,0.7875])
Extremely Bad (EB)	([0.1,0.1], [0.9,0.9])

The next step (Equation 15) is to summarize the opinion in a matrix, meaning equation 16 is used (Putra et al., 2016, Ilbahar, 2022):

$$\tilde{x}_{ij} = \frac{1}{k}\left[\sum_{\rho=1}^{k} \tilde{x}_{ij}^{\rho}\right], \qquad j = 1,2,3,\ldots,n; \qquad 1 \le \rho \le k \tag{15}$$

As a result, the decision matrix with n options and m criteria is formed as follows:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}$$

$$\tilde{x}_{ij} = \left(\left[\mu_{Lij}, \mu_{Uij}\right], \left[v_{Lij}, v_{Uij}\right]\right)$$

The first step in the WASPAS-IVIF technique is the normalization of the X matrix. For this purpose, the criteria are divided into two categories: profit, B and cost, C (Pamucar et al., 2022). If $j \in B$, then (Equation 16-19):

$$\tilde{x}_{ij} = \frac{\tilde{x}_{ij}}{\max_i \tilde{x}_{ij}} \tag{16}$$

$$\max_i \tilde{x}_{ij} = \left(\left[\max_i \mu_{Lij}, \max_i \mu_{Uij}\right], \left[\min_i v_{Lij}, \min_i v_{Uij}\right]\right) \tag{17}$$

If $j \in C$ is

$$\tilde{x}_{ij} = \frac{\min_i \tilde{x}_{ij}}{{}_i\tilde{x}_{ij}} \tag{18}$$

$$\min_i \tilde{x}_{ij} = \left(\left[\min_i \mu_{Lij}, \min_i \mu_{Uij}\right], \left[\max_i v_{Lij}, \max_i v_{Uij}\right]\right) \tag{19}$$

According to the WASPAS-IVIF method, the total relative importance of the i-th criterion can be calculated as Equation 20:

$$Q_i^{(1)} = \sum_{j=1}^{n} \tilde{\tilde{x}}_{ij}\, w_j \tag{20}$$

Equations 7 and 8 are used to calculate $Q_i^{(1)}$. On the other hand, the relative importance of the entire i-th criterion can also be calculated using Equation. 21 and 22 (Zavadskas et al., 2014):

$$Q_i^{(2)} = \prod_{j=1}^{n} \tilde{\tilde{x}}_{ij}^{\;\tilde{w}_j} \tag{21}$$

$$(\tilde{\tilde{x}}_{ij})^{\tilde{w}_j} = \left(\left[min\left(\mu_{Lij}, \mu_{Lj}\right), min\left(\mu_{Uij}, \mu_{Uj}\right)\right], \left[max\left(v_{Lij}, v_{Lj}\right), max\left(v_{Uij}, v_{Uj}\right)\right]\right) \tag{22}$$

Finally, Eq. 23 is used to rank the criteria using the WASPAS method:

$$\tilde{Q}_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} \tag{23}$$

Equations 9 and 7 are used to calculate $\tilde{Q}_i$.

4. Research findings

4.1. VFT analysis

In the initial stage of the research, a team of decision-makers comprising eight experts from diverse backgrounds, including managers, experts, and professors, was assembled as outlined in the research methodology. Various strategies were meticulously identified in the VFT process involving these expert participants to address challenges and enhance flexibility in the electricity supply chain within the Industry 4.0 era (Table 4). Implementing intelligent network systems (S1) emerged as a key approach among these strategies. By harnessing smart networks capable of collecting, analyzing, and transmitting real-time data, precise management of electricity production and consumption, both in terms of time and location, is facilitated.

Table 24. Strategies for Overcoming Challenges in Implementing a Resilient Electricity Supply Chain

Code	Strategy	Description	Reference
S1	Using intelligent network systems	Smart networks, with their ability to collect, analyze, and transmit accurate and up-to-date data, herald a new era in electricity production and consumption management, promising a future of unprecedented efficiency and control.	Zare et al., (2015), Wang et al., (2019)
S2	Anticipation and prevention of disorders	The proactive use of advanced technologies, such as the Internet of Things (IoT) and data analysis, to detect and predict malfunctions early on instills confidence in the resilience of our electricity supply chain.	Saghaei et al., (2020)), Richter et al., (2022)
S3	Use of renewable energy	By shifting our focus to energy production from renewable sources such as solar and wind, people are reducing their dependence on fossil fuels and paving the way for a more sustainable and stable supply chain.	Zhao et al., (2021), Saghaei et al., (2020)
S4	Use of energy storage	Energy storage technologies and systems can help increase stability in the face of fluctuations in production and consumption.	Wang et al., (2019)
S5	Use of microgrid networks.	Creating local and independent networks for producing and consuming electricity using renewable sources helps to balance demand and supply.	Queiroz et al., (2020)
S6	Using blockchain technology	Using blockchain technology to increase transparency, security, and accuracy in transactions and information transfer in the electricity supply chain can have a positive effect.	Queiroz et al., (2020)
S7	Using artificial intelligence and data analysis	Artificial intelligence and data analysis can effectively improve disruption prediction, optimize operations, and increase productivity in the electricity supply chain.	Queiroz et al., (2020)
S8	Development of advanced communication networks	Creating advanced and secure communication networks between different equipment and systems in the supply chain enables fast and accurate information exchange.	Wangsa and Wee, (2019)
S9	Strengthen cyber security	Increasing the security of networks and systems against cyber-attacks can be important to prevent disruptions and security threats.	Richter et al., (2022), Hosseini-Motlagh et al., (2020)
S10	Education and awareness	Creating awareness in society about the importance of electricity resilience and the role of Industry 4.0 technologies in improving it can help promote the required developments in the supply chain.	Vafadarnikjoo et al., (2022)

Furthermore, the strategies uncovered during the VFT sessions encompassed a comprehensive array, including the anticipation and prevention of disorders through advanced technologies like the Internet of Things (S2), the integration of renewable energy sources (S3) to enhance sustainability, the use of blockchain technology (S6) to bolster transparency and security, and the strengthening of cybersecurity measures (S9) to safeguard against potential disruptions. Additionally, a focus on education and awareness (S10) emerged as a crucial strategy, aiming to promote societal understanding of the significance of electricity resilience and the role of Industry 4.0 technologies in advancing improvements within the supply chain. These strategies collectively reflect a holistic and forward-looking approach toward fortifying the electricity supply chain in the era of Industry 4.0.

Moreover, the literature reviewfacilitated the recognition of linguistic variables, duly documented in Tables 2 and 3. Proceeding to the subsequent research stage, the relative significance of each index and sub-index was established through the expertise of the panel of experts, an essential step in the process, as depicted in Table 5.

Table 25. Relative importance of indicators and sub-indices

#	IP	RP	EP	IP-1	IP-2	IP-3	IP-4	RP-1	RP-2	RP-3
DM1	M	VI	U	VI	M	M	VU	I	U	VI
DM2	VI	M	VI	VI	VI	VI	VU	I	VI	VI
DM3	I	VU	I	M	I	VI	VU	VI	VI	VI
DM4	VI	I	VU	I	VI	U	VI	VI	M	VI
DM5	VI	I	M	I	VI	U	VI	VI	VI	VI
DM6	VI	VI	VI	M	M	VI	VI	VI	VI	VI
DM7	VI	VI	VI	VI	U	VI	VI	VI	VI	VI
DM8	VU	U	I	VI	VI	VU	VU	I	VU	VU

Step 5: In order to gather experts' opinions, the averaging method according to equation 14 was used. for example:

$$\widetilde{w}_1 = \frac{1}{8}\left[\sum_{\rho}^{8}([0.4,0.7625],[0,0.2115]) + ([0.9,0.9],[0.1,0.1]) + \cdots + ([0.9,0.9],[0.1,0.1])\right]$$

$$= ([0.99999985, 1\,], [\cdot,0.0000003642])$$

Step 6: By combining the opinions of experts and linguistic variables, the IVIF weights of indicators and sub-indices are as described in Tables 6:

Table 26. Aggregated weights of indicators

Criteria and Sub-Criteria	Locally aggregated weights
IP	[0.7485, 0.8225], [0, 0.17501]
RP	[0.6242, 0.70346], [0, 0.28890]
EP	[0.7532, 0.79405], [0, 0.19906]
IP-1	[0.276549, 0.53688], [0, 0.175019]
IP-2	[0.71514, 0.79520], [0, 0.19006]
IP-3	[0.6418578, 0.708395], [0.208707, 0.272394]
IP-4	[0.7, 0.7], [0.3, 0.3]
RP-1	[0.84202, 0.868354], [0, 0.143153]
RP-2	[0.7067167169, 0.7777392], [0.150129, 0.198]
RP-3	[0.89260, 0.86260], [0.1604, 0.1607]

Because the third index has only one sub-index, we consider its importance as one. Based on the rank order of the decision-making problem of the present research, the final weights of the sub-indices were obtained from the product of the local weights of the indicators in the local weights of the sub-indices of each of the indicators of the problem, which Table ۷ shows these weights:

Table 27. Final weights of sub-indices

Sub-Criteria	Final Weights
IP-1	[0.57511635, 0.66976334], [0, 0.32091634]
IP-2	[0.56128689, 0.64986296], [0, 0.34165628]
IP-3	[0.54483678, 0.61190355], [0.20870738, 0.38186085]
IP-4	[0.54940012, 0.57487816], [0.3, 0.42251270]
RP-1	[0.50055330, 0.60616453], [0, 0.38307443]
RP-2	[0.47968287, 0.56120632], [0.17550129, 0.43104936]
RP-3	[0.54050649, 0.61088411], [0.13160740, 0.38248840]
EP-1	[0.72532564, 0.79405263], [0, 0.19906558]

During Stage 3 of the research process, expert opinions were collected and aggregated using Equation 16. The resulting IVIF (Interval-valued intuitionistic fuzzy) decision matrix of expert opinions is presented in Appendix A1. This step facilitated the comprehensive synthesis of expert insights, contributing to the analytical framework's robustness and enriched decision-making process. Step 8: Using equations 16, 17, 18, and 19, the normalized IVIF decision matrix is calculated according to Appendix A2. Step 9: After calculating $Q_i^{(1)}$and $Q_i^{(2)}$ through equations 20 and 21, the values of $\tilde{Q}_i$ are determined according to Table 8.

Table 28. $\tilde{\mathbf{Q}}_{\mathbf{i}}$values

Strategies	$\tilde{Q}_i$
S1	[0.743349972, 0.817106485], [0.000000000, 0.217151760]
S2	[0.409193925, 0.535338164], [0.222354638, 0.209696697]
S3	[0.256828683, 0.405832631], [0.299830211, 0.168883582]
S4	[0.496928456, 0.627305665], [0.000000000, 0.242509585]
S5	[0.184903915, 0.276079113], [0.488400258, 0.147216919]
S6	[0.366258792, 0.492000017], [0.238890070, 0.189271880]
S7	[0.306473222, 0.455854733], [0.256295586, 0.182813609]
S8	[0.511336551, 0.638039114], [0.091083214, 0.213878104]
S9	[0.608131644, 0.714531781], [0.000000000, 0.220252736]
S10	[0.688267972, 0.776332034], [0.000000000, 0.225663948]

Step 10: Finally, each option's rank was calculated using the score function. Figure 3 shows the ranking of strategies.

Strategies	Score Function	Rank
S1	0.671652349	1
S2	0.256240377	6
S3	0.096973761	9
S4	0.440862268	4
S5	0.087317075	10
S6	0.21504843	7
S7	0.161609379	8
S8	0.422207174	5
S9	0.551205345	3
S10	0.603980263	2

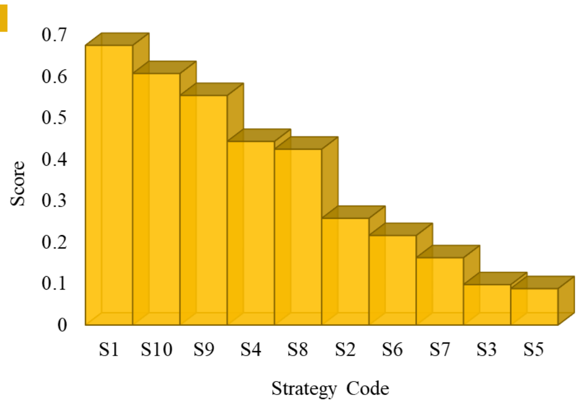

Figure 45. The final ranking of strategies

Considering the incoming strategies in facing the challenges and improving the flexibility in the electricity supply chain in the era of Industry 4.0, diverse strategies have been identified and evaluated to improve the abilities and deal with the obstacles. These strategies include using smart grid systems (S1) that improve the power grid's performance through automation and intelligent control. Also, predicting and preventing disruptions (S2) by using detailed data analysis and identifying disruption patterns so that they can be acted upon. Using renewable energy (S3) and using sustainable and environmental resources can help increase resilience and reduce environmental impacts.

According to the final calculation table, the ranking results can be evaluated. Based on the scoring function and ranking of the strategies, the strategy of using smart network systems (S1) and blockchain technology (S6) is ranked first and second, respectively. It shows that using blockchain in the electricity supply chain improves the security and transparency of transactions, reduces the possibility of errors, and increases the system's flexibility. Also, the strategy to strengthen cyber security (S9) and focus on education and awareness (S10) are among the top-rated strategies. As a result, the analysis of these tables shows that to increase flexibility and resilience in the electricity supply chain in the era of Industry 4.0, implementing smart technologies, using renewable resources, strengthening cyber security, and facilitating awareness and education can be among the key strategies.

5. Discussion and recommendations

This study highlights the essential role of Industry 4.0 technologies in enhancing the resilience of the electricity supply chain. By integrating advanced technologies such as smart grid systems, blockchain, and cybersecurity measures, the electricity supply chain can significantly improve flexibility and robustness against disruptions. The research findings suggest that these technologies facilitate better management and forecasting and ensure secure and transparent operations within the supply chain. The strategic use of these technologies is crucial, especially in a country like Iran, where energy demand is high, and the supply chain faces unique geopolitical and technical challenges.

- Electricity sector managers, like every energy systems, should actively pursue the integration of Industry 4.0 technologies (Ramezani et al., 2024). Implementing smart grid systems can enhance real-time data analysis and response capabilities, thus allowing for more efficient management of energy flows and immediate detection of faults or disruptions.
- As digital transformation escalates, cybersecurity becomes paramount. Managers need to ensure robust security protocols are in place to protect infrastructure from cyber threats (Kimani et al., 2019), which are becoming more sophisticated and frequent.

- Blockchain technology offers immense potential beyond cryptocurrency. In the electricity supply chain, it can be used to improve the accuracy, transparency, and efficiency of transactions and data management. This technology also helps mitigate fraud and errors, thereby enhancing trust among stakeholders.
- Educational programs that can help stakeholders understand the importance of Industry 4.0 technologies in the electricity supply chain are needed (Taghipour et al., 2023b). Training employees on operating and maintaining new technologies will be crucial for smooth integration and operation.
- Policymakers should provide support through incentives, subsidies, and clear regulations that promote the adoption of Industry 4.0 technologies (Sharma et al., 2021). Such policies could accelerate technological adoption and ensure a standardized approach across the industry.
- Collaboration between academia, industry, and government can lead to innovative solutions and strategies that enhance resilience. These collaborations can also facilitate shared learning and leverage expertise from various fields (Wang et al., 2022).

6. Conclusion

This research investigated strategies for enhancing resilience in the electricity supply chain within the context of Industry 4.0. The challenges and opportunities surrounding resilience implementation were explored through a descriptive-analytical approach incorporating a literature review, field studies, VFT, and fuzzy IVIF-WASPAS analysis. The study found that intelligent network systems, blockchain technology, cybersecurity strengthening, and education promotion constitute the foremost strategies based on expert evaluations. Smart grid capabilities involving real-time data exchange and AI-enabled analytics allow precise management of electricity flows. Blockchain provides transparency, security, and accuracy in supply chain transactions and communications. Robust cybersecurity defenses are essential to safeguard against disruptions.

Additionally, societal education and awareness are key enablers for advancing improvements. These findings have significant managerial and policy implications. Organizations must actively embrace Industry 4.0 technologies like automation, IoT, and data analytics to predict and mitigate disturbances through agile responses. Developing renewable energy infrastructure and AI systems will be pivotal for long-term resilience. Effective cooperation and open communication among stakeholders should also be fostered. For policymakers, the research underscores the need for investments, incentives, and standards to facilitate nationwide Industry 4.0 integration, renewables expansion, and electricity infrastructure modernization.

However, certain limitations exist, including the context-specific focus on Iran's electricity landscape. Additionally, the qualitative nature of VFT and WASPAS analyses relies on subjective expert inputs. Quantitative modeling through optimization algorithms could be incorporated in future works. There are also opportunities for expanded criteria evaluation encompassing economic, social, and environmental dimensions. Larger expert panels with global representation may provide broader perspectives.

Nonetheless, this research delivers a rigorous analytical framework combining diverse resilience concepts, Industry 4.0 viewpoints, and multi-criteria decision-making tools. The findings help define a roadmap for Iranian electricity supply chain stakeholders to embark on the transition towards intelligence, sustainability, and resilience. With apt contextualization, the strategies can inform electricity resilience enhancement globally amidst the complex transformations of Industry 4.0.

In future research, exploring the sustainable electricity supply chain further by incorporating renewable energy sources such as solar, wind, and particularly hydrogen energy offers a promising avenue. Hydrogen, as a clean energy carrier, holds the potential to revolutionize energy systems by providing a high-density energy storage solution, which can significantly enhance the flexibility and resilience of electricity supply chains. Moreover, integrating critical systems thinking methods could yield deeper insights into the systemic interdependencies and complexities within the electricity supply chain. This approach would facilitate a more holistic understanding of the barriers and opportunities in transitioning toward sustainable energy practices. Additionally, employing other systems thinking methodologies, such as Soft Systems Methodology (SSM) or System Dynamics (SD), could provide a structured way to model and simulate the impacts of various strategies on the sustainability and efficiency of the supply chain. These methods would allow for a dynamic exploration of policy scenarios and technology integration, supporting decision-makers in crafting robust strategies to navigate the challenges of the evolving energy landscape.

Disclosure statement

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

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Appendices

Appendix A1: Aggregated IVIF matrix of expert opinions (Expert 4 as an example).

Sub-Criteria	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
IP-1	PG	B	B	MG	EG	B	B	G	G	G
IP-2	PG	B	VB	M	VB	EB	B	B	VG	VG
IP-3	EG	MG	M	G	VB	MG	M	VG	VG	PG
IP-4	EG	B	M	G	EB	G	MG	MG	PG	EG
RP-1	EG	G	M	G	EB	MG	MB	MG	PG	EG
RP-2	EG	VG	VB	VG	EB	M	M	VG	PG	PG
RP-3	EG	MG	MB	MG	EB	M	M	PG	EG	EG
EP-1	EG	G	B	G	EB	G	B	G	PG	G

Appendix A2: Normalized IVIF decision matrix.

Sub-Criteria	S1	S2
IP-1	[0.15000, 0.28750], [0.45000, 0.63750]	[0.58631, 0.67887], [0.14142, 0.27042]
IP-2	[0.19200, 0.32271], [0.42776, 0.60599]	[0.47393, 0.57647], [0.22462, 0.36734]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.43209, 0.52898], [0.28517, 0.41809]	[0.66530, 0.73726], [0.00000, 0.22088]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]
Sub-Criteria	**S3**	**S4**
IP-1	[0.12360, 0.25482], [0.49394, 0.67353]	[0.51883, 0.61184], [0.00000, 0.33456]
IP-2	[0.14123, 0.27241], [0.47649, 0.65597]	[0.54145, 0.63523], [0.17955, 0.31310]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.30083, 0.39010], [0.43337, 0.56039]	[0.60095, 0.69392], [0.12510, 0.25508]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]
Sub-Criteria	**S5**	**S6**
IP-1	[0.07598, 0.10953], [0.81324, 0.87045]	[0.21821, 0.30952], [0.48356, 0.63695]
IP-2	[0.07598, 0.10953], [0.81324, 0.87045]	[0.23410, 0.31770], [0.50126, 0.63395]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.11277, 0.15106], [0.75681, 0.82566]	[0.57615, 0.66924], [0.14877, 0.27964]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]
Sub-Criteria	**S7**	**S8**
IP-1	[0.98987, 0.98987], [0.00000, 0.00000]	[0.22400, 0.34255], [0.43056, 0.59273]
IP-2	[1.00000, 1.00000], [0.00000, 0.00000]	[0.31142, 0.42480], [0.35676, 0.51316]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.83721, 0.85387], [0.10000, 0.13554]	[0.67779, 0.72980], [0.15651, 0.24019]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]
Sub-Criteria	**S9**	**S10**
IP-1	[0.66378, 0.75956], [0.00000, 0.18531]	[0.66136, 0.75438], [0.00000, 0.19425]
IP-2	[0.65013, 0.74558], [0.00000, 0.19944]	[0.98987, 0.98987], [0.00000, 0.00000]
IP-3	[0.11327, 0.12354], [0.85462, 0.88754]	[0.11327, 0.12354], [0.85462, 0.88754]
IP-4	[0.90000, 0.90000], [0.10000, 0.10000]	[0.98987, 1.00000], [0.00000, 0.00000]
RP-1	[0.08456, 0.11228], [0.88452, 0.88776]	[0.08456, 0.11228], [0.88452, 0.88776]
RP-2	[0.04987, 0.12537], [0.70386, 0.81345]	[0.04987, 0.12537], [0.70386, 0.81345]
RP-3	[0.00325, 0.00325], [0.98999, 0.98999]	[0.00325, 0.00325], [0.98999, 0.98999]
EP-1	[0.090142, 0.10236], [0.78631, 0.79986]	[0.090142, 0.10236], [0.78631, 0.79986]

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Investigating the Effect of Organizational Citizenship Behavior on Employee Performance Using the System Dynamics Approach (Case Study: Yasuj Municipality)

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ABSTRACT

As one of the emerging research fields of sustainability management, Organizational Citizenship Behavior (OCB), especially its influence on employee performance, has drawn increased attention in the academic and industrial areas. Nevertheless, existing studies mainly examine the static relationship between OCB and employee performance. Therefore, this paper aims to evaluate the dynamic impacts of OCB on employee performance in Yasuj Municipality with the assistance of a system dynamics model. Four causal feedback loops and a stock-flow diagram were developed to illustrate the dynamic influencing mechanism. Three distinct policies quantitatively simulated the possible impacts of OCB changes on the whole system and, specifically, on employee performance. The results show that increasing the Actual Increasing Rate of Project Culture (AIROC) significantly influences OCB and employee performance improvement. The higher the AIRPP (actual increasing rate of potential promotion) in the multi-policy scenario, the higher the OCB and the performance. One major contribution is that this study is one of the first to explore the potential use of system dynamics to model organizational behavior and its performance, which has implications for the practical and cultural promotion of OCB.

Keywords

Keywords: Organizational citizenship behavior, Employees performance, System dynamics approach, Simulation.

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1. Introduction

The swift expansion of technology, widespread availability of information, dissolution of geographical barriers to knowledge, the phenomenon of globalization, the proliferation of industrial and commercial organizations to address crises, hardships, and threats, as well as their survival and longevity in this fiercely competitive world, unequivocally demonstrate the necessity of learning. While advanced technology, adequate space, current equipment, and material and financial capital are important factors for advancement and success, they alone are not enough (Karimi and Akbari, 2014). Today, the crucial role of human resources in enterprises is imperative due to the dynamic economic landscape and the significance of innovation in services. In the current highly competitive business environment, organizations focus on ensuring survival, growth, and overall success. To achieve this crucial objective, the managers seek to identify and efficiently utilize resources and capital, which involves significant expenses and efforts. Therefore, the managers who apply the indicated funds in the most optimal, proficient, and fruitful manner emerge as the victors in this domain. The primary assets of any business consist of human, financial, and technical resources, which decisively shape the trajectory of other forms of capital. This is because the workforce leverages its skills and strategic thinking to acquire and utilize other resources (Hodson, 2006).

An exemplary organizational citizen is an idea and thought that encompasses a range of employee behaviors, including willingly taking on extra duties and responsibilities, adhering to the organization's rules and procedures, cultivating a positive attitude, and demonstrating patience and tolerance towards workplace challenges and dissatisfaction. Organizational theories suggest that organizational citizenship behavior significantly contributes to the competitiveness and performance of an organization. Furthermore, the inclination and readiness to behave as a responsible member of the organization are becoming increasingly important in light of the growing global competition and the need for innovation, adaptability, productivity, and responsiveness to external circumstances (Tehrani et al., 2018).

Organizational citizenship behavior is particularly crucial for organizations or business units insofar as it enhances organizational performance and sustains their competitive advantage in the market (Chang et al., 2021; Han et al., 2019; Singh and Singh, 2019; Özkan et al., 2021; Qiu and Dooley, 2022). The goal of organizational citizenship behavior is often set to help organizations and firms develop higher-quality performance, improve customer satisfaction and create better social interactions between employees, reduce risk, and increase efficiency, as well as to maintain these improvement results under a sense of community among employees (Abdullahi et al., 2020; Khalfan et al., 2022; Kowal et al., 2019; Sarfraz et al., 2022).

Nemati et al. (2016) examined the impact of social capital, commitment, and organizational citizenship behavior on work performance. The study focused on the Khoy City Municipality as a case study. The research findings demonstrated that social capital had a beneficial impact on employee commitment, organizational citizenship behavior, and work effectiveness. Furthermore, the study also demonstrated the beneficial impact of employees' dedication and the manifestation of organizational citizenship behaviors on job performance. Therefore, enhancing the procedures associated with employee dedication and organizational citizenship behaviors, which are impacted by factors like social capital, results in the enhancement of employees' job performance.

Shiravand (2014) examined the impact of organizational citizenship behavior and its many aspects on the satisfaction level of customers in the 17th district of Tehran municipality. The findings suggest a noteworthy correlation between organizational citizenship behavior and employer satisfaction. The regression model confirmed a strong correlation between social etiquette, altruism, conscientiousness, mutual personal coordination, protection of the organization's resources, chivalry, and politeness in predicting customer satisfaction. The order of importance, based on the regression model, is conscientiousness, altruism, social etiquette, protection of the organization's resources, mutual personal harmony, and chivalry.

Wang et al. (2018) conducted a research work with the aim of accessing the dynamic impacts of OCB on the organizational performance of mega-projects, utilizing a dynamic system model. The dynamic influence mechanism was illustrated by developing four causal feedback loops and a stock and flow diagram. Additionally, three distinct policies were employed to numerically predict the potential consequences of changes in OCB on the entire system.

Demonstrating human resource citizenship behaviors in service organizations is crucial due to the pivotal role of employees who directly interact with customers, as they are the driving force behind the organization. Services, in contrast to products, are both generated and consumed simultaneously. Service workers can function as service producers. The importance of service personnel in offering high-quality services has received significant attention (Binstock et al., 2003). A municipality is a non-governmental public agency that offers its citizens a wide range of public services. Employees play a crucial role in municipalities as service organizations. Consequently, the employees’ voluntary and optional activities, known as organizational citizenship behavior, can greatly influence people's opinion of service quality.

Employees' job performance significantly impacts the overall success of organizations, including the municipality (Mirsepasi et al., 2011).

Although existing studies have demonstrated that OCB positively contributes to employee performance (Braun et al., 2013), two problems are still found in previous studies. Firstly, most existing papers have studied the relationship between OCB and employee performance from a static and isolated perspective without systematically considering the interrelationships among different influencing factors. Secondly, the existing studies have mainly concentrated on qualitative analyses based on surveys, failing to quantify the impact of OCB on employee performance.

Therefore, this study aims to assess the impacts of the OCB on employee performance inside the Yasouj city municipality with the aid of the System Dynamics (SD) approach. The reasons for adopting an SD approach are mainly two-fold. Firstly, since there are numbers of elements within the OCB system and their relationships tend to change and are complicated, the SD approach is demonstrated as a well-established method for studying and managing such complex feedback systems (Wang et al., 2018), and facilitating better understanding on the mutual relationships between the behavior of a system. Secondly, elements in the OCB system are largely interdependent (Nielsen et al., 2009). SD modeling can discover and illustrate interrelationships among elements and facilitate the measurement of dynamics among elements (Coyle, 1996). In addition, the SD approach is also effective in evaluating the consequences of new policies and structures (Sterman, 2002). Taking the aspects above, the SD approach is considered a suitable method for fulfilling this study's research aims. The proposed model is also expected to help decision-makers better understand how OCB affects employee performance.

The rest of this paper is organized as follows: Section 2 entails the literature review, including an explanation of the concept, dimensions, and driving factors of OCBs. Section 3 introduces SD modeling with a detailed process of model development. Section 4 is the policy analysis, discussing a base run and three policy scenarios (two single-policy scenarios and one multi-policy scenario). Section 5 concludes the study.

2. Literature review

OCB was first put forward in the 1980s and defined as "individual behavior that is discretionary, not directly or explicitly recognized by the formal reward system, and that, in the aggregate, promotes the effective functioning of the organization" (Organ, 1988). Afterward, OCB attracted the interest of many scholars, and many studies were conducted on it. However, there is rather limited literature on OCB in the context of megaprojects. Similar to the definition of OCB in organizational areas, OCB in the megaprojects field can be defined as the positive behaviors of participants that are not recognized by formal contracts or requirements but would lead to the effective achievement of the project goals (Yang et al., 2018). For example, in the South-to-North Water Transfer project, the local government held a labor contest (a typical practice in China to motivate and improve OCB engagement in the project implementation), and all participants in this megaproject were involved. Participants voluntarily competed in safety, quality, schedule, innovations, environmental protections, and so on (Yang et al., 2018). Participants could only win by exceeding the typical requirements and achieving high performance. Meanwhile, winners were only awarded medals, trophies, and so forth without compensation (Tang et al., 2013). Currently, existing studies have already demonstrated that OCB plays an important role in improving management effectiveness, organizational efficiency, labor productivity, and so forth, eventually benefiting the megaproject on the whole (Patanakul et al., 2016).

Although OCBs have been observed in many megaprojects, studies in the context of megaprojects are still limited, especially on the dimensions and driving factors. One of the most presentative studies on the dimensions of OCB is the seven-dimensional model established by Podsakoff (Podsakoff et al., 2000), which includes helping behavior, sportsmanship, organizational loyalty, organizational compliance, individual initiative, civic virtue, and self-development. However, the research conducted by Podsakoff mentioned above was conducted in permanent organizations, which are, in fact, different from temporary organizations like project-based organizations (Nielsen et al., 2009). (Braun et al., 2013). Thus, megaproject OCBs would have unique dimensions and motivations (Braun et al., 2013). pointed out that no matter the project compliance or individual compliance, its essence is to obey the organization's regulations and related rules, and the difference between the two kinds of behavior is only the subject on which they should be compliant. The nature of organizational loyalty and sportsmanship behavior is initially individual staff dedicated to their work, namely adhering to the high self-demand, having the initiative to work overtime, and working in extreme conditions voluntarily without any supervision; hence, the two behaviors can be summarized as conscientiousness (Farh et al., 2004). Civic virtue refers to good interpersonal relationships in organizations, and the core is the maintenance of harmonious relationships (Braun et al., 2013). Self-development and individual initiative mean work completed creatively or spontaneously improving work skills (George and Jones, 1997). Thus, these two behaviors can be interpreted as innovation in the megaproject context. Helping behavior means providing direct help to others and taking the initiative to work with colleagues (Podsakoff et al., 2014). While in megaprojects, He et al. (2015) believed this behavior should be interpreted as collaboration behavior. Therefore, project compliance behavior, innovation behavior, collaboration behavior, conscientiousness, and harmonious relationship maintenance behavior are summarized as the five dimensions of OCB in this study.

In addition, the driving factors are another sub-topic to be researched in the OCB field, and employee characteristics, task characteristics, leadership behaviors, and organizational characteristics are the most important driving factors for conducting OCB (Podsakoff et al., 2000). However, in megaprojects, participants act on actions on behalf of the enterprises they belong to; thus, their behavioral motivations are more likely to be significant in sociality and the pursuit of long-term interests (Li and Liang, 2015). Meanwhile, megaprojects are normally launched and sponsored by governments; that is, participants are mostly state-owned enterprises or other successful enterprises cooperating with the government, especially in mainland China (He et al., 2015). Hence, enterprises are likely to achieve their political appeal by participating in the construction of megaprojects. To be specific, executives of state-owned enterprises are more likely to be promoted due to their good performance in megaprojects (Wang et al., 2018).

Moreover, aside from internal factors like the potential promotion mentioned above, the external environment drives OCB. Practically, the external environment has an important impact on participants' behavior, such as regulations, project culture, corporate reputation, and so forth (Cao and Wang, 2014). Therefore, as summarized above, the driving factors considered in this study include project culture, potential promotion, corporate reputation, and public satisfaction.

3. Model development

3.1. Steps of model development

SD, established by Forest in 1958 and designed based on systems thinking, has been widely used in various disciplines. Over the past two decades, it has been used to address economic, environmental, societal, agricultural, and other systems of great complexity. This method is particularly widely applied to the disciplines of construction activities, such as political decision-making systems (Yuan and Wang, 2014). Generally, an SD model can be visualized by a causal loop or stock-flow diagram. A causal loop diagram is continuously developed as a conceptual model of systems to be studied. In contrast, a stock-flow diagram is established based on a causal loop diagram and computer simulation.

This paper primarily uses a five-step procedure to construct the model (Figure 1). Firstly, the boundary of the system and variables that can significantly influence the system's behavior should be identified. Based on that, a causal-loop diagram can be established to describe the system simply. Afterwards, a stock-flow diagram will be developed according to the causal-loop diagram. Furthermore, model validation should start testing the established model's confidence and robustness. Finally, policy analysis, consisting mainly of a base run simulation and three policy scenarios, would be conducted to simulate and analyze the impacts of the devised management policies after the model validation.

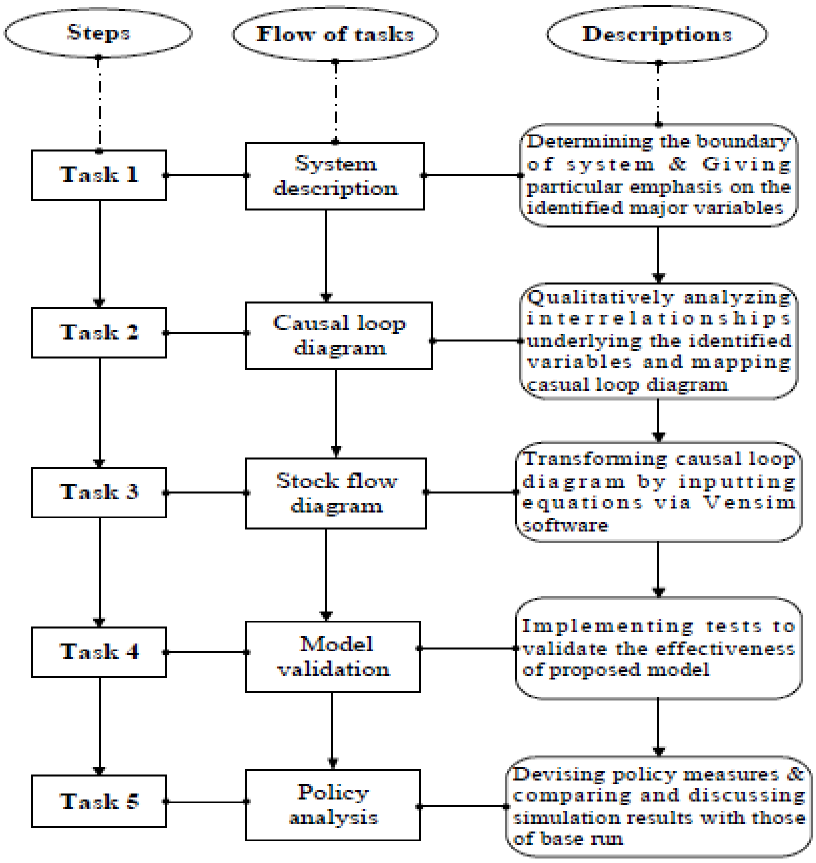

Figure 46. The research path for model development

3.2. The problem of dynamics

It is one of the most important parameters in evaluating the performance of OCB. In this research, OCB is the only factor affecting employees' performance. Other factors are beyond the scope of this research. Yasouj municipality has made many efforts to promote OCB, but OCB has had an upward trend from 2017 to 2022. Moreover, all indicators affecting this parameter (job satisfaction, organizational culture, employee opportunities for promotion) had an upward trend with a very low slope. It seems that by increasing the growth rate of employee opportunities for promotion, the growth rate of organizational culture, and the promotion of other criteria that influence the promotion of OCB and finally improving the performance of employees, a better position of improvement can be reached. Therefore, investigating OCB is very necessary so that by using the research results, necessary measures can be taken to improve OCB and move towards more conscious planning to enhance the performance of employees.

3.3. Time domain and system boundary

This model's time horizon, which is intended for simulation, is 11 years, starting in 2017 and ending in 2027. Its geographical border is Yasouj Municipality..

3.4. Key pattern variables

According to the subject literature, the background of the research, and a survey of academic experts and specialists, the influential factors and components of OCB were identified in this research. The components of OCB include conscientiousness behavior, organizational adaptive behavior, collaborative behavior, innovative behavior, and harmonious relationship maintenance behavior. Its influential factors mainly included organizational culture, reputation, employee empowerment, and job satisfaction. These variables define the boundary of the model. Moreover, in this model, OCB is the only variable that affects performance. The variables examined in this model are specified in Table 1.

Table 29. The descriptions of the variables used in the model

Acronym	Descriptions	Variable Type	Unit of measurement	Acronym	Descriptions	Variable Type	Unit of measurement
AIROC	Actual increasing rate of organizational culture	Constant	Percent	CRIHRM	changes rate index of harmonious relationship maintenance	Auxiliary	Percent
AIRPP	Actual increasing rate of potential promotion	Constant	Percent	CRIIB	changes rate index of innovation behavior	Auxiliary	Percent
AIRPS	Actual increasing rate of public satisfaction	Constant	Percent	CRIOC	changes rate index of organizational compliance	Auxiliary	Percent
AROCB	Adoption rate of organizational citizenship behavior	Auxiliary	Percent	CRIEP	changes rate index of employees performance	Auxiliary	Percent
ATAI	Advanced technology adopted initiatively	Constant	Percent	IEP	changes rate index of employees performance	Auxiliary	Percent
AVC	Accumulated value of conscientiousness	Stock	Percent	OCBA	Organizational citizenship behavior adoption	Auxiliary	Percent
AVCB	Accumulated value of collaboration behavior	Stock	Percent	OCI	Organizational culture increment	Flow	Percent
AVHRM	Accumulated value of harmonious relationship maintenance	Stock	Percent	PCI-1	Personal compliance increment	Flow	Percent
AVIB	Accumulated value of innovation behavior	Stock	Percent	EP	The Employee performance	Flow	Percent
AVOC	Accumulated value of organizational compliance	Stock	Percent	EPI	employees performance increment	Stock	Percent
AVPC-1	Accumulated value of organizational culture	Stock	Percent	PPII	Project program improved initiatively	Constant	Percent
AVPP	Accumulated value of potential promotion	Stock	Percent	PPMAC	Conscious participation in project meetings and activities	Constant	Percent
AVPS	Accumulated value of public satisfaction	Stock	Percent	PPOI	Potential promotion opportunities increment	Flow	Percent
BCP	Benefits of corporate reputation	Auxiliary	Percent	PSI	Public satisfaction increment	Flow	Percent
CBI	Collaboration behavior increment	Flow	Percent	PTC	Participation in training consciously	Constant	Percent
CCA	Coordination conflicts actively	Constant	Percent	SPE	Shares with project experience	Constant	Percent
CGR	Compliance with governmental requirements on the organization	Constant	Percent	TVOCB	Total value of organizational citizenship behavior	Auxiliary	Percent
CI	Conscientiousness increment	Flow	Percent	VC	Value of conscientiousness	Auxiliary	Percent
CMRC	Conduct mission requirements consciously	Constant	Percent	VCB	Value of collaboration behavior	Auxiliary	Percent
COA	Compliance with organizational arrangements	Constant	Percent	VHRM	Value of harmonious relationship maintenance	Auxiliary	Percent
OMC	organizational management changing	Auxiliary	Percent	VIB	Value of innovation behavior	Auxiliary	Percent
OMP	organizational management performance	Auxiliary	Percent	VOC	Value of organizational culture	Auxiliary	Percent
HOSD	Helps others to solve the difficulties	Constant	Percent	VOC-1	Value of organizational compliance	Auxiliary	Percent
HRMI	Harmonious relationship maintenance increment	Flow	Percent	VPP	Value of potential promotion	Auxiliary	Percent
HRS	Harmonious relationship with stakeholders	Constant	Percent	VPS	Value of public satisfaction	Auxiliary	Percent
IBI	Innovation behavior increment	Flow	Percent	WAOCB	Willingness to adopt organizational citizenship behavior	Auxiliary	Percent
IIC	Increasing index of conscientiousness	Auxiliary	Percent	WOI	Work overtime initiatively	Constant	Percent
IICB	Increasing index of collaboration behavior	Auxiliary	Percent	Y	Yearly	Constant	Percent

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3.5. Causal loop diagram

Key variables were identified when developing a qualitative model based on the literature (discussed in Section 2). In this study, the key variables in the proposed model are two main aspects: the identified dimensions of OCB and its driving factors. OCB refers to project compliance behavior, innovation behavior, collaboration behavior, conscientiousness behavior, and harmonious relationship maintenance behavior. Its motivations mainly involve project culture, potential promotion, corporate reputation, and public satisfaction. These variables not only serve as essential units of the model, but they define the boundary of the model.

Additionally, in the established model, OCB is the only factor that influences the performance of megaprojects, which means the time, budget, and quality in this study. The other factors that are out of the scope of this study are time, budget, and quality. The other factors are out of the scope of this study. After identifying the variables with the potential to influence the behavior of the proposed system, a qualitative analysis was carried out to identify the interactions among the variables. Figure 2, which consists of four feedback loops that determine the system's behavior by establishing connections among variables, illustrates the conceptual model of the qualitative analysis. Positive feedback loop R1: It can be seen from Figure 2 that the adoption of OCB would be reinforced.

Itself through the positive chain. Suppose that the employee performance accelerates through adopting OCB, bettering the employee performance during the construction phase. Consequently, considering the relationships between enterprises and the government, the organization's leader could have a higher potential for promotion (Müller et al., 2014). That is, participants in organizations are more willing to augment OCB, which will affect employee performance again (Yen et al., 2008). Positive feedback loop R2: In this loop, adopting OCB could reinforce itself through the feedback chain. Suppose that OCBs accelerate, then the organization`s performance will be positively influenced, and the public’s satisfaction will be increased (Wang et al., 2018).

Furthermore, it positively contributes to the corporate reputation and thereby motivates participants to increase OCB (Wang et al., 2013). Hence, the magnified adoption of OCB will further accelerate the project performance. Positive feedback loop R3: This one shows a similar influence loop as R1. The only difference is that in loop R3, the improvements in the adoption of OCB directly lead to improvements in the Organizational culture (Wang et al., 2013). Negative feedback loop B1: In this loop, a change of any variable would negatively affect itself. If there is an increase in the adoption of OCB, then employee performance will be accelerated.

As a result, the public's satisfaction would be improved, which indicates that governmental regulations or policies would decline (Müller et al., 2014). Due to reduced willingness to OCB, the adoption of OCB will decrease accordingly.

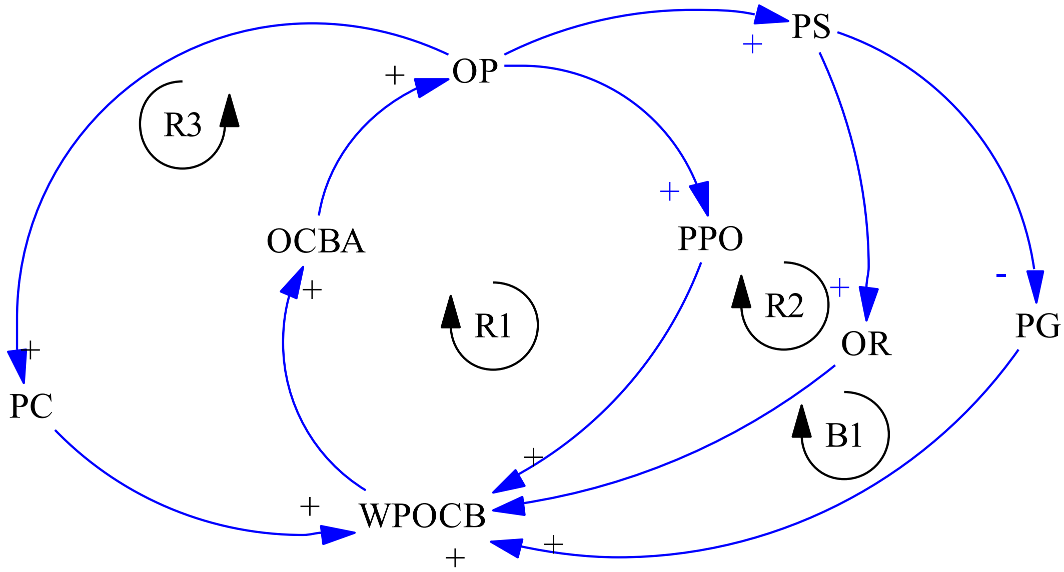

Figure 47. The causal loop diagram of the OCB system

3.6. *Stock-Flow diagram*

With the interrelationships underlying the identified variables defined within the causal-loop diagram, a stock-flow diagram was developed to quantify their impacts with the assistance of the Vensim software. A stock-flow diagram is a more detailed illustration of a causal-loop diagram. Furthermore, a stock-flow diagram consists of different kinds of icons so that the computer-based simulation can be run. To facilitate a better understanding, the proposed model and brief definitions of the variables within the model are shown in Figure 3 and Table 1, respectively. Before performing the simulation, it is necessary to ensure that all the variables in the model can be quantified. The variables used in this model were divided into three categories: Constant, dependent, and qualitative. Each type of variable has corresponding data sources. The value of the constant variables—expected to remain unchanged and will not be affected by other variables during the simulation period—were generally quantified by referring to the materials available, such as literature. The values of the dependent variables depend on one or more variables within the model in terms of mathematical functions. Various functions in the Vensim software can quantify the values of these kinds of variables (Li et al., 2014). The values of the qualitative variables were quantified in this study by the judgment of experts. Detailed data and equations related to the established model are shown in Appendix to facilitate an understanding the quantification process.

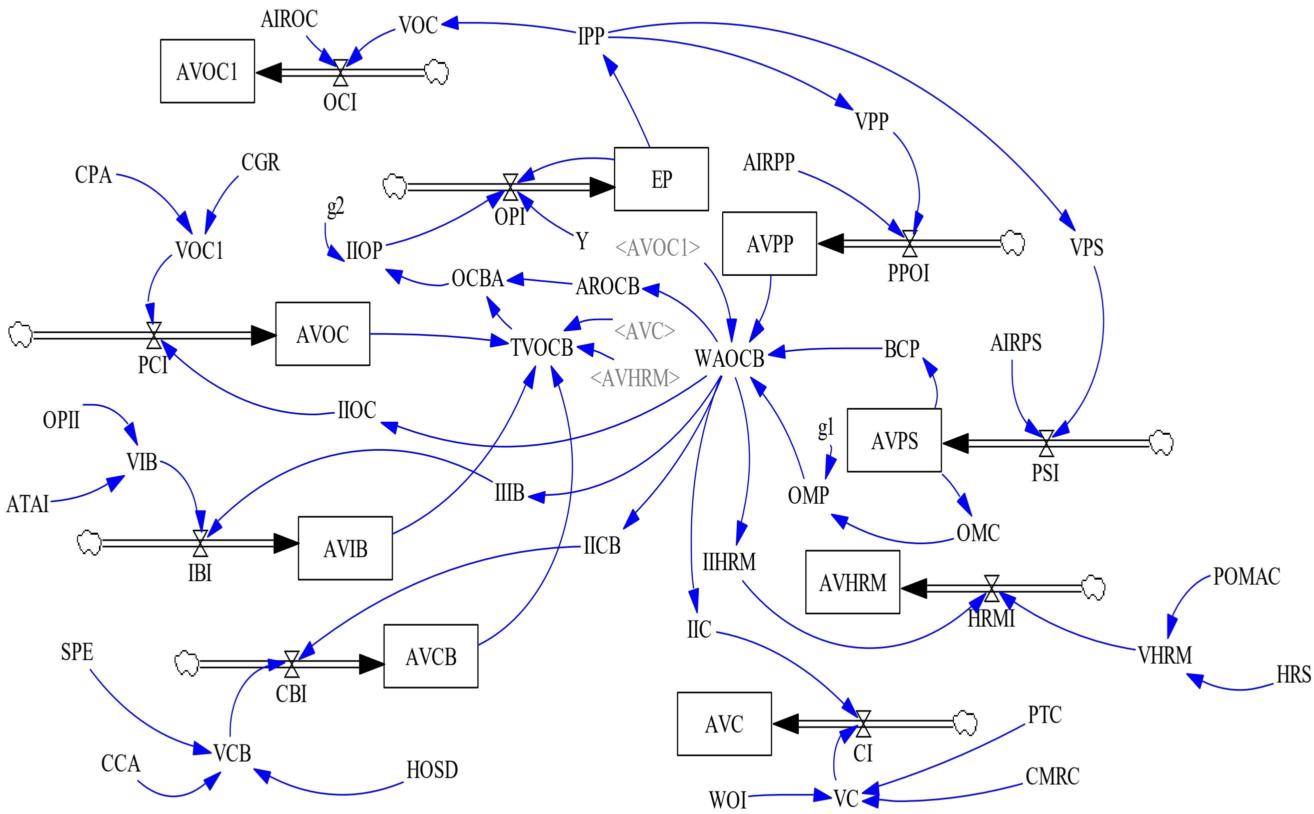

Figure 48. The stock-flow diagram of the model

3.6.1. Analyzing the behavior of the AVC index

AVC is considered one of the important aspects of accepting OCB, and it greatly impacts the promotion of willingness to accept OCB. Many indicators influence factors in this dimension. This research investigates the factors of a person's willingness to work overtime, volunteer missions, and conscious and voluntary participation in education. AVC among employees has had an upward trend with a low slope between 2017 and 2021. As is shown in Figure 3, from 2022 to 2027, according to the prevailing conditions of society and remote work, the sense of duty of the employees in doing the work during overtime hours or in remote work has had a relatively steep upward trend. According to the simulated 11-year period, this trend has an upward trend, and the results and changes of this factor are presented in Figure 4.

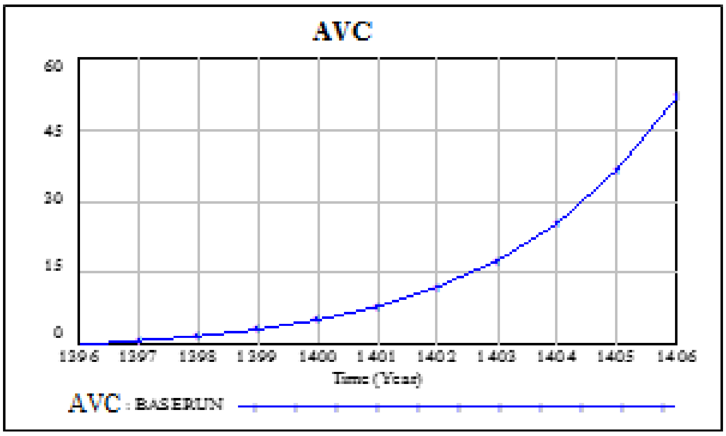

Figure 49. Simulation of conscientiousness index

3.6.2. Analyzing the behavior of the AVOC index

As can be seen in Figure 5, the AVOC of employees from 2017 to 2027 has been upwardly trending due to the upward trend of the influential indicators with a relatively steep slope.

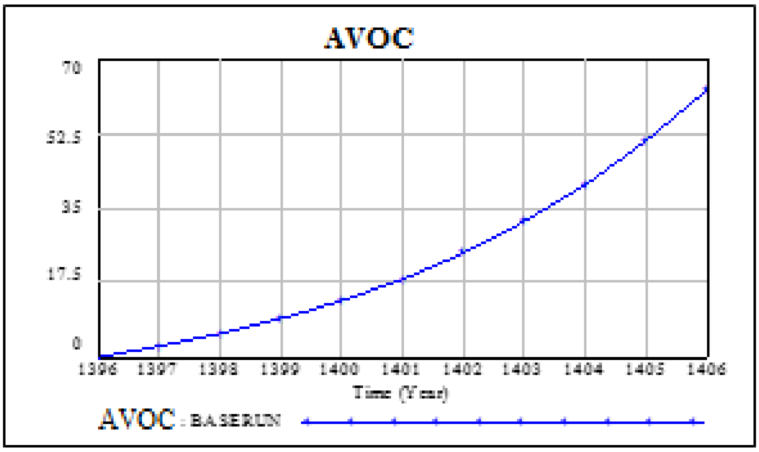

Figure 50. Simulation of organizational AVOC index

3.6.3. Analyzing the behavior of the maintenance of the AVHRM index

The maintenance of AVHRM within our organization, a key responsibility shared by colleagues and managers, is a pivotal factor in shaping employee performance and fostering a conducive work environment. This factor, like others, is on an upward trajectory, but its potential for growth in the coming years is particularly promising. By instilling a sense of enthusiasm among employees to actively participate in organization meetings and collaborate in activities, we can further amplify the impact of AVHRM. As illustrated in Figure 6, the AVHRM index has demonstrated a significant increase from 2017 to 2022, reaching an impressive 8.53%.

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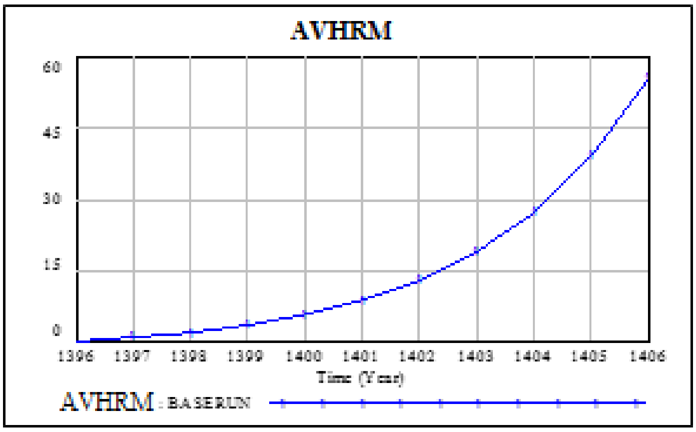

Figure 51. Simulation of the maintenance of AVHRM index

3.6.4. Analyzing the behavior of the AVCB index

AVCB is considered one of the other important aspects of accepting OCB, and it has a great impact on promoting willingness to accept OCB. This research investigates the factors of transferring experience and knowledge, helping others to solve problems and conflicts of active cooperation. Between 2017 and 2020, the cumulative value of collaborative behavior had an upward trend with a small slope, and this trend is increasing in the coming years, with the difference considering that the factors influencing AVCB change over time in an organization. It becomes an organizational culture, and knowledge and experience transfer foundations become strong. It is expected that after 2023, the incremental growth rate of this factor will increase dramatically compared to before. The results and changes of this factor are presented in Figure 7.

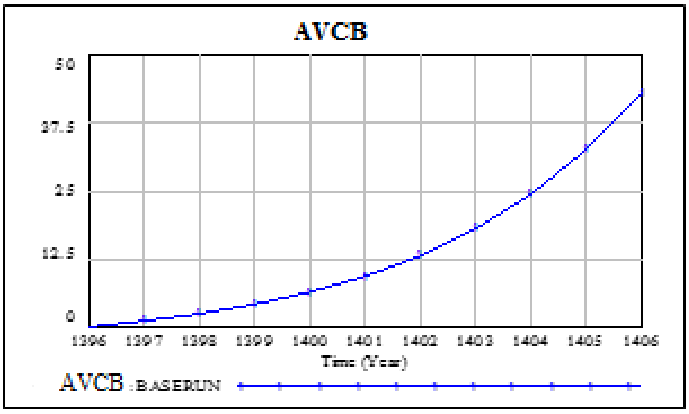

Figure 52. Simulation of the AVCB index

3.6.5. Analyzing the behavior of the AVIB index

As you can see in Figure 8, the AVIB from 2017 to 2027 has had an upward trend due to the upward trend of the influential indicators with a relatively steep slope.

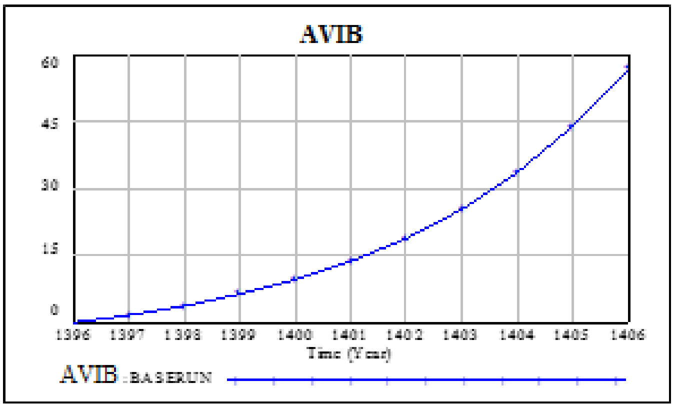

Figure 53. Simulation of innovative behavior index

3.6.6. Analyzing the behavior of the EP index

The EP index, a significant metric in OCB performance, has shown a gradual upward trend from 2017 to 2023. This trend, though slow, has a substantial impact. As shown in Figure 9, the OCB index has increased from 5% to 6.40% during the period of 2017 to 2022, primarily due to the positive trend of the EP index.

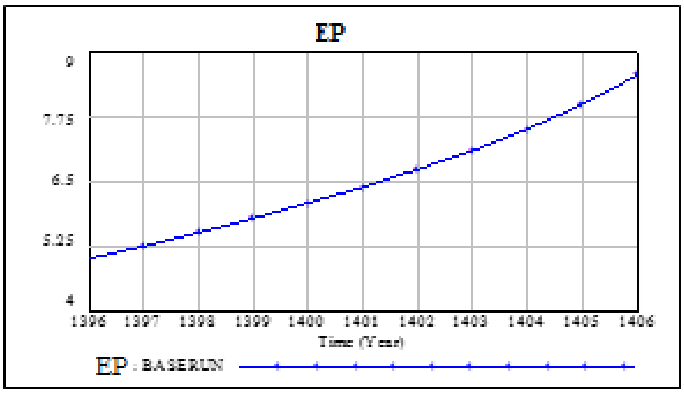

Figure 54. Simulation of employee performance index

3.6.7. Analyzing the behavior of the OCB index

One of the most important parameters in evaluating the performance of OCB. All indicators affecting this parameter (job satisfaction, organizational culture, employee opportunities for promotion, organization's reputation) had an upward trend with a very low slope. As seen in Figure 10, OCB showed an upward trend from 2017 to 2022. In these years, OCB has increased to 6.48%, and this is due to the upward trend of the indicators affecting this index.

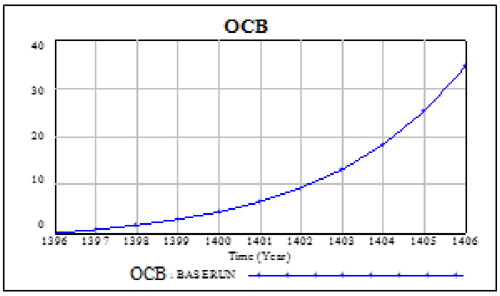

Figure 55. Simulation of OCB index

3.6.8. Analyzing the behavior of the AVOC-1 index

As Figure 11 shows, the OC increased from 4.90% to 5.60% from 2018 to 2023.

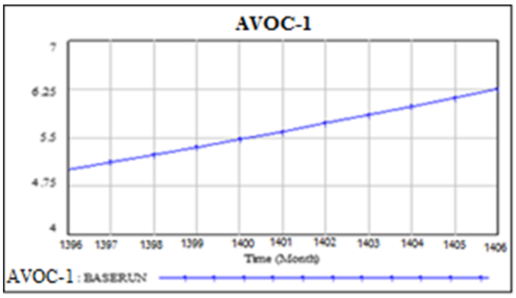

Figure 56. Simulation of organizational AVOC-1

3.6.9. Analyzing the behavior of the AVPS index

As shown in Figure 12, EP has increased from 5% to 5.90% from 2018 to 2023.

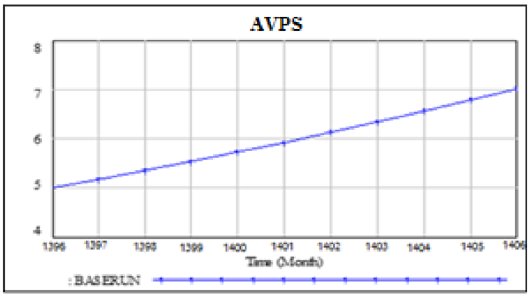

Figure 57. Simulation of AVPS index

3.6.10. Analyzing the behavior of the AVPP index

As shown in Figure 13, employee promotion opportunities increased from 5% to 7% from 2018 to 2023.

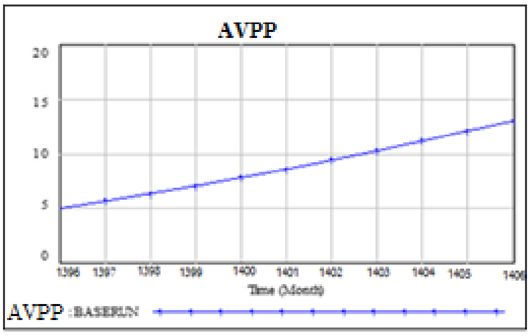

Figure 58. Simulation of AVPP index

4. Results of policy scenarios

4.1. Single-policy scenario

Considering the contribution of OCB to the improvement of employee performance, scholars in the academic and industrial areas have carried out various research on how to promote OCB. According to existing studies, political motivations, especially when reflecting a promotion, and project culture are widely regarded as typical factors (Li et al., 2014). Given that illustrating all factors concerning OCB is impractical due to the limited length of the paper, the two factors mentioned above were selected to simulate the policy analysis. Various scenarios were simulated and analyzed by implementing the two policies individually and in combination. Policy scenarios A and B are single-policy scenarios, meaning that only one variable was changed while the others remained unchanged. Policy scenario C is a multi-policy scenario in which two variables were changed simultaneously.

4.1.1. Scenario A: promotion effect

This one is a single-policy scenario examining the impacts of changing the AIRPP on EP, OCBA, AVC, AVCB, AVHRM, AVIB, and AVOC. To analyze the various possible situations, two sub-scenarios aside from the base run (the initial value of the AIRPP is 0.05) were designed in which the AIRPPs were 0.2 and 0.4, respectively. Moreover, these two scenarios were defined as PSA-1 and PSA-2. Table 1 shows that the increase in the AIRPP significantly contributed to the improvement in the OCBA, thereby enhancing the performance of the organization's employees. Specifically, the OCBA in PSA-1 and PSA-2 reached 77.67 and 82.85, respectively. Meanwhile, the EP in PSA-1 and PSA-2, reaching 41.9 and 44. 4.

In addition, the significant increase is also illustrated in the other five selected variables, namely, AVOC, AVIB, AVCB, AVC, and AVHRM, with values of 14.63, 18.37, 58.62, 33.38, and 59.32 in PSA-1 and 14.77, 18.53, 59.02, 38.72, and 59.72 in PSA-2, respectively, at the end of the simulation period. A possible reason for these simulation results is that the increased promotion opportunities drive the employees to work more actively in such ways as to improve their special skills and to have more of an initiative to participate in project meetings and activities, which are likely to improve OCB and contribute to a better performance of employees.

4.1.2. Scenario B: cultural effect

The policy scenario B, similarly to Scenario A, is also a single policy scenario that is designed to verify the effect of the increase in the AIROC on EP, the OCBA, the AVC, the AVCB, the AVHRM, the AVIB, and the AVOC over the simulation period. To examine the impact of the improvement in the AIROC on the selected variables, two devised scenarios were simulated under policy scenario B for comparison against the baseline scenario, namely PSB-1 and PSB-2. The initial value of the AIRPC was 0.05 in the base run and increased to 0.2 and 0.4 in PSB-1 and PSB-2, respectively**.** As presented in Table 2, the results indicated that the rise in the AIROC could increase the value of the OCBA and EP from 81 and 43.67 in run PSB-1 to 85.11 and 45.25 in run PSB-2 at the end of the simulation period. The values of the AVOC, the AVIB, the AVCB, the AVC, and the AVHRM arrived at 14.67, 18.42, 58.75, 33.50, and 59.44 in PSB-2, and 14.87, 18.65, 59.3, 37.16, and 60.01 in PSB-2. The improvements in all the selected variables could probably result from the fact that the employee was influenced by a positive organizational culture within organizations and contributed to a high quality of their daily work, which is likely to lead to an improvement in performance. However, although the selected variables have increased in both PSA and PSB, some differences still exist in the simulation results of these two policy scenarios. Firstly, the simulation results of PSB are more moderate than those of PSA, indicating that organizational culture is more effective than providing opportunities for promotion to improve OCB and employee performance.

Secondly, PSA and PSB posed different effects on the AVPC, the AVIB, the AVCB, the AVC, and the AVHRM. Specifically, in Scenario A, the AVPC, the AVC, and the AVCB are the top three variables that improved significantly/In the meantime, the AVPC, the AVC, and the AVHRM are the top three in Scenario B. This result suggests that Scenario A could have more significant effects on collaboration behavior than on maintaining a harmonious relationship in Scenario B. The explanation is that project culture effectively contributes to fostering a harmonious atmosphere within organizations (Wang et al., 2018), especially in countries like China, where there is an emphasis on harmony and people show deep concern for group harmony.

Table 30. The simulation results of policy scenario A

	PSA-1							PSA-2						
Year	**OCBA**	**EP**	**AVOC**	**AVIB**	**AVCB**	**AVC**	**AVHRM**	**OCBA**	**EP**	**AVOC**	**AVIB**	**AVCB**	**AVC**	**AVHRM**
1396	0	5	0	0	0	0	0	0	5	0	0	0	0	0
1397	0.462	5.71	0.49	0.53	0.94	2.80	0.95	0.48	5.71	0.49	0.53	0.94	2.80	0.95
1398	1.21	6.54	1.11	1.22	2.27	5.72	2.30	1.27	6.54	1.11	1.23	2.27	5.79	2.30
1399	2.42	7.50	1.88	2.10	4.13	8.77	4.18	2.55	7.51	1.88	2.10	4.14	8.98	4.19
1400	4.33	8.65	2.82	3.20	6.70	11.70	6.78	4.56	8.65	2.83	3.21	6.72	12.35	6.80
1401	7.34	10.04	3.98	4.59	10.24	14.93	10.36	7.74	10.05	3.99	4.60	10.27	15.93	10.39
1402	12.04	11.77	5.38	6.31	15.06	18.29	15.24	12.73	11.8	5.41	6.34	15.12	19.72	15.3
1403	19.41	14.21	7.09	8.45	21.61	21.79	21.87	20.55	14.35	7.13	8.50	21.72	23.74	21.97
1404	30.94	18.41	9.15	11.1	30.49	25.45	30.85	32.82	18.77	9.21	11.17	30.65	28.04	31.02
1405	49.06	26	11.64	14.36	42.47	29.30	42.98	52.16	26.86	11.74	14.47	42.73	32.67	43.24
1406	77.67	41.9	14.63	18.37	58.62	33.38	59.32	82.85	44.4	14.77	18.53	59.02	38.72	59.72

Table 31. The simulation results of scenario B

	PSB-1							PSB-2						
Year	**OCBA**	**EP**	**AVOC**	**AVIB**	**AVCB**	**AVC**	**AVHRM**	**OCBA**	**EP**	**AVOC**	**AVIB**	**AVCB**	**AVC**	**AVHRM**
1396	0	5	0	0	0	0	0	0	5	0	0	0	0	0
1397	0.48	5.71	0.49	0.53	0.94	2.80	0.95	0.48	5.71	0.49	0.53	0.94	2.80	0.95
1398	1.27	6.54	1.11	1.22	2.27	5.71	2.30	1.28	6.54	1.11	1.23	2.27	5.78	2.30
1399	2.53	7.50	1.88	2.10	4.13	8.73	4.18	2.56	7.51	1.88	2.11	4.14	8.94	4.19
1400	4.53	8.65	2.82	3.21	6.71	11.87	6.79	4.60	8.66	2.83	3.22	6.73	12.29	6.81
1401	7.66	10.05	3.98	4.59	10.25	15.12	10.37	7.82	10.06	4	4.61	10.29	15.82	10.42
1402	12.57	11.8	5.39	6.32	15.08	18.48	15.25	12.89	11.81	5.43	6.36	15.16	19.56	15.34
1403	20.25	14.32	7.10	8.46	21.64	21.99	21.9	2.87	14.38	7.16	8.53	21.79	23.51	22.05
1404	32.27	18.69	9.17	11.12	30.54	25.64	30.9	33.44	18.86	9.26	11.23	30.77	27.73	31.13
1405	51.16	26.64	11.67	14.4	42.55	29.47	43.05	53.34	27.1	11.8	14.55	42.92	32.25	43.42
1406	81	43.67	14.67	18.42	58.75	33.50	59.44	85.11	45.25	14.87	18.65	59.3	37.16	60.01

4.1.3. *Scenario C: dual effects*

This multi-policy scenario is designed to simulate the influence of the combined changes in the AIRPP and the AIRPC to facilitate a comprehensive understanding of how their changes affect the OCBA and EP. To be specific, five sub-scenarios were set, namely PSC-1 (AIRPC = 0, AIRPP = 0.4), PSC-2 (AIRPC = 0.1, AIRPP = 0.3), PSC-3 (AIRPC = 0.2, AIRPP = 0.2), PSC-4 (AIRPC = 0.3, AIRPP = 0.1), PSC-5 (AIRPC = 0.4, AIRPP = 0).

As illustrated in Table 3, two main results should be highlighted. Firstly, PSC-1 observed the most significant improvements both in OCBA and MPP, reaching 81.83 and 44.01, respectively; then followed by PSC-2, PSC-3, PSC-4, and PSC-5.

This simulation result shows that the higher the value of the AIROC in the sub-scenarios, the higher the value of the OCBA and EP would be. This finding is consistent with previous studies, which stated that promotion opportunities are more effective than the project culture in improving OCB and employee performance (Le et al., 2016), but also echoes the simulation results in the single-policy scenario. Secondly, the AIROC is 0 in PSC-1, or whenever the AIRPP is 0 in PSC-5, the values of OCBA and EP were not estimated as 0. The reason for this is that the system is organic while running in a highly iterative manner and because promotion and Organizational Culture are not the only two driving factors in this system; thus, even though the AIROC or the AIRPP is set to zero, it would not lead to a zero in OCBA and EP.

Table 32. The simulation results of scenario C

Year	PSC-1		PSC-2		PSC-3		PSC-4		PSC-5	
	OCBA	EP	OCBA	EP	OCBA	EP	OCBA	EP	OCBA	EP
1396	0	5	0	5	0	5	0	5	0	5
1397	0.48	5.71	0.48	5.71	0.48	5.71	0.48	5.71	0.48	5.71
1398	1.27	6.54	1.27	6.54	1.27	6.54	1.27	6.54	1.28	6.54
1399	2.54	7.51	2.54	7.51	2.55	7.51	2.55	7.51	2.55	7.51
1400	4.55	8.65	4.56	8.65	4.57	8.65	4.58	8.65	4.58	8.65
1401	7.70	10.05	7.72	10.05	7.75	10.05	7.77	10.05	7.79	10.06
1402	12.65	11.8	12.7	11.8	12.74	11.8	12.79	11.8	12.84	11.81
1403	20.39	14.33	20.48	14.34	20.58	14.35	20.67	14.36	20.76	14.37
1404	32.53	18.73	32.7	18.75	32.88	18.78	33.06	18.8	33.23	18.83
1405	51.61	26.75	51.95	26.81	52.28	26.88	52.62	26.95	52.96	27.02
1406	81.83	44.01	82.47	44.25	83.11	44.49	83.75	44.73	84.4	44.97

5. Conclusions

Considerable studies have been conducted to examine the relationship between OCB and employee performance in the last few decades. However, there is still a gap in studying the interdependent and dynamic relationships among the variables within the OCBs in the organization. Therefore, this study proposes using system dynamics to quantitatively study the impact of OCB on employee performance. Based on SD modeling, both a causal loop diagram and a stock-flow diagram were proposed to identify the major variables and to describe their interrelationship. Once the model was validated, three policy scenarios, including two single policy scenarios and a multi-policy scenario, were adopted to simulate the performance of employees at various levels of OCB adoption in organizations. The simulation results indicated that an increase in the AIROC has more obvious effects on the improvement in OCB and in the performance of employees than those of the AIROC. Moreover, the simulation results of the multi-policy scenarios show that the higher the value of the AIRPP in combinations (the total value has been restricted), the higher the value of OCBA and employees' performance would be.

The main contributions of this study lie in four aspects:

- The OCB system's inherently dynamic nature, which needs to be addressed and has been neglected, has been well envisaged.
- The SD model not only facilitates the illustration of interrelationships among the variables from a quantitative perspective but also deepens the stakeholders' understanding of the entire system of OCB.
- The established model can serve as a laboratory and a platform to better simulate the potential effects of OCB on employees' performance and test the different scenarios of the possible futures that have been relatively less studied before.

Finally, the policy scenarios could identify the benefits that OCB would bring, delivering a clearer and perhaps more realistic view of the appropriate actions that improve employees' performance in the real world.

Organizational citizenship behavior can help the municipality improve the performance of employees and provide services in the following scenarios:

- Enhancing employee morale and satisfaction: Organizational citizenship behaviors, such as assisting colleagues and actively participating in volunteer activities, heighten employee morale and job satisfaction. Increased job satisfaction subsequently results in enhanced performance and decreased employee turnover.

- Enhancing collaboration and synchronization: When employees willingly assist one another and engage in teamwork, the organization's degree of cooperation and harmony is heightened. These collaborations enhance the procedures and overall efficiency of the municipality.

- Promoting innovation and creativity: Organizational citizenship behaviors can foster employees' creativity and facilitate the presentation of novel solutions. These advancements can potentially enhance work procedures and boost production within the municipality.

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- Improving service to citizens: It's the employees who, by demonstrating organizational citizenship behavior, go above and beyond to serve citizens. This issue can improve the quality of municipal services to citizens and increase public satisfaction, making each employee a key player in this process.

Organizational citizenship behavior generally substantially influences the municipality's performance and the quality of services offered to citizens. It is achieved by enhancing work relationships, boosting job satisfaction, and fostering employee collaboration and unity.

Despite significant contributions, the two main limitations cannot be ignored. On the one hand, the SD method only pays attention to the general dynamic trends of prediction and does not emphasize the accurate value in a specific year. Therefore, it is suggested that is be applicable to long-term predictions that do not require accurate results. On the other hand, the SD model is a simplification and an abstraction of the system in the real world. Thus, only significant variables and their interrelationships are considered in the model development process in this study, which would adversely impact the accuracy and reliability of the simulation results.

Therefore, future research is encouraged to encompass more variables in the OCB system to increase its credibility and predict accuracy. In addition, given the limited length, only three policy scenarios have been simulated and analyzed by comparing the results with the base scenarios. In the future study, using the method proposed in this study, more similar simulations composed of different designed policies can be conducted and analyzed under different scenarios.

Disclosure statement

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

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Appendix

Equations of the model
ATAI = 4.07
CCA = 4.17
AIROC = 0.05
AIRPP = 0.05
AIRPS = 0.1
AVC(t) = AVC(t - dt) + (CI) ×dt
INTI AVC = 0
AVCB(t) = AVCB(t - dt) + (CBI) × dt
INTI AVCB = 0
AVHRM(t) = AVHRM(t - dt) + (AVHRMI) × dt
INTI AVHRM = 0
AVIB(t) = AVIB(t - dt) + (IBI) × dt
INTI AVIB = 0
AVOC(t) = AVPC(t - dt) + (PCI-1) × dt
INTI AVOC = 0
AVPP(t) = AVPP(t - dt) + (PPOI) × dt
INTI AVPP = 5
AVPC-1(t) = AVPC-1(t - dt) + (PCI) × dt
INTI AVPC-1 = 5
AVPS(t) = AVPS(t - dt) + (PSI) × dt
INTI AVPS = 5
HRS = 4.23
CBI = VCB × IICB
IICB = 1/5 × IAOCB
VCB = 1/3 × (CCA + HOSD + SPE)
CMRC = 4.28
CGR = 4.48
CI = IIC × VC
IIC = 1/5 × IAOCB
CPA = 4.38
PPMAC = 4.06
PTC = 4.21
VC = 1/3 × (CMRC + PTC + WOI)
BCP = 1/2 × AVPS
GMC = 1/2 × AVPS

GMP = GRAPH(GMC)
([(0,0)-(100,80)],(0,0),(10,3),(20,6),(30,11),(40,16),(50,22),(60,26),(70,29),(80,31),(90,32.5),(100,33))
HRMI = IIHRM×VHRM
IIHRM = 1/5 × IAOCB
VHRM = 1/2× (BHRS + PPMAC)
HOSD = 4.37
IAOCB = 1/4 × (AVPP + GMP + BCP + AVPC-1)
IBI = IIIB × VIB
IIIB = 1/5 × IAOCB
VIB = 1/2 × (ATAIAATI + PPII)
IEP = EP
EPII = 3.98
OCBA = OCBAR ×TVOCB
OCBAR = IF THEN ELSE(IAOCB >= 100, 0.1, IAOCB/10)
VPC = 1/3 × IPP
PCI = AIRPC × VPC
PCI-1 = IIPC × VPC-1
IIPC = 1/5 × IAOCB
VPC = 1/3 × IPP
VOC-1 = 1/2 × (CGR + CPA)
MPP = MPP(t × dt) + (PPI) ×_ dt
INTI MPP = 5
PPI = IIPP × Y × MPP
IIPP = GRAPH(OCBA)
([(0,0)-(100,1)],(0,0),(10,0.02),(20,0.08),(30,0.13),(40,0.18),(50,0.24),(60,0.31),(70,0.35),
(80,0.39),(90,0.41),(100,0.42))
PPOI = AIRPP × VPP
PSI = AIRPS × VPS
VPS = 1/3 × IPP
SPE = 4.41
TVOCB = IF THEN ELSE((AVC +AVCB + AVHRM + AVIB + AVPC) > 100, 100,
(AVC + AVCB + AVHRM + AVIB + AVPC))
WOI = 4.29

Guide for Authors

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