Ferdowsi University of Mashhad

JOURNAL OF SYSTEMS THINKING IN PRACTICE

Print ISSN: 2980-9460
Online ISSN: 2821-1669
Volume 4, Issue 1, Winter, 2025

Editor-in-Chief
Alireza Pooya (Prof.)

JOURNAL OF SYSTEMS THINKING IN PRACTICE (JSTINP), Quarterly

Web: jstinp.um.ac.ir

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Journal of Systems Thinking in Practice (STINP)

FERDOWSI UNIVERSITY OF MASHHAD
Editorial Office:Systems Thinking In Practice Group, Faculty of Economics and Administrative sciences, Ferdowsi University of Mashhad, Mashhad, Iran. Phone: +98(51)3880-6356

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Web: jstinp.um.ac.ir

About the journal

- **Publisher:** Ferdowsi University of Mashhad, Iran
- **Adheres to:** the guidelines of the Committee on Publication Ethics (COPE)
- **Review time:** 65 days
- **Frequency:** Quarterly
- **Open access:** Yes
- **Licensed by:** CC BY 4.0
- **Policy:** Duble blind peer-reviewed
- **Indexed and Abstracted**: Yes
- **Language:** English
- **Article Processing Charges:** No
- **Contact email:** jstinp@um.ac.ir

Publication Date:

Journal of Systems Thinking in Practice (JSTINP) is published 4 times a year. Volume 4, Issue 1, March 2025.

JOURNAL OF SYSTEMS THINKING IN PRACTICE (JSTINP), Quarterly

Web: jstinp.um.ac.ir

Volume 4, Issue 1, 2025

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Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir
Online ISSN: 2821-1669, Print ISSN: 2980-9460
Research Article
DOI: 10.22067/JSTINP.2024.88831.1109
JSTINP 2025; Vol. 4, No. 1

Alternative Roof Market Analysis Based on a Hybrid Dynamic Systems Approach and Multi-criteria Decision-Making Method

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How to cite this article

Siadati, A., Hasani, A. 2024. Alternative Roof Market Analysis Based on a Hybrid Dynamic Systems Approach and Multicriteria Decision-Making Method, *Journal of Systems Thinking in Practice*, *4*(1), pp.1-26. doi: 10.22067/jstinp.2024.88831.1109.

URL: https://jstinp.um.ac.ir/article_46109.html.

ABSTRACT

Recent advances in construction methods and sustainable development have allowed urban developers to significantly reduce urban environmental problems caused by building expansion, such as increased energy consumption, greenhouse gas emissions, and the urban heat island effect. Newer alternative roofs could be potential solutions for these urban environmental problems. However, economic and social issuesadopting have hindered the penetration of this market. This study used the systems dynamics approach to perform a comprehensive analysis of the influential factors affecting the alternative roof market, such as economic, social, legal, technical, and environmental capabilities. Then, the performance improvement scenarios were evaluated and ranked according to their relative priority based on the simulation results. The results of this case study in Iran indicate that the combined scenario of the growth of urban space according to the increase in the economic coefficient of green space can be focused on more than other scenarios. However, all the designed scenarios have made significant beneficial changes in the key variables of the system under investigation. The results show that the alternative roof market has significant growth potential solution.

Keywords

Alternative roofing, Roof market Analysis, Sustainability, System dynamics, Multi-criteria decision making.

Article history

Received: 2024-07-06
Revised: 2024-11-10
Accepted: 2024-12-11
Published (Online): 2025-03-17

Number of Figures: 15 **Number of Tables: 5** **Number of Pages: 26** **Number of References:38**

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1. Introduction

Since the 1980s, sustainable development has been noted as a fundamental concept in the global strategy of the United Nations Organization. Sustainable development is defined as development that meets the needs of the current generation without compromising the ability of the future to meet their own needs in the form of economic, social, and environmental aspects. One of the recent issues presented as a new idea in sustainable development is sustainable architectural design. Sustainable architecture refers to buildings that have the least destructive effect on the environment and the man-made environment. In addition, sustainable architecture is effective in the sustainable cycle of the environment and the optimal function of the future (Zandiyeh and Parvardi Nejad, 2010). With the growing population, the need for construction and energy increases. However, fossil resource limitations have led to environmental concerns, including an increase in greenhouse gas emissions (GGEs) and air heat. Therefore, efforts to limit the energy consumption of buildings have led researchers to look for solutions to save energy and preserve the environment. By consuming more than 40% of total energy, buildings exert significant pressure on urban areas (Alshayeb and Chang, 2018) and play a significant role in the emission of greenhouse gases (Alirezaei et al., 2016). In addition, the rapid growth of urbanization to accommodate growing urban populations increases urban runoff and subsequent risks of flooding and water pollution. It adds to heat-related illnesses through the urban heat island effect. This phenomenon leads to increased energy consumption (Bai et al., 2017). These problems, including increased energy demand, greenhouse gas emissions, floods, and heat-related illnesses, have economic and environmental consequences for policymakers and societies (Santamouris et al., 2018). Therefore, buildings play an essential role in urban sustainability, making the urban construction industry an ideal target through which to mitigate these problems. Recent advances in construction and sustainable methods have allowed urban developers to significantly reduce the adverse impacts of buildings (Phillips et al., 2017). One of these forms of sustainable construction is the alternative roof. Alternative roof systems such as green roofs, solar roofs, and photovoltaic roofs offer an opportunity to improve urban sustainability. A green roof is a specially designed system that is installed on the roof to grow and support vegetation. In a green roof, a series of roofing layers are placed under the vegetation to create drainage and waterproof insulation and to protect the roof below it from damage caused by roots. In the solar roof, installed solar panels provide renewable energy for the building. A photovoltaic roof is a set of green roofs and solar panels that are effectively combined on the roof of a building into a single integrated system.

From its construction through operation, a building acts as a complex and dynamic system consisting of various subsystems (Thompson and Bank, 2010). They linked the obtained data to a building information model for improving the decision-making process in building design, retrofit, and operation. In addition, urban processes that are affected by buildings include construction and operations that are randomly connected (Bai et al., 2017). For example, different roof systems have different effects on the depth of annual urban runoff. In the same way, the choice of roofing system can also have a reinforcing or balancing role in the energy-saving potential of the building that may cope with the potential increase in energy demand due to population growth. Therefore, the existence of these interrelationships between the practical elements in the roofing industry has led to addressing the problem of modeling and analyzing subsystems with a systematic view and analyzing the causality between subsystems in an integrated way (Onat et al., 2014). System dynamics modeling allows the integration of these interactions, represented by feedback loops, between the subsystems that make up the building and between the building and its urban environment (Fong et al., 2009).

New systems of alternative roofs could be potential solutions for growing urban environmental problems affected by climate change. However, economic and social concerns, such as the adoption of alternative roofs, have delayed this market penetration despite its excellent growth potential. .This study comprehensively analyzes the key factors affecting the alternative roof market using the integrated system's dynamics approach with a multi-criteria decision-making method. For this purpose, key economic, social, legal, technical, and environmental aspects have been considered in the developed dynamic model.

2. Literature review

Due to the intense attention given to sustainable development in the construction industry, extensive studies have been conducted on alternative roofs in recent years. Using simulation tools, Mahmoody et al. (2012) studied and evaluated the effects of green roofs on reducing temperature and cooling the environment. They evaluated the impact of green roofs on reducing environmental temperature. The results indicate that a green roof leads to less heat transfer than a conventional one. In addition, shading and evaporative cooling plants and the role of roof layers that all perform similar insulation effectively decrease heat transfer. In another study, Vahedi et al. (2012) investigated the integration of solar photovoltaic systems and green roofs. In solar panels, efficiency and output power decrease with increasing temperature. Conversely, direct sunlight increases plant evaporation and transpiration, reducing vegetation and green roof

efficiency. Therefore, vegetation on the roof cools it, increasing the panel's output and efficiency.

Additionally, the shade of panel blocks direct sunlight from hitting the plant, reducing evaporation and transpiration and promoting plant growth and development. Mohammadi et al. (2019) conducted a life cycle assessment to compare the environmental effects of green and conventional roofs and analyzed environmental concerns using simulation tools. The results indicate that the green roof, during its lifetime, has fewer environmental influences than a normal roof. Furthermore, it is addressed that in some impact groups, the environmental impacts of green roofs were more greater than those of normal roofs, and the main cause was utilizing glass fiber and polyester in its layers. Zanganeh et al. (2015) investigated the factors affecting the non-use and development of green roofs for reducing heat islands in the Mashhad metropolis using the hierarchical analysis method (AHP). The obstacles identified in the way of developing green roofs include the high cost of green roofs compared to conventional roofs, the affordability of energy, the absence of a native green roof industry and applied research, the lack of economic justification in plans for both individuals and officials and the absence of codified laws. Darvish et al. (2018) analyzed solar reflection and reflective surfaces in typical roofs as a passive solution to reduce the control of solar energy absorption and reduce the temperature and energy consumption in Ray City as a case study. The obtained results indicate that growing roof surfaces with reflective materials have a significant impact on diminishing the surface as well as the roof's surrounding air temperature. Saiz et al. (2006) reviewed the environmental benefits of green roofs and their potential for heat reduction, annual energy savings, and summer cooling loads. The main specificity of a green roof is its small solar absorptance, which leads to lower surface temperature and decreases the heat flux through the roof. The results indicated that green roofs significantly affect annual building energy consumption. Castleton et al. (2010) reviewed the current literature and highlights for evaluating the potential of green roofs to save energy. Using simulation tools, Susca et al. (2011) investigated the role of green roofs on the effects of greenhouse gases and the amount of CO_2 emissions in the air. For this purpose, the surface albedo effect is evaluated by using a climatological model. Obtained results indicate that green roofs with thermal resistance and plants' biological activity play a crucial role.

Bianchini and Hewage (2012) analyzed green roofs using Monte Carlo simulation tools with the presence of social, economic, and technical variables. The results indicate various advantages of green roofs as a sustainable alternative for urban areas and industry zones.

Costanzo et al. (2016) investigated conventional and green roofs using a simulation tool to analyze their role in reducing greenhouse gas production and energy consumption. Obtained results indicate that many variables impact green roof performance that should be considered in roof design, such as local climate conditions. Li et al. (2014) investigated the cooling capability of green roofs using the climatic composition of the region. They addressed the importance of managing moisture and surface albedo on the performance of green roofs. Morakinyo et al. (2017) conducted a parametric study on the effects of four different types of green roofs on outdoor and indoor temperatures and the amount of cooling in different climates and urban densities. Santamouris et al. (2018) analyzed the effect of green roofs on the emission of greenhouse gases in the surrounding environment under different reduction strategies. In a review study, Besir and Cuce (2018) investigated the effect of green roofs and facades on the amount and quality of GGEs and energy consumption.

Hui and Chan (2011) investigated the performance of photovoltaic roofs from the perspective of energy consumption management using energy system simulations and field measurements. Scherba et al. (2011) investigated the roof energy balance and the associated net sensible heat flux through an energy balance model for several alternative roof systems, including photovoltaic roofs. Lamnatou and Chemisana (2014) evaluated the life cycle performance of a photovoltaic roof. Alshayeb and Chang (2018) conducted an experimental and comparative analysis of different examples of photovoltaic roofs. Van Lith et al. (2018) analyzed the thermal performance of green and solar roofs according to the indoor and outdoor air and surface temperatures. Odeh (2018) also investigated the effect of roof shading caused by installing solar roofs on the thermal performance of buildings. These studies indicate the importance of developing integrated alternative roofs for optimal performance.

Yan (2009) investigated and analyzed macro strategies to increase the solar roof market in the country. Hsu (2012) also investigated the effects of government subsidies on Taiwan's solar roof market. Flynn et al. (2010) analyzed the market effect of solar renewable energy certification on solar roof adoption as a renewable energy. For this purpose, a price support mechanism based on the auction procedure for the solar portion of the target renewable portfolio standard has been adopted. The results indicate that system dynamics can be a tool for analyzing and improving sustainability plans. Kelly et al. (2020) analyzed the dynamics of alternative roofs and their effects on the urban environment in the United States. For this purpose, potential impacts of economic, social, and developmental investment issues are considered alternative roof markets. The results indicate that the alternative rood market

has a substantial growth and market penetration potential. Zheng et al. (2021) investigated the role of alternative roofs in water resource management using a quantitative analytical approach.

Gonçalves and Abrahão (2023) investigated and evaluated the environmental effects of photovoltaic roofs in an integrated structure. The results indicate that the most significant positive impacts were linked to local economic development, electrical supply security, and grid decarbonization. In addition, adverse impacts were connected to original structure visibility and worker safety issues. Hekrle et al. (2023) make an economic assessment of green roofs using cost-benefit analyses. Basyouni and Mahmoud (2024) systematically reviewed green roof materials and highlighted the potential of bio-composite insulation panels. Liberalesso et al. (2023) evaluated financial subsidies for green roofs using the micro-scale analysis method. They highlighted the need to review the procedures for developing and granting public incentives at the municipal and/or macro-scale level for green roofs.

Moreover, the need to develop an efficient system for evaluating the performance of alternative roofs and analyzing their market is strongly felt, considering the comprehensive roles of economic, social, legal, technical, and environmental aspects in this decision-making environment. On the other hand, considering the dynamic and complex relationships between role-playing variables and the possibility of potential nonlinear feedback over time through the role of a set of variables, there will be a need for dynamic analysis of this complex system related to the market of alternative roofs. Therefore, this study proposes a comprehensive model for analyzing the market of alternative roofs in the metropolis of Mashhad as a real-life case study. The multi-criteria decision-making method has been integrated for evaluation planning scenarios based on the obtained simulation results.

3. Problem statement and research method

Library resources were used in this study to identify variables and relationships between them. Then, the fuzzy Delphi technique was used to confirm the identified variables and cause-and-effect relationships. The community of experts consists of experts in the field of environment and specialists of the Housing and Urban Planning Department in Razavi Khorasan Province with at least 15 years of experience related to the research problem. In analyzing the alternative roof market, numerous quantitative and qualitative factors mustbe considered. The influence of these factors on each other and their interactive relationship is inevitable despite any time delays and potential causal effects. If these delays, as well as casual loops, are not taken into account, the modeling results will deviate significantly from reality. Therefore, the dynamics of the

system must be considered.

The key research question of this study is: "How can we analyze the alternative roof market using systems dynamics while considering key aspects of economics, social factors, legal issues, technical aspects, and the environment?" Consequently, this study aims to analyze the dynamics of the alternative roof market and evaluate planning scenarios for system improvement using a multi-criteria decision-making method.

The general steps of the dynamic analysis method are as follows: (1) determining the framework of the problem, including choosing the subject, identifying key variables, determining the time horizon, and providing a dynamic definition of the problem; (2) formulating a dynamic hypothesis, including creating an initial hypothesis, focusing on interpolation and mapping the model boundary diagram, cyclic root diagram, and flow state diagram; (3) formulating the simulation model, including identifying the structure and decision rules, estimating parameters, behavioral relationships, initial conditions, and conducting tests to ensure the consistency of the goal and boundary; (4) conducting the test, including comparisons with reference behaviors, limits, and sensitivity analysis; and (5) policy design and evaluation, including scenario determination, policy design, and analysis. This study analyzed scenarios for the future alternative roof market for 25 years. Figure 1 presents the overall steps of the system dynamic modeling approach in this study.

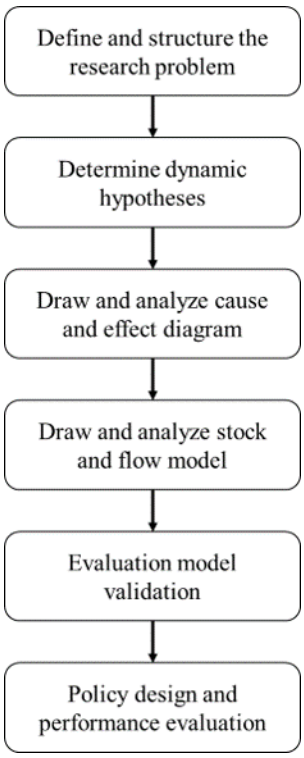


Figure 1. Modeling steps with a system dynamics approach

Various factors play a role in the analysis of the alternative roof market, such as implementation and exploitation costs, energy consumption, energy supply costs, technological factors, consumer attitudes and awareness, compatibility with other urban infrastructures, population change, and access to technology. According to the studies conducted in this field, the variables of population expansion, urban runoff, and the effect of greenhouse gases govern the dynamics of modeling subsystems. Urban runoff is the surface runoff of rainwater and landscape irrigation. Three roof options can be considered for roof market analysis: solar, green, and photovoltaic. Finally, the alternative roof market could be evaluated. The developed cause and effect diagram and stock-flow diagram are presented in Figures 2 and 3, respectively.

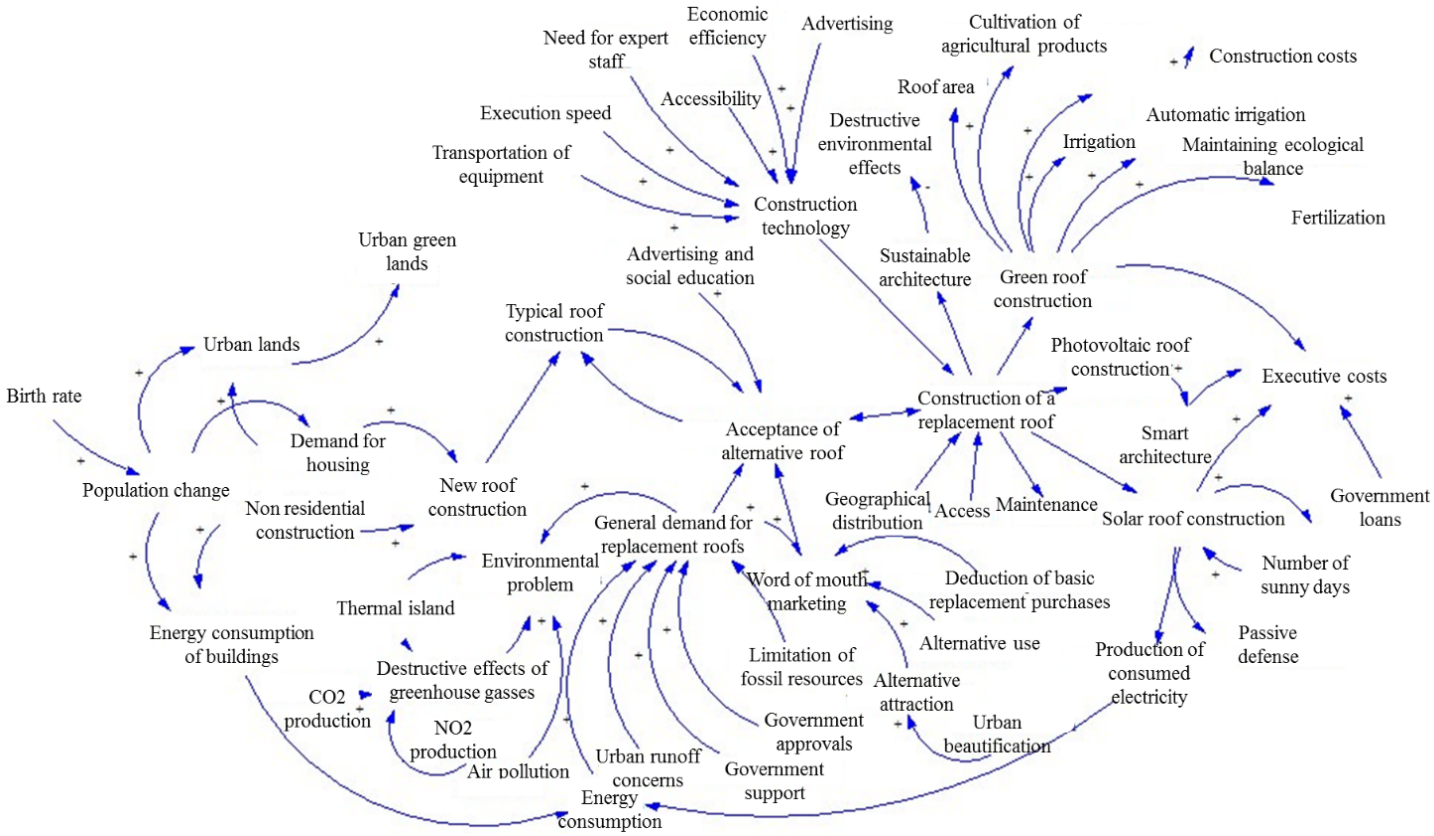


Figure 2. Proposed cause-effect diagram for alternative roof market analysis

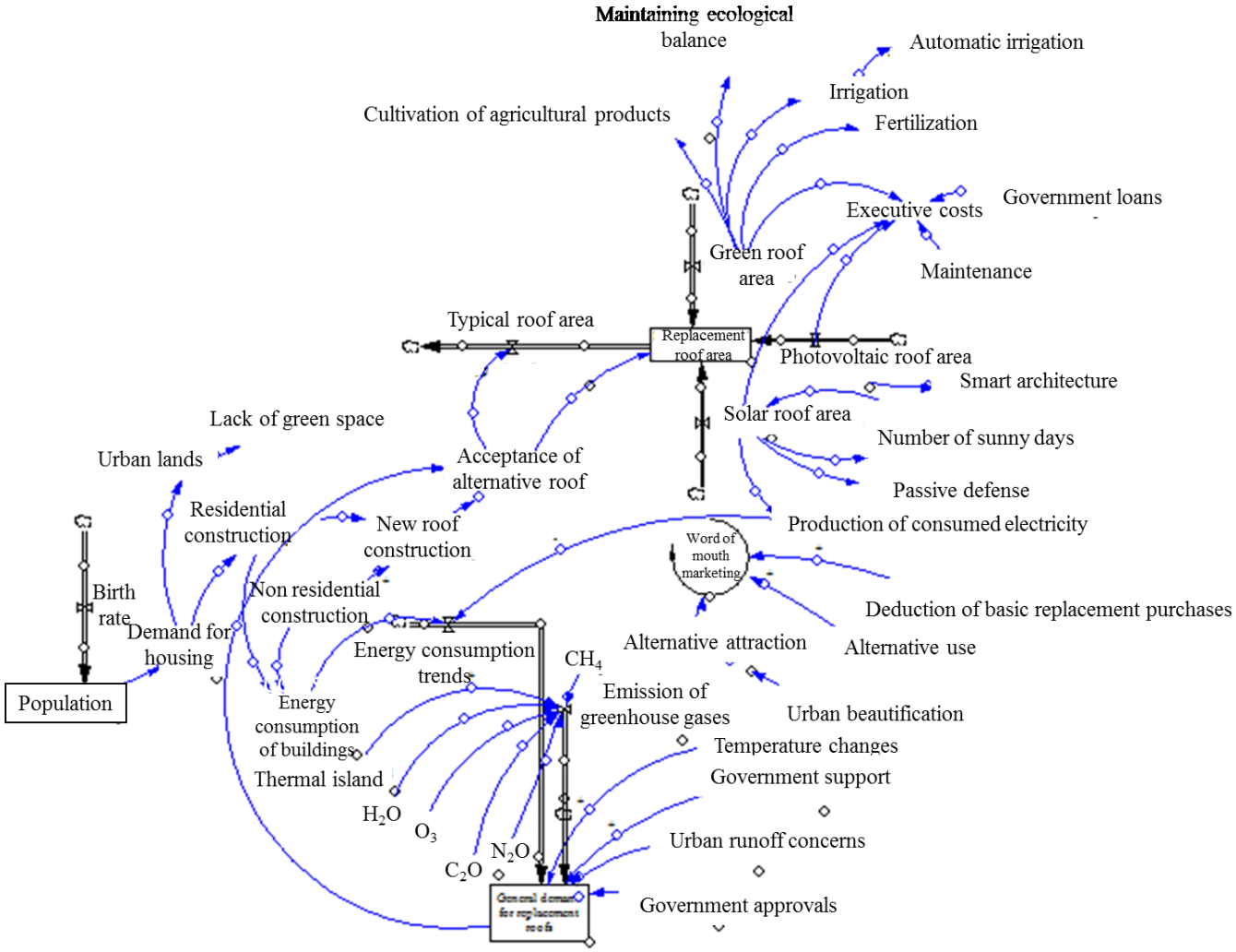


Figure 3. Proposed flow diagram for alternative roof market analysis

The amount of energy consumption of buildings is calculated in kilowatt-hours, which varies according to the area of the roof of each building. The effect of the type of roof on the amount of climate change should be regarded. The green roof with an average vegetation cover of 60 cm can reduce the heat of the air by up to ten degrees and effectively control the flow of water by up to 45 percent. With the increase in demand for new roofs the demand for roof replacements, the construction of new roofs is rising. When accepting new roofs is based on and replacing existing ones, non-standard roof options are more readily accepted. The higher the acceptance rate of alternative roofs, the lower the acceptance and construction of traditional roofs. Therefore, a negative relationship exists between the construction of alternative and normal roofs, creating a restraining effect between them. Population growth is one of the factors influencing the construction of new roofs. As the population increases, so does the demand for housing. This leads to the construction of new buildings, which leads to the expansion of urban areas and a decrease in urban green spaces. The increased demand for housing results in more

residential constructions, with the size of new roofs depending on the size of the building's foundation. The increase in temperature disturbances, the heat of the ground, and the urban heat island have an effective role in replacing a new roof.

On the other hand, the speed of energy consumption is decreasing with new roofs. As a result, the demand for new roofs is increasing to reduce annual energy consumption. The roles of awareness, advertisement, and governmental support are also effective in accepting new roofs. In addition, word-of-mouth marketing promotes the attractiveness of alternative roofs. With the expansion of the population and the production of carbon dioxide, nitrogen dioxide, and other air pollutants, the volume of harmful greenhouse gases released increases, leading to an increase in environmental problems. On the other hand, the destructive effect of pollutants causes warm air to remain in the Earth's atmosphere, ultimately expanding the temperature or heat island. This cycle continues until one of the variables in this loop decreases or remains stable at a desired level.

Applied relations and their related mathematical functions are presented in Table 1.

Table 1. Applied variables and related mathematical functions in the proposed dynamic model

Variable	Formula
Advertising and social training	Cost / Number of admissions
Energy consumption	=(cost + 30) × 365
Executive costs	= Constant
Government budget	=497 million rial
Greenhouse gas (GHG) emissions	= QGHG = A × EF
Housing demand	=E(t)=H-V+H(t)+ru(t)
Maintenance	=Staff cost + equipment cost + number of breakdowns+(total maintenance time/total number of repairs)
Non-residential/Residential Construction	=Useful infrastructure = density × (total area of land × percentage of land construction)
Population	= INTEG (birth -death – migration)
Urban heat island	=ΔTu-r(max)=7.45+3.97ln(H/W)
Urban lands	Constant
Urban runoff	= Constant, 56mm

Due to ranking rank the scenarios of the alternative roof market analysis, the fuzzy TOPSIS technique is selected for ranking preferences based on their similarity to the ideal solution. The criteria weights of the decision matrix in the fuzzy TOPSIS method are calculated via the AHP (Rashidi and Cullinane, 2019). All of the applied formulas in the proposed system dynamics model are considered based on the findings of the literature and expert opinions.

The validity of the proposed system dynamics model and the obtained results are evaluated as follows:

- **Boundary Adequacy Test:** This test examines the model's behavior in the case of changing the defaults related to the model's boundary, applying the development policies

of the model boundary, and so on. The first step in this test is to determine the variation range. One method uses a model boundary range chart, which summarizes the range by listing key internal and external variables and variables outside the model. Due to carry out this test, the causal diagrams of the model were provided to the experts to fix the deficiencies and provide relevant suggestions.

- **Structure verification test:** In this test, the integrated level of the model is examined to answer the question of whether the structure of the model includes the descriptive knowledge of the model system. Since this study is based on a review of the subject literature and has been widely used to complete the information from the experts' point of view, the obtained model is expected to have structural validity.
- **Dimensional consistency test:** This test uses Vensim software to determine the units of variables and their harmony with reality.

Figure 4 shows that with the increase in the demand for the construction of conventional roofs, the amount of conventional roof construction also increases, and the model's behavior is quite reasonable. When the demand for a normal roof triples, the construction of a normal roof in 2043 will reach approximately 160 square kilometers. Figure 5 shows the variable behavior of urban land area if the population variable is tripled. If the population triples, the urban land area of 1416 will reach more than 150 square kilometers.

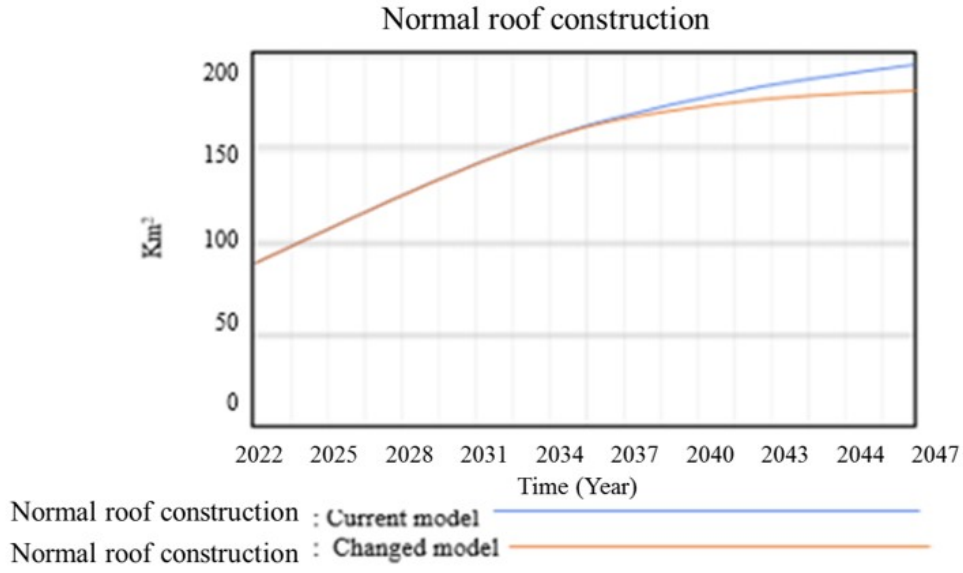


Figure 4. Comparison of normal roof construction in the main model and limit conditions of normal roof demand

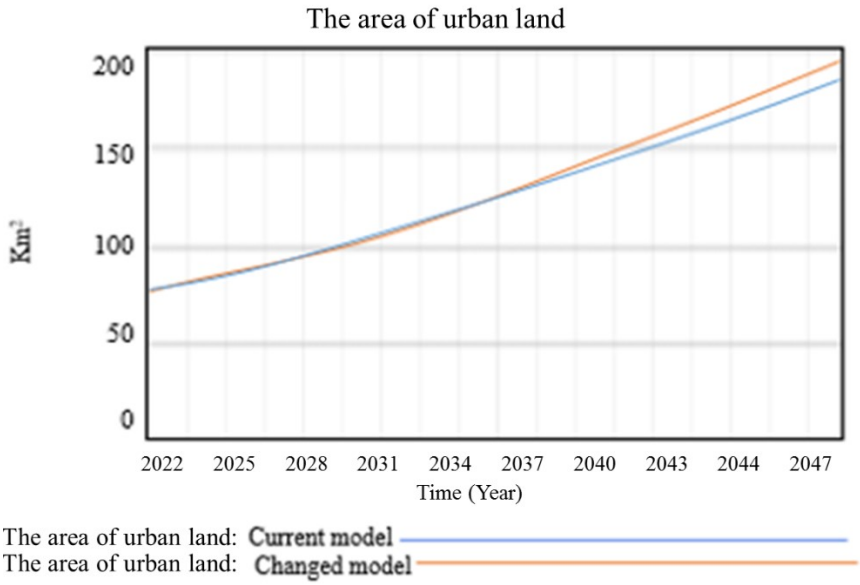
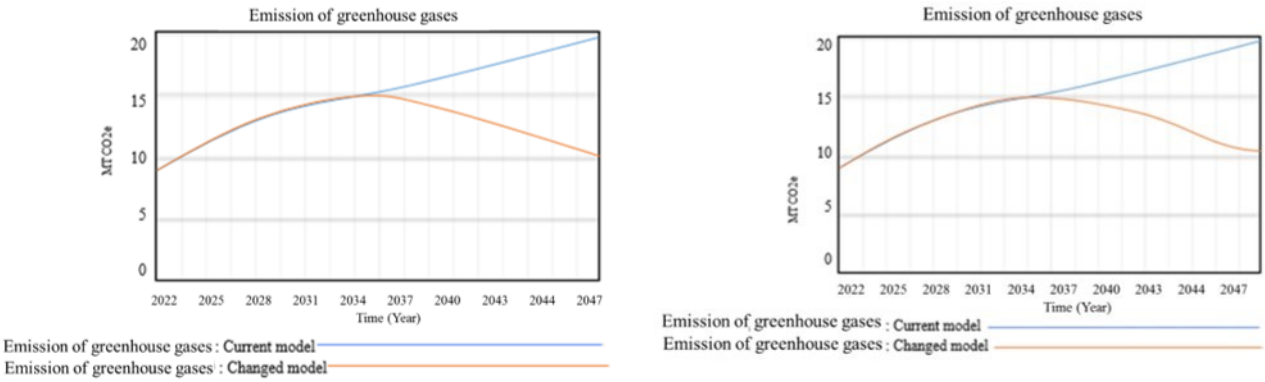


Figure 5. Comparison of the area of urban land in the main model and population limit conditions

Figure 6 shows GGEs if the amount of CO_2 and NO gas production reach half of their amount in 2047, respectively. With the reduction of half of the carbon dioxide production in 2025 and a delayed trend until 2047, GGEs will reach approximately 10 million tons of carbon dioxide equivalent. Additionally, with a 50% reduction in nitrogen oxide emissions in 2025, the amount of GGEs during its delayed process in 2022 reached 12 million tons of carbon dioxide equivalent, which is an entirely reasonable behavior of the model. Among other limit changes given in this section is the impact of building energy consumption on the overall energy consumption trend. If the energy consumption in buildings remains constant despite the increase in population, the trend of energy consumption in 2027 will continue to be constant (see Figure 7).



a: CO2 limit conditions b: N_2O limit conditions

Figure 6. Comparison of GGEs in the main model and limit conditions

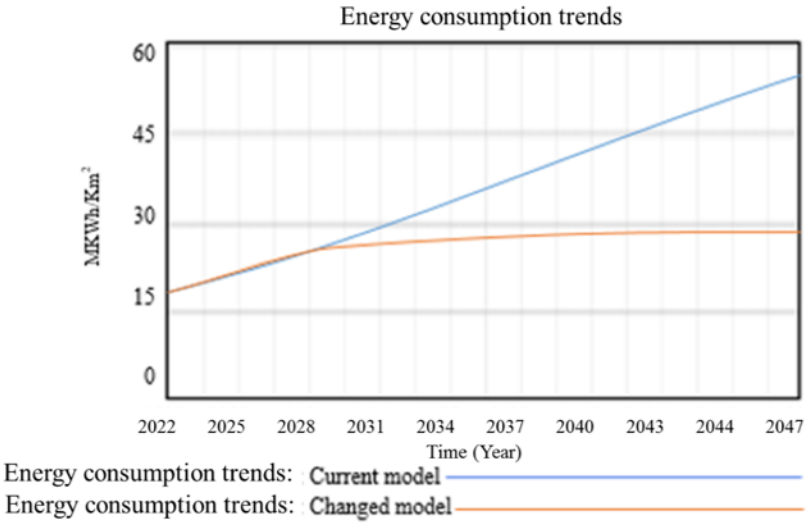


Figure 7. Comparison of the trend of energy consumption in the main model and the limiting conditions of energy consumption of buildings

- **Behavior reproducibility test:** This test aims to answer the following question: "To what extent does the model's behavior agree with the behavior observed from the real system?" (See Figure 8). Statistical methods compare the model's simulated behavior with existing reality. This test uses two coefficients of determination and the mean square error. The coefficient of determination expresses the percentage of changes in the real variable covered by the simulated variable. The mean square of the errors represents the average deviation of the simulated model from the real system. The coefficient of determination of the key variables of the model is greater than 0.8, which indicates that the model can simulate more than 80% of the changes in the main variables. According to the analysis of the values of the calculated statistical indicators, the model was evaluated regarding the reproduction of the appropriate reference behavior.

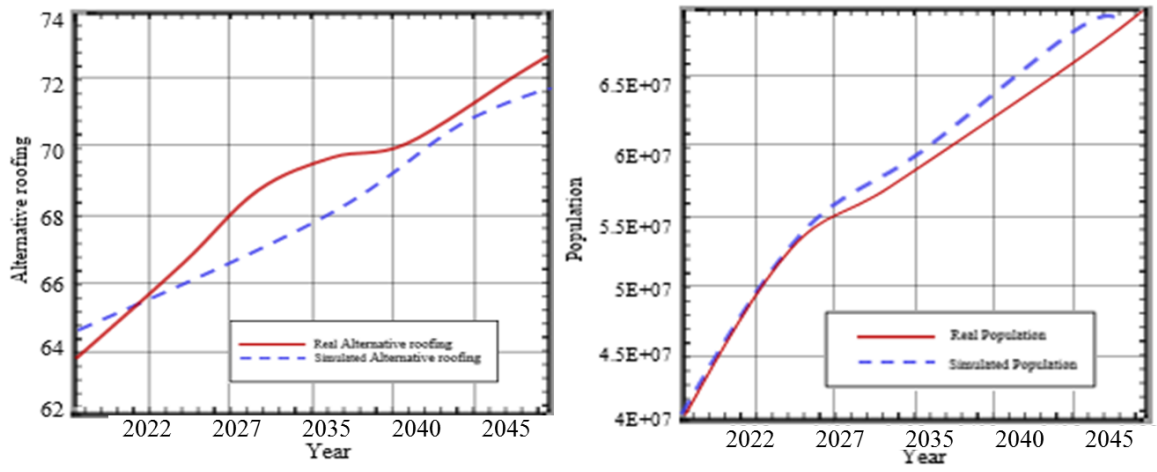


Figure 8. Reproducing the behavior of the population variables and the alternative roof demand

4. Results analysis

According to the implementation of various tests, the model has sufficient validity and accuracy. In this section, the study model is implemented to predict the behavior of key variables. In order to simulate statistical data, this information must be obtained from the National Statistics Center of Iran. The implementation model in this study starts in 2022 and will continue for 25 years until 2047. Fixed values or model parameters were entered into the model to run in the initial year. According to the available information, in some cases, the data were entered into the model as a time series. After that, the behavior of some key variables if the current situation continues is shown in Figure 9.

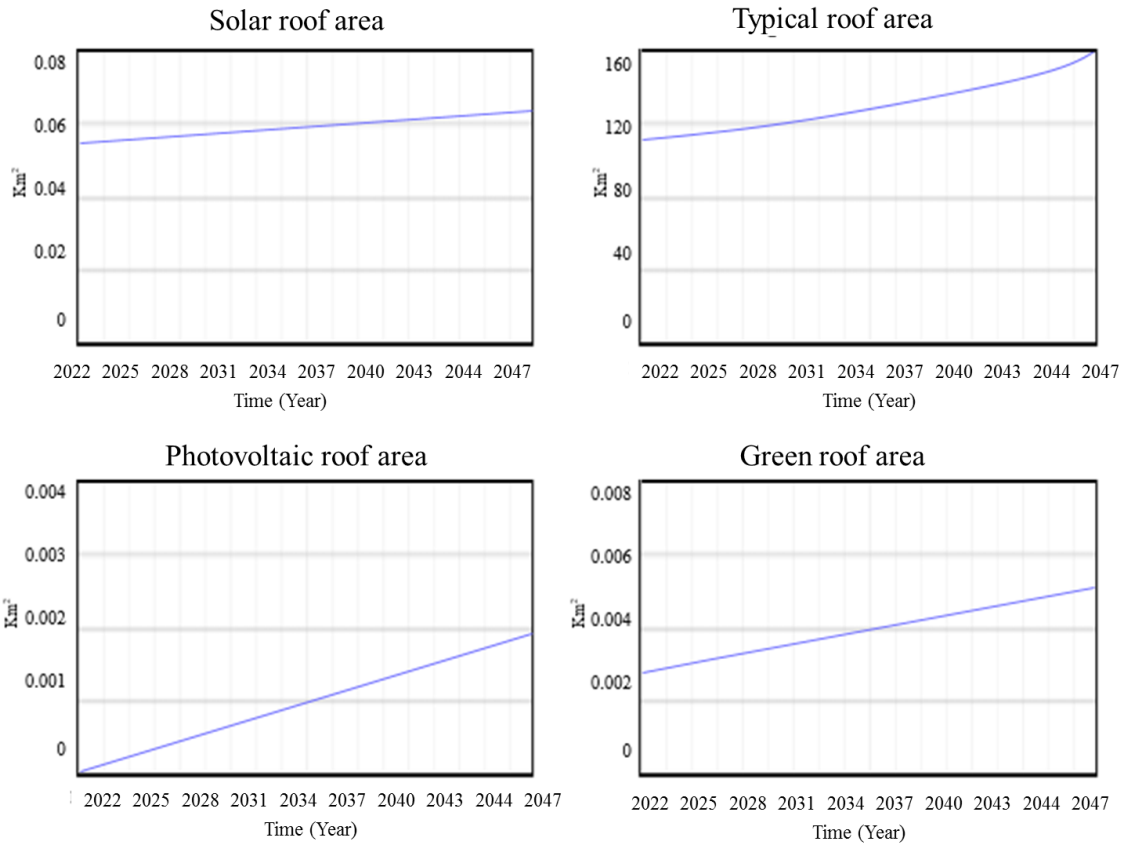


Figure 9. The behavior of some key variables after running the model

4.1. Scenario Planning

In order to analyze the proposed scenario, we changed the values of several key parameters to determine the amount of change in the key variables as performance measures. The total behavior of essential variables is analyzed under each scenario implementation. The results of these changes are shown for 2047 as the final year of the simulation planning period. The details of the scenario are given below.

4.1.1. Scenario 1: Green roof economic technology penetration rate growth

According to the technological goals of the government regarding the expansion of technology in the field of alternative roof construction, this scenario considers the extent of the economic growth of green roofs from the perspective of technology expansion. The scenario assumes that the Mashhad municipality will increase the availability of green roofs within a favorable period by focusing on marketing activities such as increasing the green roof advertising budget and training the workforce in developing and constructing related equipment by technical and professional organizations. On the other hand, with the expansion of equipment and facilities related to the construction of green roofs, cost reduction occurs, and the government can increase accessibility by considering facilities or reducing prices specific to applicants for the construction of green roofs. Therefore, it is expected that with the training of skilled and expert personnel to become familiar with the infrastructure of green roofs with high strength and durability, the exterior design of green space, the training of environmental adaptations to the plant type in each region, access to technology, and the development of domestic technology, the penetration rate of green roof technology will increase economically. In this regard, the values of the auxiliary variables mentioned in Table 2 have been changed based on the base year value and the desired amount to investigate their effect on the model.

Table 2. Auxiliary variables input to the model under the first scenario

	Value	
Variable	**Base year rate**	**Input amount**
Advertisements	7000 (Million Rials)	75 (Billion Rials)
Specialist staff training	-	Training in the production and development of parts and equipment Green space infrastructure training with a base year of 15 to 30 years
Availability	-	Increase up to 30%
Economic efficiency (cost reduction)	Constant	Cost reduction up to 20%

4.1.2. Scenario 2: Development of urban green space in Mashhad with environmental goals

Considering the goals of Mashhad municipality based on the vertical development of green space and urban productivity regarding the efficiency of roofs in residential and nonresidential areas, the focus of this scenario is on the expansion of green space with an emphasis on reducing pollutants, providing government support, and increasing the share of marketing. The goal is that with increasing population, the amount of greenhouse gas production will increase at a slower rate. On the other hand, with the growth of building construction, the production of green

roofs should increase the amount of urban green space. Therefore, in this regard, the per capita energy production by buildings and environmental pollutants, including greenhouse gases, were considered auxiliary variables. Additionally, marketing shares and government support, such as long-term loans, are considered (see Table 3).

Table 3. Auxiliary variables input to the model under the second scenario

	Value	
Variable	**Base year rate**	**Input amount**
Advertising and marketing costs	100 Million Rilas	50 Billion Rials
Government loans	120 Million Rilas	50 Billion Rials

4.1.3. Scenario 3: Easing the rules and removing obstacles to adopting alternative roofs

The purpose of developing this scenario is to focus on implementing facilitation policies for adopting and using alternative roofs. According to the protective laws to increase the attractiveness and acceptance of alternative roofs, the government can allocate protective laws, including facilitating the construction of alternative roofs, such as building permits on the condition that alternative roofs are created according to geographical conditions, reducing the costs of providing the finishing work of buildings, providing construction loans with long-term repayment, providing support laws to facilitate the maintenance costs of alternative roofs, increasing the number of requests and, as a result, increasing the acceptance and construction of alternative roofs.

4.1.4. Scenario 4: Increasing the process of clean energy production with the view of return on investment

Consistent with energy storage, this scenario is presented to produce clean energy in buildings. Mashhad Municipality can take an essential step in saving energy from fossil fuels by identifying suitable points for constructing solar roof infrastructure. By allocating funds for the construction, implementation, and maintenance of solar roofs, Mashhad Municipality will receive a return on investment in a short period. On the other hand, the amount of clean energy production will increase, which means an increase in the storage of fossil fuels. Since the construction of large solar power plants has the possibility of more significant damage, it is assumed that the implementation platform will be quickly provided with the construction of smaller solar power plants.. It will also provide the opportunity to create jobs in this field. Solar panels account for 3% of the base year's income of 25 million monthly. It is expected that with

this amount of income from the construction of a 5-kilowatt solar power plant, the return on investment will occur within seven years (see Table 4).

Table 4. Auxiliary variables input to the model in the fourth scenario

	Value	
Variable	**Base year rate**	**Input amount**
Construction and implementation costs	15 Billion Rials (5 kW power plant)	80 Billion Rials (5 kW power plant)
Maintenance costs	3% of total annual income	3% of total annual income

4.1.5. Scenario 5: The growth of the economic penetration coefficient of green roofs is consistent with the approval of executive laws

The fifth scenario is introduced as a multiple and combined scenario. In this scenario, focusing on integrating scenarios 1, 3, and 4, the process of model changes was investigated. This scenario aims to facilitate the approval process related to implementing alternative roofs with economic goals. Therefore, the government can increase accessibility by providing the implementation costs of alternative roofs, increasing the expert force, attracting investors, and providing production or assembly equipment. As the practicability of alternative roofs expands, the government's protective laws also increase. This scenario can be one of the most compelling alternative roof market analysis scenarios.

4.2. Investigating performance evaluation criteria in scenarios

According to the policies proposed in this study, performance evaluation criteria were investigated based on the following variables: the area of the alternative roof, its acceptance, environmental problems such as greenhouse gases, its attractiveness, and clean energy production.

4.2.1. The area of the alternative roof

According to Figure 10, the amount of the area of the alternative roof in the base state of the model significantly differs from that in the implementation of the model scenarios. The maximum area of the replacement roof is approximately 3.7 times the minimum amount of the replacement roof in the base model. In implementing the first scenario, the number of graphs in the model increased by 2.27. The lowest amount of green roof area growth occurred by facilitating the executive rules of accepting alternative roofs and applying clean electricity production policies, which increased the area of alternative roofs by two times. Therefore, applying each of the proposed policy determines the graph's growth trend.

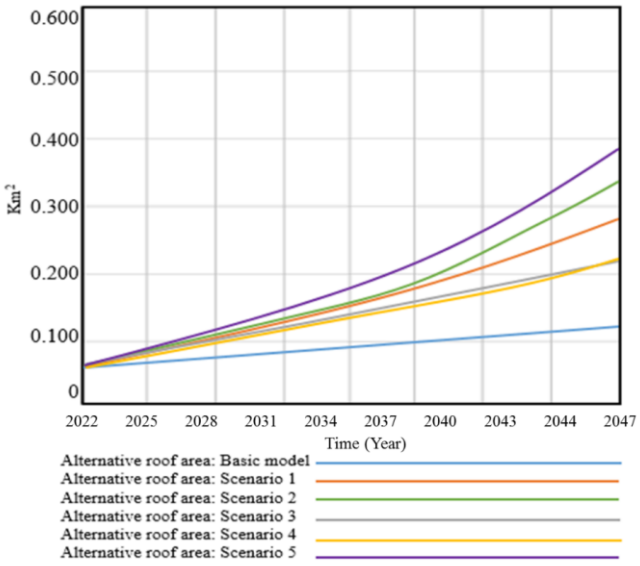


Figure 10. Comparison of alternative roof areas under different model scenarios

4.2.2. Attractiveness rate of the alternative roof

According to the graph resulting from applying the scenarios on the base model, the flow of the model shows an upward trend (see Figure 11). The distance between the maximum attraction rate of the alternative roof and the base model equals 1.1. The highest adoption rate of alternative roofs occurred in the second scenario, i.e., the increase in urban green space and the application of the combined scenario. The graph results show that green roofs have a high absorption capacity due to the design and beautification of the urban space. Due to the increase in urbanization and the increase in the temperature of cities due to industrialization, there is a greater tendency to choose plants and green covers and reduce pollutants. On the other hand, with the application of protective laws, more people are attracted to alternative roofs. Geographical location plays an essential role in choosing and accepting alternative roofs.

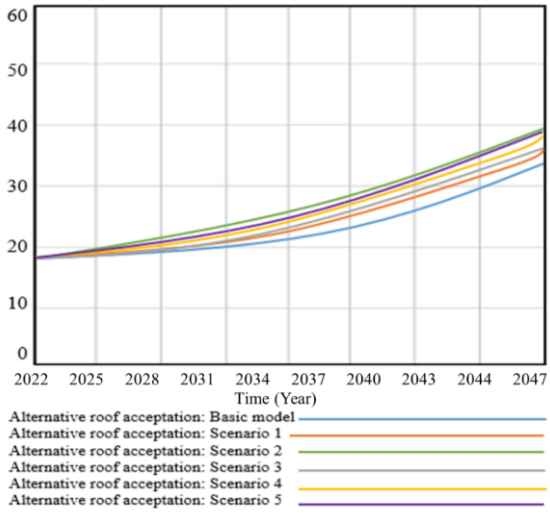


Figure 11. Alternative roof attractiveness rate under different model scenarios

4.2.3. Environmental problems

One of the most important problems of large and industrial cities is air pollution and creating heat islands. The metropolis of Mashhad is geographically located in a hot and dry region, which is one of the reasons for the increase in pollution and heat in this region. According to the graphs below, by applying the proposed policies under each scenario, we will see a future decrease in the graph of environmental concerns and GGEs (see Figures 12-13). It seems that by implementing the combined scenario, greenhouse gas production will decrease by 50% until 2047. Under the conditions of clean electricity production and reducing the share of pollution caused by fossil fuels, the amount of GGEs reaches its lowest level in 2047, approximately 25 million tons per square kilometer of the model. The downward trend of environmental concerns in the combined scenario was expected to be less steep than in the other scenarios. However, according to Figure 12, this scenario has a decreasing trend. This may be due to the long-term effect of the implementation of policy plans or the long-term efficiency of clean energy production. However, the application of each model scenario significantly reduced growth compared to the base model. Notably, the chart experiences a downward trend with a low slope, and the authorities should consider this issue.

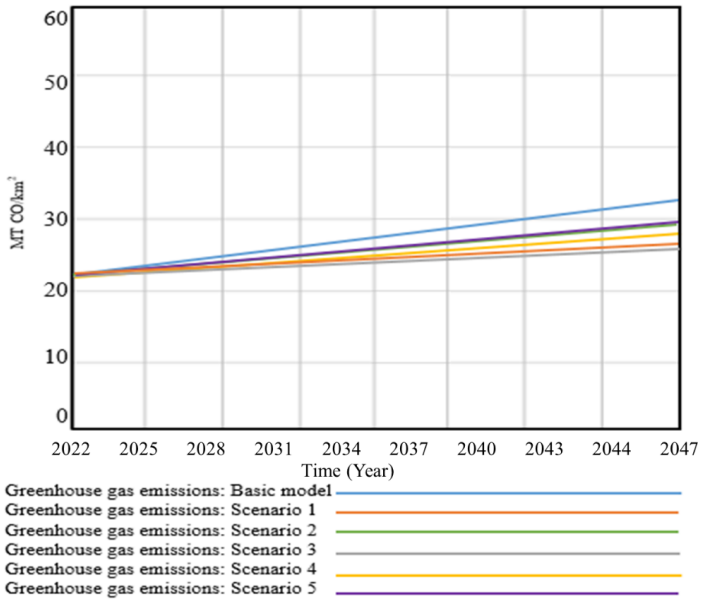


Figure 12. Emissions of greenhouse gases under different scenarios of the model

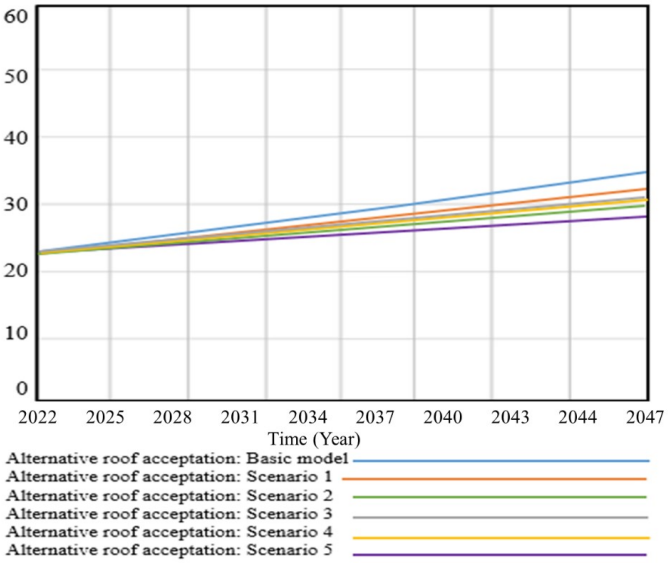


Figure 13. Environmental concerns under different model scenarios

4.2.4. Acceptance rate of alternative roofs

The acceptance and implementation of alternative roofs depend on several factors. In addition to advertising and attracting the audience to choose alternative roofs, each alternative roof's efficiency and technology level can be considered. Although advertising plays an essential role in the acceptance of a trend, forward-looking approaches such as the existence of facilities and the provision of more economical facilities have considerable power in attracting the audience. As expected, applying the combined scenario aimed at the economic penetration of green roofs from the point of view of technology aligned with clean energy production using solar and photovoltaic roofs has shown a significant growth trend in the acceptance rate of these types of alternative roofs in the model. The triple growth of the acceptance rate in the combined scenario compared to the base model shows the issue's importance. After that, using solar roofs with government facilities to produce clean electricity is a priority compared to other scenarios. This may be due to the lower annual maintenance cost of small solar power plants and the need for fewer annual repairs of photovoltaic roofs. The growth trend of accepting alternative roofs in the economic influence of green roofs from the perspective of technology and attention to urban green space will increase until 2047, with a very small difference (see Figure 15).

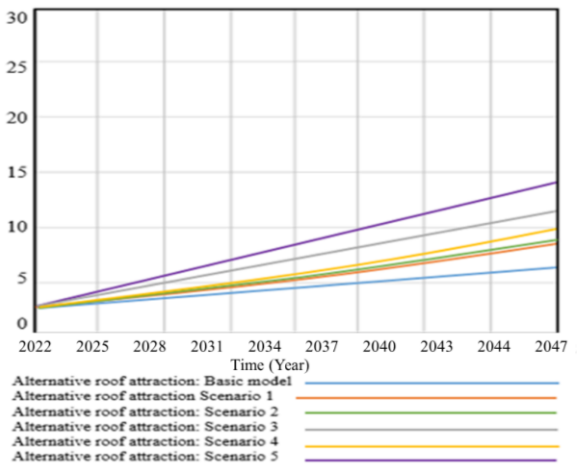


Figure 14. Acceptance of alternative roofs under different model scenarios

4.2.5. Production of clean electricity

According to the simulation results, the combined scenario has shown the most savings in energy consumption in buildings among all the presented scenarios. In the combined scenario, because solar roofs and photovoltaic roofs can meet the energy needs of buildings through solar technology and create the ability to cool buildings, the electricity consumed by buildings can be supplied from power plants. With the release of the thermal degree, it will be reduced to an acceptable level. On the other hand, by expanding the influence of green roofs by using construction technologies, they have significantly contributed to reducing energy use and cooling the environment. In fact, in the case of a green roof, this occurs by reducing the need for energy consumption and not by reducing energy consumption (such as not needing a cooling or ventilation system). According to the simulation diagrams, the trend of electricity generation in the combined scenario is up to 1.4% of that in the base model 2047.

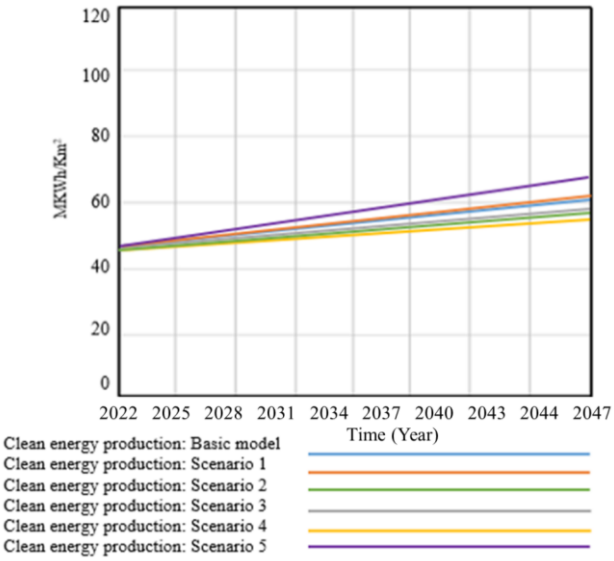


Figure 15. Clean energy production under different model scenarios

Finally, the designed scenarios were ranked using the combined method of hierarchical analysis and TOPSIS and based on the experts' opinions (see Table 5).

Table 5. Model ranking using the fuzzy TOPSIS method

CC	S^-	S^+	Scenario	Rank
0.5724	0.5277	0.3942	1	3
0.5791	0.5349	0.3888	2	2
0.4754	0.4390	0.4843	3	4
0.3179	0.2930	0.6288	4	5
0.6022	0.5584	0.3689	5	1

5. Conclusion

This study analyzed the alternative roof market via a system dynamics approach by considering extensive, influential factors and their potential cause-and-effect relationships. The results show that although the combined penetration levels of alternative roofs in the market remain marginal in almost all the simulation results, it can generally be concluded that a favorable level of demand will be created in this market. However, there is a small possibility that the trend of increasing normal roofs in the roof market will decrease dramatically. Despite the low expectation of an alternative roof market boom in the future, it is anticipated that the solar roof market will maintain its relative dominance in the alternative roof industry and have the greatest potential for future growth. Despite the considerable potential of the green roof and photovoltaic market for future growth, these markets are almost fixed in terms of investment costs and practical feasibility. Therefore, more policy support and technology development for green and photovoltaic roofs will be necessary in the future. These results are consistent with the findings of Flynn et al. (2010) and Kelly et al. (2020), which indicate the predominant share of conventional roofs in the future and the growth of the alternative roof market under the development of more supportive policies. Considering the relatively heavy green roof system, changing to lighter green roof designs or a more user-friendly design can be a more desirable option.

On the other hand, integrating light green roofs with solar and photovoltaic panels can provide many advantages concerning the roof load. Given that hybrid photovoltaic systems have more limited applications than solar roofs, contractor initiatives with green roofs can improve the performance of alternative roofs and lead to more straightforward green roofs with lower maintenance and repair costs. The results indicate that the best process for reducing runoff and the effects of greenhouse gases occurred in the combined scenarios. Since urban expansion is increasing due to the need for urban construction, it is possible to more effectively handle environmental problems by taking advantage of combined policies. Previous studies have also

noticed the importance and role of integrated alternative roof systems (Hui and Chan, 2011; Scherba et al. 2011, Van Lith et al. 2018).Since the potential of alternative roofs for reducing urban runoff seems insignificant compared with conventional and solar roofs, photovoltaic roofs significantly reduce urban runoff. The solar market is vital in reducing heat islands and air temperatures in cities due to its greater penetration rate. The share of green and photovoltaic markets is more limited due to the low penetration rate. Among the alternative roofs, photovoltaic and solar systems are relatively more effective at reducing energy consumption and GGEs due to energy production and cooling load reduction. Nevertheless, development and investment in the future growth of the green roof market, especially in combination with photovoltaic roofs, are still very important for reducing energy demand and GGEs. The level of possible penetration of the green roof market in the future is facing slight growth. Still, with the addition of photovoltaic roofs, we can consider the possibility of more penetration for the green roof market, and it can be clearly said that the green roof market alone has a lower chance of penetration. Considering the technology incorporated in the green roof market and its growth and development in the future market, the need for economic and educational policies and more technology is felt.

Among the alternative roof systems in this study, photovoltaic and solar systems are relatively more effective in reducing energy consumption and greenhouse gas emissions due to energy production and cooling load reduction. Nevertheless, development and investment in the future growth of the green roof market, especially in combination with photovoltaic roofs, is still very important to reduce energy demand and greenhouse gas emissions. The results showed that the combination of green roofs and photovoltaics led to a trend of reducing annual energy consumption by 2.8 kilowatt hours per square meter, which was consistent with the findings of Jaffal et al. (2012) (1.78 kilowatt hours per square meter annually). The simulation analysis showed a reduction of 2.1 kg of carbon dioxide per square meter of greenhouse gas emissions.

Future studies should consider other operational aspects of the technology implemented in alternative roofs, such as the technology's life cycle, maintenance, repairs, and upgrading of the system in the dynamic analysis model. It is also possible to examine the effects between key variables within the system using the fuzzy mapping approach to analyze the strength of the effect.

Disclosure statement

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

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Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir
Online ISSN: 2821-1669, Print ISSN: 2980-9460
Research Article
DOI: 10.22067/JSTINP.2025.89229.1113
JSTINP 2025; Vol. 4, No. 1

Comparison of Diffusion of Near Field Communication Technology in Mobile Phone and Electronic Payment Card Technology Using System Dynamics Approach

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How to cite this article

Madady Nia, M. M., Safaie, N. 2025. Comparison of Diffusion of Near Field Communication Technology in Mobile Phone and Electronic Payment Card Technology Using System Dynamics Approach, *Journal of Systems Thinking in Practice*, *4*(1), pp. 27-43. doi: 10.22067/jstinp.2025.89229.1113.

URL: https://jstinp.um.ac.ir/article_46240.html.

ABSTRACT

According to the Central Bank of Iran statistics, around 300,000 electronic bank cards have been issued and made available to people. Based on this, the number of cards available to each user is estimated to be between 4 and 6. On the other hand, Near-field communication technology has been unveiled by some banks and financial institutions in the country, and some store card readers have also been equipped with this technology; despite many efforts, "near-field communication" technology for mobile phone-based payments has not been developed. In this research, the state of diffusion of near-field communication technology in the mobile phone-based payment system and its comparison with the technology of electronic payment cards from 2023 (1402 In Persian) to 2041(1420 In Persian) have been investigated and evaluated. The results show the growth of near-field communication technology and the significant decrease in electronic payment card technology.

Keywords

Near field communication technology, Electronic payment cards, Technology diffusion, System dynamics..

Article history

Received: 2024-08-10
Revised: 2024-11-24
Accepted: 2025-02-14
Published (Online): 2025-03-17

Number of Figures: 5 **Number of Tables: 4** **Number of Pages: 17** **Number of References:47**

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1. Introduction

Electronic payment cards are among the most popular and common methods for conducting financial transactions and purchasing goods. The primary purpose of producing bank cards is to facilitate financial transactions, reduce risks associated with carrying cash, and decrease bank expenses (Mojdehi, et al., 2016). The first electronic payment card was issued in 1966 by Barclays Bank in Great Britain. In the following years, other banks, such as Bank of America and the National Bank of Germany, also began producing electronic payment cards. These cards are now used worldwide (Batiz-Lazo and Del Angel, 2018). NFC technology was unveiled in 2000 by Nokia, Siemens, and Samsung. This technology is based on "radio frequency identification" technology. Data can be exchanged between two devices equipped with this technology by bringing them closer together at a distance of approximately five centimeters. (Curran, et al., 2012). In many countries, electronic payment cards are being replaced by payment technology based on near-field communication technology (Samouti and Fathi, 2020). Southeast Asian countries, especially China, are among the leading countries in the use of communication technology. The nearest field is in mobile phone-based payment systems, and this trend is growing in European countries, but in our country, the use of electronic payment cards is still the leader in financial transactions. In this research, we seek to investigate the growth or decline of these two payment methods in the years between 2023(1402 In Persian) and 2041(1420 In Persian) in the country. In this article, the subject literature will first be discussed, including the history of electronic payment cards and payment systems based on mobile phones, NFC technology, and publishing technology. Then, the background of the research, the research method, and the research findings are written, and at the end, the selected scenarios, discussion, and conclusions are given.

2. Literature review

A bank card is an electronic payment device that enables the user to withdraw and deposit funds from a bank account. As a result of advancements in electronic payment technologies and methods, the bank card can now serve as a primary means of payment and withdrawal at all Iranian and international banks and exchanges.

2.1. History of electronic payment cards

Electronic payment cards are among the most significant developments in banking. These cards were first issued in the 1950s in America by the New York City Bank. The subsequent

advancement in electronic payment cards occurred in the 1960s when the "Bank America Card" was introduced to customers, allowing them the option to pay by card. Bank cards became widely accessible to the public during the 1960s and 1970s. In 1967, the Berkeley Bank of London also began issuing electronic payment cards. The 1970s, "Mastercard" entered the market in competition with "Bank America Card,periodIn the 1970s, Mastercard entered the market in competition with the Bank America Card, and in a short period, it became one of the most popular bank cards. With the emergence of serious competition between these two cards, other services and features were added to bank cards (Zumello, 2011). Despite the emergence of electronic payment cards in previous decades, the 1980s saw significant growth in their distribution and use. During this decade, with the introduction of internet payments, this technology became one of the most popular payment methods worldwide. Today, these cards enable access to banking services, online shopping, and international payments. With advancements in technology, bank cards have changed dramatically; they now utilize chip and PIN technology for enhanced safety and security (Thangavel, 2023).

Electronic payment cards are divided into two general categories: cards with magnetic strips and cards with electronic chips. With magnetic strip cards, customer and bank account information is stored on a black magnetic strip located on the back of the card. The information on the card is displayed by swiping the card in the card reader or inserting it into the ATM (Fancher, 1997). There are three slots on these cards. Usually, the first slot contains information such as the owner's name and account number. The second and third slots contain control information such as password, country code, authorized amount, and current currency. When the card-accepting company receives the card information, it measures the validity of the data in the magnetic strip, such as the correctness of the card number, the use of the card, and the limit of the card used (Iranicard.ir, 2023). In electronic payment cards with an electronic chip, information such as the bank account number, name of the cardholder, expiration date, and security information such as the three or four-digit CVV2 (Card Verification Value 2) or CVC2 (Card Validation Code 2) code, as well as the customer's bank information, is stored in the electronic chip and can be entered into the card reader or It is possible to make a transaction at an ATM. Bank card information can be transferred to the reader through an electronic chip. A bank card reader can read the information encoded in the electronic chip and use it to make a transaction (Mojdehi et al., 2007). Electronic chip technology is replacing magnetic tape due to higher security. Both electronic payment card technologies are currently still in use around the world. The electronic payment card is one of the most common payment tools that allows users

to make and conveniently make purchases faster, more securely, and more conveniently. One of the advantages of paying with a bank card is its faster speed than cash payment. Paying with an electronic payment card makes the shopping process quick and easy, and with its help, you can quickly pay for your purchase electronically (Krivoshia and Kurolo, 2018). Paying with a bank card is more secure, and in addition to reducing the risks of cash or check payment, it sends your personal information to the banking system in an encrypted form (Ming-Yen Tehu et al., 2013).

2.2. History of NFC (Near Field Communication) technology

"Near field communication" technology is a standard wireless communication method between electronic devices at close distances (less than ten centimeters). In late 2002, two companies, Philips and Sony, introduced NFC technology for non-contact communication. This technology was officially used in December 2003 with a bit rate of 106, 212, and 424 kbps and a central frequency of 13.56 MHz to communicate between two devices equipped with this technology. In 2004, Nokia, Philips, and Sony established the "Near Field Communication" association to promote this technology (Curan, Miyar, and McGarvey, 2012).

This technology is based on "Radio Frequency Identification" technology and works in two active and passive interfacepassive-interface communication modes. Based on the operation mode of the device, there are three methods and: read, peer-to-peer, and card emulation. The first of these modes allows passive reading and exchange of data stored on compatible carrier tapes such as NFC tags. In the card emulation mode, the data stored in the device can be read using an external reader such as a store card reader. Peer-to-peer mode includes connecting two separate devices equipped with this module. The two-way communication of these devices enables the active exchange of information between them (Leong et al., 2013). NFC protocol can realize a communication network using devices equipped with this technology. The exchange of information between systems also requires at least an agreement between the exchange parties about the exchange codes and data structure (Mohandas et al., 2015).

NFC technology suits small payments and crowded places with high transaction rates. On the one hand, the shortness of the communication time in this technology makes the payment process as fast as possible in such places. On the other hand, its short range ensures the security of the transaction and users' data and prevents the interference of the transaction of several users. It prevents each other (Mehrnezhad et al., 2015). Due to the newness of this technology, payment service providers based on NFC are mainly creating platforms. They are suitable for

the broad application of this method. On the other hand, most mobile phone manufacturers have provided phones with the capability of this technology, and it is expected that in the coming years, most of the mobile phones produced will have this capability.

2.3. Technology diffusion

The word dissemination means spreading information, technologies, innovations, behaviors, beliefs and diseases among the population. These cases can be modeled using the diffusion model among the target society. In the classical definition, diffusion includes innovation transmitted through specific channels over time between members of a social system (Rogers, 2003). In publishing, the target society is divided into two parts. The first group is the group that is aware of information, technology, innovation, etc., and the second group does not have any awareness or knowledge about the mentioned items. Over time, the second group is reduced and added to the first group (Page, 2018). Therefore, diffusion is a social process among people in response to learning innovation, such as a new evidence-based approach to expand or improve a service or product (Dearing and Cox, 2018).

Diffusion of technology has been used experimentally in various disciplines over the past years, is evolving, and continues to be applied to emerging innovations and social issues (Dearing and Meyer, 2006). Agriculture, medicine, education, communication, and marketing are among the various fields in which technology diffusion has been applied (Greenhalgh et al., 2005). Technology diffusion has been used for various studies on mobile applications, such as understanding customer acceptance of mobile payment systems (Shirtzet al., 2010), and social network adoption through diffusion theory (Span, 2022). In another study, they studied the dissemination and acceptance of online education for students during COVID-19 disease (Raman et al., 2022; Lee and Fanguy, 2021).

2.4. Research background

2.4.1. Background of external researches

Polasik et al. (2013), in research they conducted in the field of payment methods in Poland, found that payments based on NFC technology have higher time efficiency than other payment-researched payment methods in Poland and that payments based on NFC technology are more time efficient than other methods. In other research, Karsikko (2015) focused on identifying the drivers and inhibitors of mobile payment diffusion among Finnish consumers. The primary findings of this study indicate that mobile payments were perceived as a relatively positive

phenomenon; however, security emerged as a major concern compared to card payments. The results underscore a favorable attitude towards mobile payment acceptance. Yang et al. (2015), in research titled "Understanding Perceived Risk in Mobile Payment Acceptance," found that compatibility has the most significant impact on the intention to use mobile payment services. Sajid & Hedara (2016) investigated mobile phone payments utilizing NFC technology in Norway. The results and hypotheses from this research confirm that mobile payments using this technology are easy for consumers to use and effective for the intended purpose. Oliveira et al. (2016), in a study titled "Mobile Payment: Understanding the Determinants of Customer Acceptance and Intention to Recommend the Technology," discovered that compatibility, security, performance expectations, innovation, and social advertising significantly influenced mobile payment acceptance and intent to recommend the technology.

In other research, Subramanian (2017) examined the factors affecting the use of mobile phone payment systems based on near field systems based on near-field communication in supermarkets. He found that transaction speed, advertising, security, legal infrastructure, call rate, and word-of-mouth advertising can affect users' use of mobile payment based on NFC technology. In a study, Luna et al. (2017) examined the adoption of NFC technology for mobile phone payments in Brazil. The findings show that attitude, personal innovation in information technology, advertisingintention to use, and technical and legal infrastructure determine the purpose of using this technology for payment. Liébana-Cabanillas et al. (2018), in their supplementary research, published an article with the topic analysis of user acceptance of mobile payment systems in social networks, and in it to explain acceptance, legal infrastructure, and social advertising were included in the technology acceptance model. The merged results showed that companies results showed that companies could consolidate their business model using alternative payment systems resulting from new technical developments. Stanivuković et al. (2018) conducted a research titled. Predicting the demand of users of near-field communication based on mobile phones in the Serbian market. They considered risk, reliability, compatibility, advertising, legal infrastructure, and technology limitations. Existing migration cost, innovation, and personality were investigated.

Kawshalya (2020) evaluated the factors influencing the slow adoption of payment services based on near-field communication from the perspective of Sri Lankan customers and service providers. The research framework included nine independent factors and two mediating factors. A survey was distributed among consumers to identify the factors affecting their adoption of NFC-enabled payments. Structural equation modeling was used to analyze the

collected survey data. The research findings demonstrate that only the perceived ease of use positively influences the adoption of NFC-enabled payments. Compatibility, awareness, and the intention to use directly affect perceived ease of use; consequently, they indirectly positively impact the adoption of NFC-enabled payments in Sri Lanka. Technical issues such as limited battery power of point-of-sale (POS) devices, uncertainty regarding consumer transaction security, associated initial and recurring costs, and inadequate government regulation were identified as factors contributing to the slow adoption of NFC-enabled payments from the service providers' perspective. Li and Zheng (2023), in their research comparing cash payments, bank card payments, and mobile payments, found that factors such as word-of-mouth advertising and optimism driven by the image of technology significantly enhance users' willingness to utilize technology-based mobile payments compared to other payment methods. Hamzah (2023), in his research conducted during the COVID-19 pandemic, discovered that the use of NFC technology and mobile phones for purchasing goods and services has increased, and users are inclined to adopt these methods to prevent contracting the virus. They prefer not to use traditional payment methods or contact cards.

They found that factors such as risk, use and traditional resistance can prevent the spread of mobile payment technology. Still, In another study conducted by Madady Nia et al. (2023), titled "Technology Diffusion Model in NFC Technology in Mobile Phone Payment System in Iran," the proposed model and scenarios for the diffusion of this technology were presented. The results indicated that the call rate and legal infrastructure are significant factors in the spread of NFC technology. By 1420, this technology will be widely adopted in the country. In a separate study, Rabaai et al. (2024) examined the value of mobile payment from the perspective of resistance to technology. They found that risk, usage, and traditional resistance could hinder the spread of mobile payment technology. However, with the onset of COVID-19, this resistance has diminished, leading users to adopt contactless payment technologies to protect their health gradually.

2.4.2. Background of internal researches

In a study, Sarlak et al. (2013) found that despite the increasing trend of mobile efficiency in commerce, mobile banking was not well received. They stated that contrary to the growing trend of mobile phone efficiency in business, banking through mobile phones was not very well received, they found that trust in accepting electronic banking through mobile phones is effective in its acceptance. Mousavi Haghighi and Tajik (2014), in an article entitled Simulation

of the diffusion process of new products with the approach of system dynamics approach, using the bass diffusion model, investigated the technology diffusion process and word-of-mouth advertising, call rate, and quality as the most criticalessential variables. Influential on the publication introduced. Doosti (2014) in research entitled "Investigation of the infrastructure of NFC technology implementation in Qarz-al-Hasaneh Mehr Iran Bank," the primary purpose of this research is to investigate the legal and technical infrastructure of NFC technology in Iran's Qarz-al-Hasaneh Mehr Bank. The results of the tests showed that all the infrastructures for implementing this technology in this bank are above average. Karimi (2016) in the research conducted on the investigation of determining factors in the acceptance of mobile phone payment systems based on NFC by users, stated that despite the ability of this payment system, its use in the country has not yet expanded. The obtained results show that factors such as attitude, mental norms caused by image technology, trust, and usefulness have a positive effect on the intention to use this technology. Homayounfar et al.,(2017), in an article titled "Designing a Dynamic Model of New Product Development with an Emphasis on Bass Diffusion Theory," found that in addition to word-of-mouth advertising, the call rate and increasing the budget for research and advertising have an effect. It is more about attracting customers. Bastan et al. (2017), in their research, presented a simulation model of bank card acceptance by bank customers using the system dynamics approach. The results showed that improving the policies of increasing advertisements and services that can be provided effectively influences customers' intentions. A research study presented a simulation model of bank card acceptance by bank customers using the system dynamics approach. The results showed that improving the policies of increasing advertisements and services that can be provided effectively increases customers' intentions to use. Madady nia et al. (2023) in research entitled In their 2023 research titled "Drivers and Inhibitors of the Diffusion of NFC Technology in the Mobile Phone Payment System," Madady Nia et al. examined the factors influencing the adoption of NFC technology in mobile payment systems. They identified trust, social advertising, word-of-mouth advertising, and the image of the technology as the most critical factors impacting the spread of this technology. Drivers and Inhibitors of the Diffusion of NFC Technology in the Mobile Phone Payment System investigated the factors affecting the diffusion of this technology in the mobile phone payment system. trust, social advertising, word-of-mouth advertising, and the image of the technology were mentioned as the most critical factors affecting the spread of this technology.

3. Research methodology

After interviewing the elites and obtaining the dimensions and model components and indicators of the NFC technology diffusion model in mobile phone payment systems, the systems dynamics modeling method will be used for the quantitative research model in the next part. The system dynamics technique is based on information-feedback theory. It uses symbols to map business systems through diagrams and equations, and programming language is used for computer simulation. One of the most important goals of system dynamics modeling is to propose various policies to improve the system's performance and to choose the policy that provides the best implementation results (Chu et al., 2009). System dynamics technique based on existing feedback and delays show a picture of the system so that the dynamic behavior of complex physical, biological, and social systems can be better understood. The most basic principle expressed by system dynamics is that feedback and delays create the behavior of systems. The dynamics of system behavior are the result of the structure that governs the system (Faqih et al., 2013).

3.1. System dynamics

System dynamics were presented in the mid-1950s by one of the professors of the Massachusetts Institute of Technology named Forster as a new way to manage the performance of companies. He believed the human brain cannot interpret social systems' behavior with linear and one-way logic. Hence, multi-loop nonlinear feedback systems should be used to analyze various phenomena. By proving the efficiency of system dynamics and technological progress, the use of computer software to implement this method was expanded (Vennix et al., 1997).

System dynamics is a method for understanding, evaluating, and quantitatively and qualitatively analyzing the nonlinear behavior of complex systems over time. System dynamics is one of the efficient approaches to analyzing dynamic systems in various fields such as management, economics, biology and engineering. To define the model and simulate the behavior of a phenomenon, the relationship between the parameters in that phenomenon should be determined. In dynamic systems, each decision's output will affect its future input. System dynamics is considered as one of the branches of systems theory. In this approach, concepts such as feedback loops, accumulation-flow diagrams, and time diagrams display time-based changes and interactions between different system parts. Finally, the behavior pattern of the system is obtained in the specified time interval.

4. Research findings

According to the research background and experts' opinions, the variables of NFC technology users, magnetic card users, and new potential users as stock variables and variables of birth rate, death rate, contact rate, legal infrastructure, image of WOM (word of mouth) advertising technology WOM, the effect of media advertising and trust were used in model building and simulation. The causal loop diagram is shown in Figure (1).

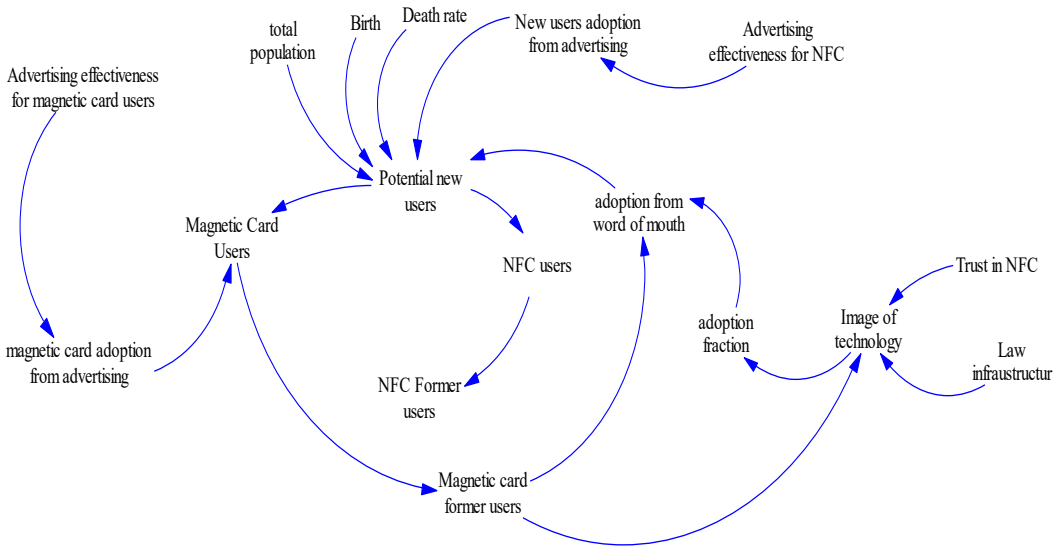


Figure 16. Causal loop diagram

Magnetic card users, NFC users and potential new users are the state variables in this model. The stock-flow model designed in Vensim software is shown in Figure (2).

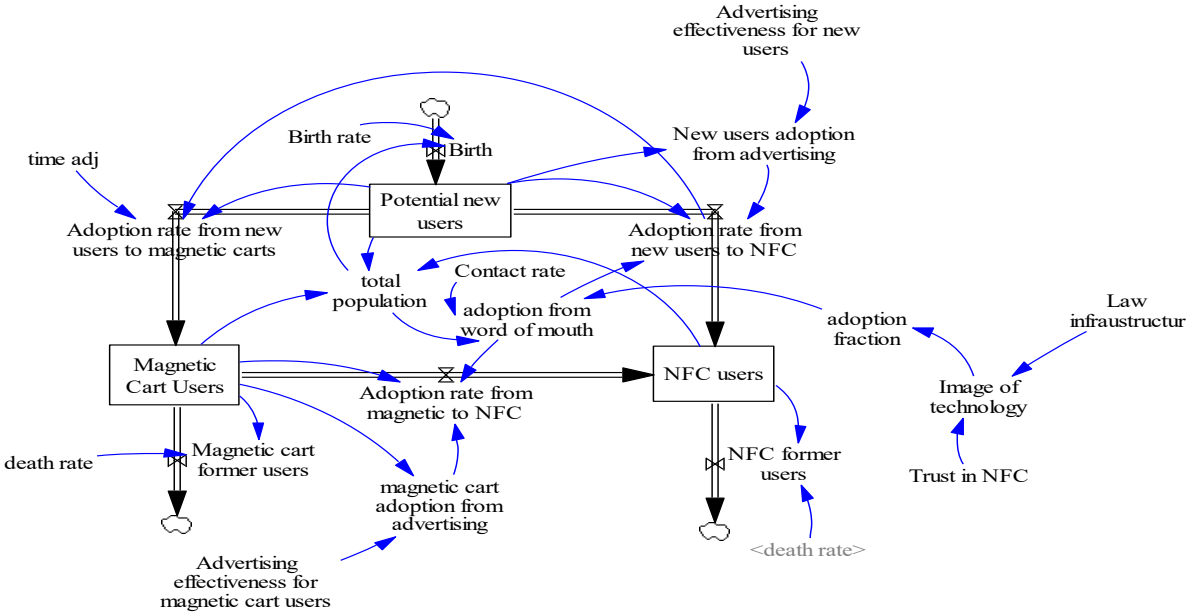


Figure 17. Stock-flow diagram of the integrated diffusion model of NFC technology and magnetic payment cards

The equation of variable is shown in Table1.

Table 6. Equation of variable

Variable	Equation
Potential new users =	Birth-Adoption rate from new users to magnetic carts-Adoption rate from new users to NFC
Magnetic Cart Users =	Adoption rate from new users to magnetic carts-Adoption rate from magnetic to NFC-Magnetic cart former users
NFC users =	Adoption rate from magnetic to NFC+Adoption rate from new users to NFC-NFC former users
Adoption rate from new users to magnetic carts =	Potential new users/time adj-Adoption rate from new users to NFC
Adoption rate from new users to NFC =	New users adoption from advertising+adoption from word of mouth*Potential new users
Adoption rate from magnetic to NFC =	Magnetic Cart Users*adoption from word of mouth+magnetic cart adoption from advertising
Magnetic cart former users=	death rate*Magnetic Cart Users
NFC former users=	death rate*NFC users
Birth =	total population*Birth rate
New users adoption from advertising =	Advertising effectiveness for new users*Potential new users
Image of technology =	Law infraustructur+Trust in NFC
adoption from word of mouth =	Contact rate*adoption fraction/total population
total population =	Magnetic Cart Users+NFC users+Potential new users
magnetic cart adoption from advertising =	Advertising effectiveness for magnetic cart users*Magnetic Cart Users

4.1. Scenario analysis

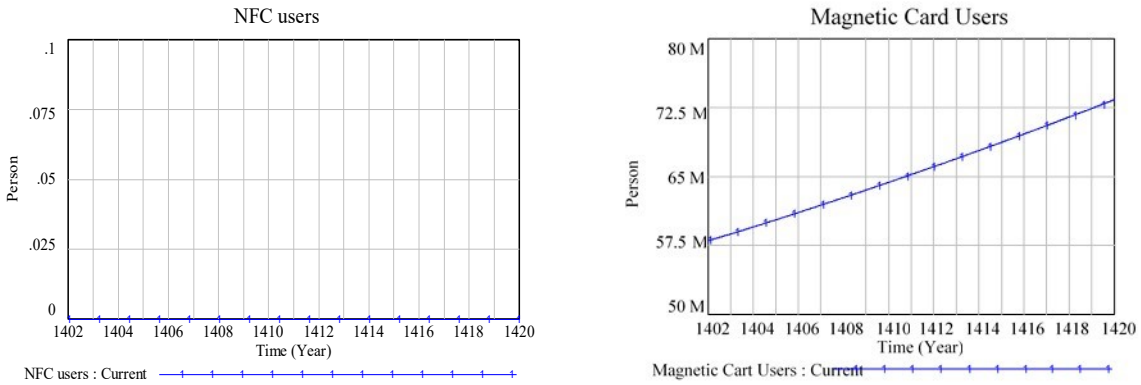
According to the model presented in Figure (1) and experts' opinions, four influential variables were used as key variables in the scenario development to investigate the diffusion of NFC technology and the decline of payment technology based on magnetic payment cards. Below, we describe selected scenarios.

4.1.1. First scenario: Continuation of current conditions

In the first scenario (Table 2), it is assumed that no action will be taken regarding the dissemination of NFC technology, and the process of using magnetic payment cards will continue with the previous process. The results show that the number of users of NFC technology have not grown at all (Figure 3-a), but the number of users of magnetic payment cards will reach 73 million people according to the population growth (Figure 3-b).

Table 7. Defined parameters regarding NFC technology in the simulation of continuing current conditions

NO	Parameters	Value in the continuation simulation of current conditions
1	Advertising effectiveness for new users	0
2	Advertising effectiveness for magnetic cart users	0
3	Trust in NFC	0
4	Law infrastructure	0



a: NFC technology adopters b: Acceptors of magnetic cards

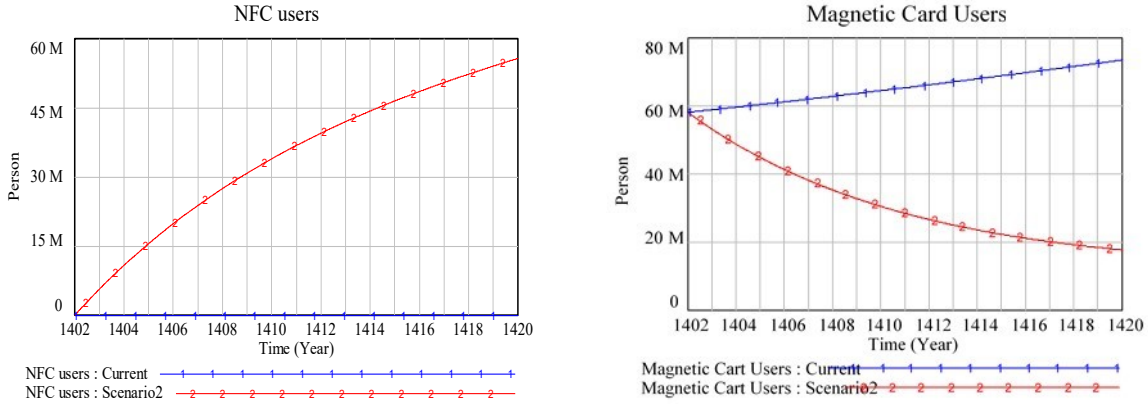
Figure 18. Simulation results in the first scenario

4.1.2. The second scenario: Improving the legal infrastructure and trust in conditions of low advertising effectiveness

In this scenario (Table 3), trust and legal infrastructure have reached their maximum value, and the effect of advertising on new users and the effect of advertising on magnetic cards are at their minimum value. In this situation, the adoption of NFC technology has grown to about 55 million users (Figure 4-a), and the adoption of magnetic cards has decreased to about 18 million users (Figure 4-b).

Table 8. Defined parameters regarding the NFC technology in the simulation of the second scenario

NO	Parameter	The value in the simulation of the first scenario	The value in the simulation of the second scenario
1	Advertising effectiveness for new users	0	0.1
2	Advertising effectiveness for magnetic cart users	0	0.1
3	Trust in NFC	0	1
4	Law infrastructure	0	1



a: Near field communication technology adopters b: Acceptors of magnetic cards

Figure 19. Simulation results in the second scenario

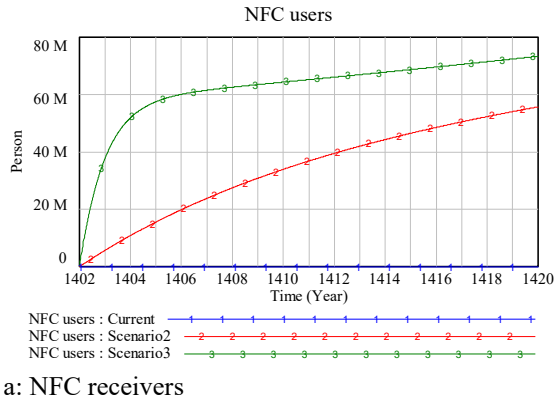
4.1.3. The third scenario: Improvement of legal infrastructure, trust in conditions of high effectiveness of advertising

In the third scenario, the four factors selected are increased to their maximum value, and in this condition, the development status of NFC technology and the decline of technology based on magnetic payment cards are evaluated.

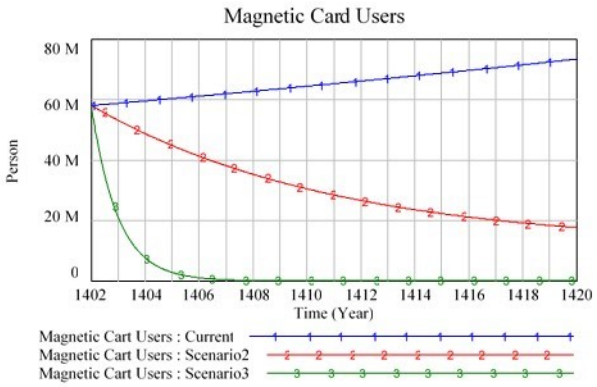
According to the parameters written in Table 4, the rate of growth of NFC technology has been exponential and very fast, reaching almost 63 million users by 2029 (1408 In Persian) and more than 73 million users in 2041 (1420 In Persian) (Figure 5-a). In the same situation, bank card acceptors have gradually decreased, reaching almost zero since 2029 (1408 In Persian) (Figure 5-b) and accounting for a few users.

Table 9. Defined parameters regarding NFC technology in the simulation of the third scenario

No	Parameter	The value in the simulation		
		First scenario	Second scenario	Third scenario
1	Advertising effectiveness for new users	0	0.1	1
2	Advertising effectiveness for magnetic cart users	0	0.1	1
3	Trust in NFC	0	1	1
4	Law infrastructure	0	1	1



a: NFC receivers



b: Card acceptors

Figure 20. Simulation results in the third scenario

5. Discussion and conclusion

The two technologies mentioned in the research have features that can have their fans among users. Payment card technology benefits from ease of use, but maintaining a large number of them carries many risks. On the other hand, NFC technology has the feature of high transaction speed, and there is no need to maintain multiple bank cards. Given the emergence of NFC technology in recent decades and the expansion of its use in electronic banking, the use of this technology is growing in many countries. Despite the many efforts made in our country to spread this technology, it has not been widely accepted due to factors such as trust, legal and

technical infrastructure, lack of a clear image of the technology, advertising, and many other things.

In this research, two technologies electronic payment cards and mobile payment technology based on NFC technology, have been examined and compared. According to the designed scenarios, the best scenario for expanding this technology as an alternative to electronic payment cards is the third scenario, which, according to Figures 7 and 8, will be replaced by 2027 (1406 In Persian), which is approximately three years from now. It can be done quickly. It will be possible, but given the relatively high population of elderly people and the lack of easy use of NFC technology by this segment of society, it is suggested to use the second scenario, which will carry out this replacement at a slower pace and a slower pace. The gentler slope of this research can to greatly help banks and financial institutions that have made great efforts in this direction in previous years but have not succeeded in expanding "NFC" technology in the mobile payment system.

One limitation of the research is the lack of data in the field of NFC technology. Another limitation is the lack of up-to-date data on electronic payment cards. After the diffusion of the NFC payment system and re-implementation of the model, it is possible to obtain a better output.

Considering the growth of technology and the spread of mobile phones equipped with NFC technology, it is suggested that after two years of implementing this technology in the mobile payment system, simulation based on new parameters, again and in case of using the second scenario which brought the gradual growth of NFC technology, the policies should be implemented based on the third scenario which was faster.

Disclosure statement

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

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Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir
Online ISSN: 2821-1669, Print ISSN: 2980-9460
Research Article
DOI: 10.22067/JSTINP.2024.89580.1117
JSTINP 2025; Vol. 4, No. 1

Modeling Customer Purchase Behavior in the Insurance Industry Using System Dynamics

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How to cite this article

Jalalat, S., Shahroodi, K., Fadaei, M., Homayounfar, M. 2024. Modeling Customer Purchase Behavior in the Insurance Industry Using System Dynamics, *Journal of Systems Thinking in Practice*, *4*(1), pp.44-69. doi: 10.22067/jstinp.2024.89580.1117.

URL: https://jstinp.um.ac.ir/article_46017.html.

ABSTRACT

The Iranian insurance industry is a system in which each of the population segments, customers and their types, revenue management, various investment methods, and advertising methods have nonlinear and bidirectional relationships with each other. Analyzing this industry requires a tool to consider all the essential variables and incorporate the relationships between them in the analysis and simulation. System dynamics is a powerful approach for modeling and simulation that has shown its applicability in analyzing and predicting the behavior of complex systems. Therefore, this article used this tool to model and simulate the impact of advertising on the behavior of life insurance customers and its relationship with revenue and asset management. The system dynamics model was drawn, formulated, and validated with the help of the Vensim software. The model extraction process consisted of a comprehensive review of existing studies on customer behavior, identification of key variables related to life insurance purchasing behavior, consulting with insurance industry experts to validate the initial variables and identify factors specific to the Iranian context, drawing causal loop diagrams, and converting them into stock and flow diagrams. Statistical data were collected using the annual reports of the Iran Insurance Company, the Statistical Center of Iran, the statistical yearbooks of the Central Insurance of Iran, and semi-structured interviews with experts. After optimizing the structure and parameters of the model, simulation was performed over a 10-year horizon, and the results were analyzed in three scenarios. The first scenario showed that of continuing the current conditions would lead to an increase in the gap between life insurance expenses and revenue. In the second scenario, the effect of increasing the advertising budget was examined, which prevented the increase in this gap but the existence of a difference. The third scenario showed that a 10% improvement in the rate of word-of-mouth advertising dissemination, while compensating for the costs, will lead to the company's profitability.

Keywords

Modeling, Customer purchase behavior, System dynamics, Life insurance.

Article history

Received: 2024-08-25
Revised: 2024-11-16
Accepted: 2024-11-27
Published (Online): 2025-03-17

Number of Figures: 21 **Number of Tables: 2** **Number of Pages: 26** **Number of References:24**

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1. Introduction

According to Kotler and Keller (2009), purchase behavior is the study of how individuals or groups buy, use, and dispose of goods, services, ideas, or experiences to satisfy their needs and wants. A customer decides to purchase in response to the imbalance caused by unmet needs and wants. Typically, a customer undergoes five stages of purchase behavior: need recognition, information search, evaluation of alternatives, purchase decision, and post-purchase behavior (Shah et al., 2019). The development of new technologies (such as the Internet of Things, artificial intelligence, machine learning, digital currencies, blockchain, cloud computing, mobile devices, and cognitive systems) is transforming the competitive landscape in various ways and at different levels. Organizations increasingly use new strategies, data, and business models developed or derived from new technologies to understand consumer choices and behavior and gain a competitive advantage.

In this context, the insurance industry, like many other markets and financial sectors, faces increased competition and complexities in understanding customer purchase behavior. In the insurance industry, one of the critical studies is understanding the behavior and motivations of individuals inclined to purchase insurance (Chen et al., 2022). The insurance industry is considered a development indicator and plays a crucial role in supporting other institutions within the economy. Therefore, the significantly impact the industry's growth and development and, consequently, the country's economic growth and development. However, research shows that one of the gaps in the Iranian insurance industry is the lack of specialists who are simultaneously educated, specialized, and experienced in insurance and marketing. The technical managers of insurance companies are primarily experts in insurance matters, while marketing specialists lack sufficient knowledge of insurance technicalities. This weakness is more pronounced in non-life insurance sales, such as life insurance. Everyone faces risks in life. Since risk is almost always present, it must be properly and adequately. One way to mitigate this risk is by purchasing insurance from an insurance company (Alfiero et al., 2022). Life insurance is a type of insurance that provides services to manage risks related to an individual's life or death (Sukmaningrum et al., 2023). With the increasing number of deaths and life-threatening diseases, the importance of life insurance as a necessity for protecting individuals is becoming more evident (Keat et al., 2020). Life insurance is one of the most common financial tools for households to compensate for the loss of assets due to premature death caused by severe illness or significant health issues (Chen et al., 2022).

In Iran, life insurance constitutes a small share of the insurance industry's activities compared to the global average and other regional countries, indicating the presence of barriers and issues in this process. The low penetration rate and lack of development of life insurance in our country highlight the need to study the demand for life insurance despite its benefits and potential. The insurance industry faces complex challenges in understanding and predicting customer purchasing behavior .The intention to purchase a life insurance policy can be influenced by various economic, social, cultural, and individual factors. Numerous studies have been conducted on the reasons for the underdevelopment of life insurance in Iran, most of which focus on the factors affecting the demand for these policies. However, what is lacking is a comprehensive examination of this issue with a dynamic approach, modeling the relationships between the contributing factors while considering interactions and maximum realistic considerations.

Therefore, the present research addresses several critical research gaps in the customer behavior literature in the insurance industry. One gap is the insufficient use of system dynamics: While many studies have examined the fixed factors affecting the purchase of insurance, there is a need for more studies that demonstrate the dynamic and evolving nature of customer behavior over time. Another gap is the lack of a comprehensive model. Existing research often focuses on separate aspects of the insurance industry. More comprehensive models are needed that integrate factors related to demographic variables, customer acquisition, advertising effectiveness, financial resources, and investment strategies. Additionally, few studies have determined the long-term effects of different advertising strategies on customer acquisition and profitability in the insurance sector. It can also be noted that the comparison of the relative effectiveness of traditional advertising methods versus word-of-mouth marketing has been limited, particularly in the field of insurance, and over extended periods, sufficient studies do not exist. By addressing the aforementioned gaps, this study aims to develop a more comprehensive and dynamic understanding of customer behavior in the insurance industry and provide theoretical insights and practical tools for decision-makers.

Today, advanced technologies enable the development of new methods and support for software tools that can assist the insurance sector. System dynamics (SD) analysis is a very efficient and well-known method for studying system behavior. System dynamics refers to system changes and behaviors over time under different conditions (Safaie et al., 2023). Hence, utilizing the SD approach, the behavior of variables is displayed concerning each other over time, and the effect of variables on each other is well-reflected in simulating the behavior

(Modares et al., 2023). Also, system dynamics is an evaluation method to increase learning in complex systems and designing effective policies. Recording and investigating the critical functional points of the systems is one of the best ways of organizing the correct and rapid reactions to the issues related to the systems; it takes the form of a prospective scenario that takes as its criterion the past and the present behavior of the system's environment. Recording this scenario entails applying the knowledge and technique that correctly identifies the problem by taking advantage of a systematic method and presenting the fastest and most proper reaction to overcome the created challenges .This knowledge is the system dynamics(Amiri, 2023).

Given the topic's significance, this study aims to enrich the scientific literature on customer purchase behavior in the insurance industry by designing an appropriate model. This model seeks to provide a practical tool for effective use by insurers and insureds, allowing for the analysis and evaluation of various policies, including advertising and educational policies, under different market risk conditions .This study develops a comprehensive and dynamic model of the life insurance industry that illustrates the feedback loops and time delays between demographic variables, customers, revenue management, investment strategies, and advertising effectiveness in Iran's life insurance market. The present model provides a framework for policymakers and industry leaders to understand the long-term impacts of different strategies on Iran's life insurance market and determines the magnitude of the long-term effects of advertising strategies on customer acquisition and company profitability. Additionally, analyzing various scenarios provides practical insights for insurance companies to optimize advertising strategies and improve profitability. It demonstrates the potential of system dynamics as a decision-support tool for insurance companies to evaluate policies and strategies under defined scenarios.

This article is organized as follows: First, the system dynamics approach is briefly explained. Then, with the help of subsystem diagrams, an overview of the system under study is presented. Next, the involved variables are introduced, and the relationships between them are defined in causal loop diagrams and stock-and-flow diagrams. Subsequently, the mathematical relationships between the variables are determined, and the simulation is conducted using Vensim software. Finally, the results of various scenario analyses over a ten-year horizon are presented after ensuring the model's validity through conventional system dynamics validation methods.

2. Literature review

Numerous studies have explored the factors influencing customer behavior, with some specifically focusing on the insurance industry.

Zhao et al. (2023) conducted a study to investigate the impact of multi-level factors on the purchase decisions of green housing (GH) customers in China using a system dynamics approach. Despite being recognized as a key approach to addressing environmental issues and enhancing human life quality, green housing faces marketing and sales policy challenges in China due to limited market demand. This study proposed a system dynamics model to explore the interactions between producers, residents, governments, the social environment, and product features and to examine the dynamic impact mechanisms on purchase decisions. The results indicated that GH purchase decisions are influenced by a complex interplay of factors at various levels that dynamically interact. Specifically, advertising and education effectively increase perceived benefits, administrative regulations effectively reduce perceived risks, and economic incentives have minimal impact on perceived benefits. This study provides a new systematic and dynamic perspective on the interdependent structure of multi-level factors influencing buyer decisions, offering enlightening implications for policymakers and business decision-makers to jointly promote GH development.

Teixeira et al. (2024) conducted a review study on consumer purchasing behavior. The results show that the number of citations on this topic has increased more than 2.5 times in the past two decades and is predicted to double in future decades. Jacobs et al. (2021) studied dynamic customer purchasing behavior. They propose a new model linking purchase motivation with product and customer characteristics and frequency. This model even considers the interdependence of motivations, which can lead to better prediction performance and provides deep insights into purchasing behavior that was not possible using standard models. Managers can use such insights to create more intuitive, informed, and effective marketing actions.

In another study, Nursiana et al. (2021) aimed to examine the fundamental variables influencing customer purchase behavior in the insurance industry. The results showed that product quality positively and significantly impacted purchase intention, company reputation, and perceived risk. Company reputation had a positive and significant effect on purchase intention and a minor positive effect on service quality. Product quality had a positive but insignificant impact on service quality, while service quality had a positive and significant effect on purchase intention. Perceived risk had a negative and significant impact on purchase

intention, a positive and significant effect on service quality, and a positive and significant impact on company reputation.

A study on factors influencing the intention to purchase life insurance found that having previous negative health experiences motivates individuals to purchase insurance to reduce the risks of income loss due to illnesses and disabilities. A survey conducted in Australia, Brazil, Germany, Hong Kong, Italy, Spain, Mexico, the UK, Sweden, and the USA showed that those with negative health experiences were 25% more likely to intend to purchase health insurance compared to others (Innocenti et al., 2019). The perception of risk has long been studied in research, such as psychological or psychometric approaches. Kunreuther and Michel-Kerjan (2015) indicated that risk perception is a process describing the subjective evaluation of an imminent event. Research by Yang and Peng (2020) on the impact of risk perception on insurance purchase intention showed that fear of natural disasters leads individuals to lower their risk assessment when purchasing insurance, prompting quicker purchases of natural disaster insurance.

A study on the journey from intention to decision in life insurance purchase, conducted by Dragos et al. (2020), revealed that besides the strong positive relationship between insurance education and insurance demand, specific behavioral factors such as trust and previous experience influence insurance purchase decisions. Additionally, Ulbinaite et al. (2014), in their study on "The complexity of the insurance purchase decision-making process," stated that capitalizing on the benefits of growing insurance markets, particularly in Asia, requires improving the understanding of relevant consumer expectations and behaviors. In this regard, they present an approach for modeling and analyzing how consumers decide to purchase insurance services. This model includes various consumer characteristics such as quality of life, risk exposure, perception of security needs, insurance usage culture, and affordability. Danaye Nematabad et al. (2017) conducted a study to present a system dynamics model for analyzing consumer preferences, showing that social influence and environmental conditions impact preferences and, sometimes, shift individuals' preferential behavior from one product to another.

3. Research methodology

This research is applied in terms of purpose, descriptive, and based on mathematical separation in nature. Data collection was done through library and field methods. The secondary statistical data included historical data on life insurance sales, customer numbers, and financial

performance, which were obtained from the annual reports of the Iran Insurance Company (2011-2022). Demographic data were also extracted from the Statistical Center of Iran, and industry data were collected from the statistical yearbooks of the Central Insurance of Iran. In order to collect primary data, semi-structured interviews were conducted with seven experts selected using the Delphi technique. These included two senior managers from Iran Insurance Company, three university finance specialists, and two active life insurance sales representatives. Then, through an iterative testing process and consulting with experts and professors, the model's structure and parameters were optimized.

The research is based on the methodology of system dynamics (Sterman, 2000). Accordingly, Figure 1 shows the research steps.

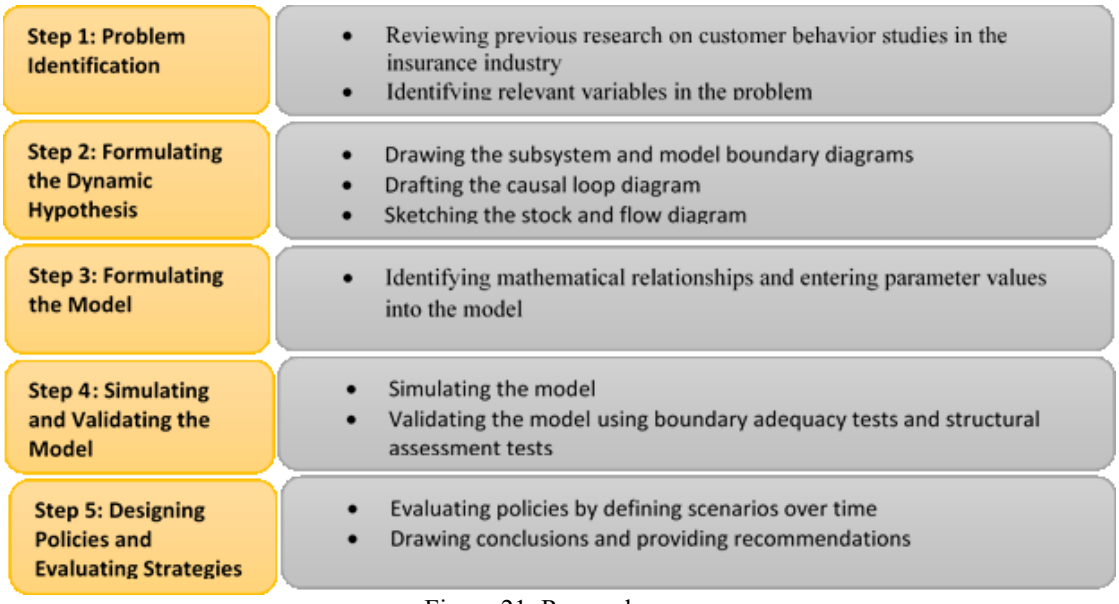


Figure 21. Research process

In the first step of the above figure, the literature on customer behavior in the insurance industry is reviewed, followed by identifying research gaps. In the second step, the subsystem diagram is presented, and the variables and dynamic assumptions of the research are formulated in a causal loop diagram. In this step, loops and feedback are shown with positive and negative signs, and the arrows are marked based on their positive or negative impact. In the third step, after identifying the stock and flow variables, the stock and flow diagram is drawn, and the mathematical relationships between the variables are determined using the logic of relationships, existing data, and expert opinions. In the fourth step, the mathematical model is simulated using software designed for system dynamics modeling. Vensim PLE software is used. Validation is performed to ensure that the model accurately represents the realities within the system in this research,. Validation involves structural assessment tests, extreme condition

tests, dimensional consistency tests, integration error tests, and boundary adequacy tests, confirming the model's validity. The fifth step tests strategies by quantifying their impact using the model. It is noteworthy that in the process of developing the research model, field data were collected through interviews and expert opinions. The expert statistical population consisted of university professors, insurance industry specialists, and managers employed in the Insurance Company.

4. Model development

4.1. Subsystem diagram

Figure 2 represents a broad picture of the system under study. The model presented in this research generally includes the population and potential customers, actual customers, advertising, the insurance company's financial resources, and investment. External factors affecting this system pertain to investment risks in various markets.

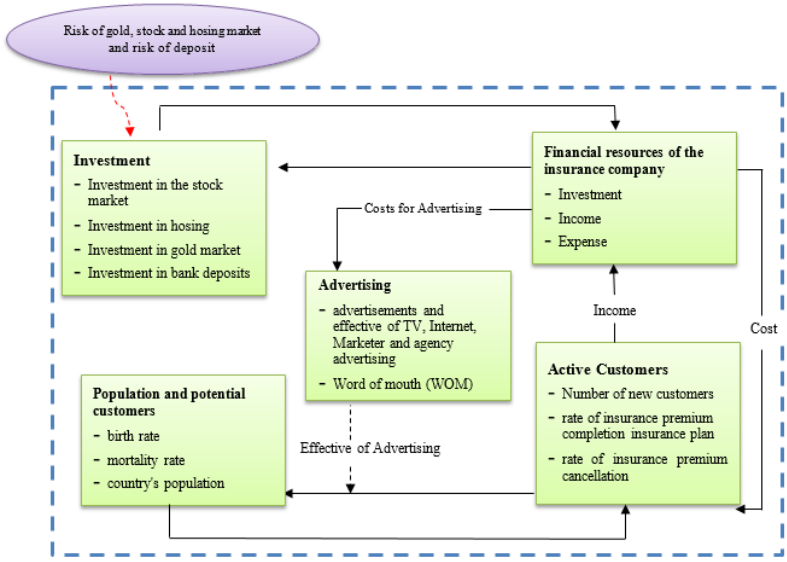


Figure 22. Diagram of research subsystems

4.2. Dynamic hypotheses

The dynamic hypotheses of the research are presented in the causal loop diagram shown in Figure 3. The positive loop R1 and the negative loop B1 shape the behavior of the population variable. As the population increases, it exhibits a growing behavior due to higher birth rates, which is controlled by the loop related to mortality. The positive loop R2 indicates the impact of word-of-mouth advertising; as the number of actual customers of a business, such as the insurance industry, increases, this self-reinforcing loop converts potential customers into actual ones. Another control loop, modeled in the form of loop B2, shows that as the number of actual

customers increases, the rate at which these customers retire increases with a delay, thus controlling their numbers.

The third reinforcing loop, R3, relates to the impact of other advertising methods (television, internet, marketers, and insurance agents). The more actual customers the insurance industry has, the more advertising budget will be allocated due to higher revenue. Consequently, the number of actual customers will increase if the advertising is effective. In the control loop B3, as the financial resources of the insurance industry increase, the conversion rate to assets such as stocks, housing, gold, and bank deposits will rise, ultimately controlling the financial resources available to the industry. Additionally, the reinforcing loop R4 indicates the impact of the profit from each type of asset on the amount of assets, where the profit itself is influenced by risks such as those in the housing market, stock market, and gold market, including risks from recession, price changes, central bank regulations, and more.

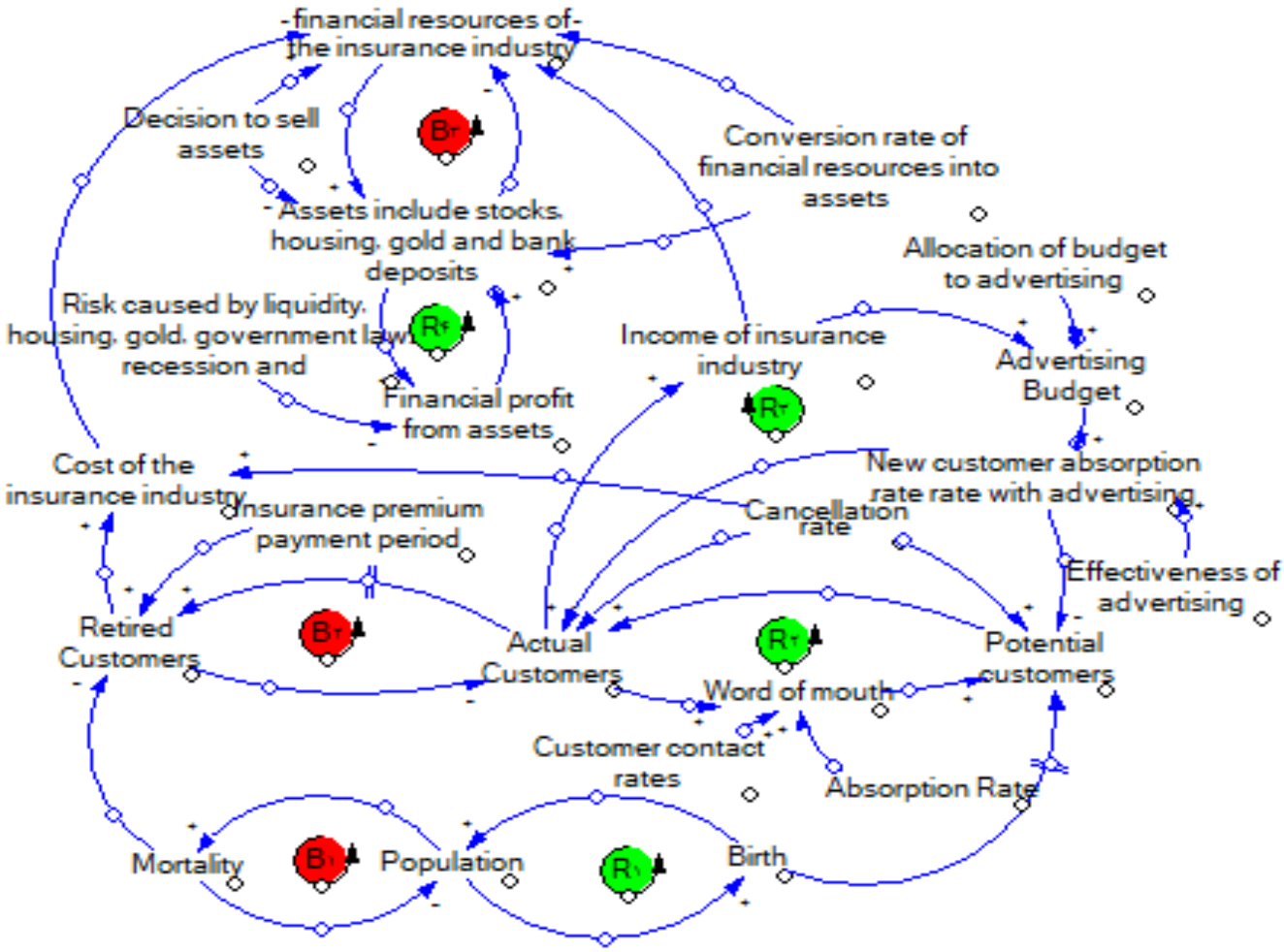


Figure 23. General cause and effect diagram of the research

4.3. Stock-Flow diagram

The key variables used in the stock-flow diagram include 104 auxiliary, flow, and stock variables, with the most important ones, along with their type, unit, and source, presented in Table 1. It is worth noting that the variables related to the risks impacting the insurance industry, advertising (through word-of-mouth, television, internet, marketing, and insurance agents), and assets (in the domains of housing, gold, stock market, bonds, and bank deposits) have been merged for simplification in the table below.

Table 10. Key variables defined in the model

No	Variable name	Persian equivalent	Type	Unit
1	Potential customers	Potential customers	Endogenous	People
2	Actual customers	Actual customers	Endogenous	People
3	Averagely income from each customer	Averagely income from each customer	Endogenous	Rial/(People*Year)
4	Finished customers with 40<life<70 life<40 and life>70	Finished customers by age group	Endogenous	People
5	New customers	New customers	Endogenous	People/Year
6	Adoption fraction	Adoption fraction in word-of-mouth advertising	Exogenous	DMNL
7	TV internet marketer and agency Advertising budget	Advertising budget by four methods	Endogenous	Rial/Year
8	TV internet marketer and agency Advertising effectiveness	Advertising effectiveness by four methods	Endogenous	DMNL
9	Adoption from TV internet marketer agency Advertising and words of mouth Advertising	New customers acquired through advertising	Endogenous	People/Year
10	Risks from: Bankruptcy; Business; Central bank policy; Cyber attack; Demand; Deposit market; Depreciation; Dollar; Gold market; Gold ounce; Gold tax; Governmental; Holding; Housing market; Law; Liquidity; Real stock market; Tax	Risks affecting the insurance industry	Exogenous	DMNL
11	Governmental support	Government support for the stock market	Endogenous	DMNL
12	Expected profit of gold deposit housing and stock market	Expected profit from four assets	Exogenous	1/Year
13	Real profit of gold deposit housing and stock market	Actual profit from four assets	Endogenous	1/Year
14	Decision to sell gold, housing stock and deposit	Decision to sell four assets	Endogenous	Rial/Year
15	Investment in Gold Stock housing market and deposit	Increase in investment in four assets	Endogenous	Rial/Year
16	Average cost of canceling	Average cost paid for policy cancellation by customers	Exogenous	Rial/People
17	Averagely cost per finish	Average cost paid to each customer after insurance ends	Exogenous	Rial/(People*Year)
18	Birth rate	Birth rate	Endogenous	People/Year
19	Country population	Country population	Endogenous	People
20	Canceling rate	Insurance cancellation rate	Endogenous	People/Year
21	Contact rate	Contact rate in word-of-mouth advertising	Exogenous	1/Year

No	Variable name	Persian equivalent	Type	Unit
22	Cost of insurance finish	Cost paid to each customer after insurance period ends	Exogenous	Rial/Year
23	Cost of insurance canceling	Cost paid to each customer after cancellation	Exogenous	Rial/Year
24	Deposit to funds	Rate of converting deposits to available liquidity	Endogenous	Rial/Year
25	Cost to funds	Average annual cost ratio to available liquidity	Exogenous	1/Year
26	Desired cost to funds proportion	Expected average annual cost ratio to available liquidity	Endogenous	1/Year
27	Funds	Financial resources	Endogenous	Rial
28	Income rate	Income rate	Endogenous	Rial/Year

Taking into account variables such as financial resources, stock market assets, housing market assets, gold market assets, and company deposits in banks, potential customers, actual customers, and customers whose insurance policies have expired, divided by age groups under 40, between 40 to 70, and over 70 years old as stock variables, the stock-flow diagram has been created and is shown in Figure 3.

4.4. Formulating the model

After drawing the stock-flow diagram, it is necessary to define the mathematical relationships between the variables. The most important relationships are provided below, illustrating the number of assets divided by housing, gold, stock market, and bank deposits considered as stock at the start of the simulation period.

$$P_K = \int I_k + B_k - S_k + P_0 \qquad (1)$$

$K\epsilon$ Housing, gold, stock market and deposits

The company's financial resources (F) are also calculated based on variables such as revenue (RI), current expenses (C), the amount of sales, and investment in each type of asset.

$$F = \int (RI + S_k - C - I_k) + F_0 \qquad (2)$$

The profitability of each of the four markets is calculated similarly to the relationship presented in Equation 3, which is used for the housing market. In this equation, the actual profit (AP) is calculated from the product of the expected profit (EP) and the risks affecting the housing market (R_i), such as demand risk, tax risk, regulatory risk, and depreciation risk.

$$AP = EP \times (1 - \sum R_i) \qquad (3)$$

$i\epsilon$ Demand, tax, law and depreciation risks

 DOI: 10.22067/JSTINP.2024.89580.1117

The impact of advertising in the model is based on four types of advertising: television, internet, marketers, and insurance agents. Word-of-mouth advertising is calculated based on the diffusion model from Sterman's book (2000) and Equation 4. In this equation, the number of customers attracted through word-of-mouth advertising (AW) is calculated based on the number of actual customers (AC), potential customers (PC), total population (TP), the impact of this type of advertising (AF), and the contact rate (CR).

$$AW = \frac{PC \times AF \times CR \times AC}{TP} \quad (4)$$

The number of individuals attracted through television, internet, marketer, and insurance agent advertising is calculated according to Equation 5. In this equation, the number of individuals attracted through this type of advertising (Atv) is calculated based on the effectiveness of the advertising budget (AE - lookup function) and the allocated budget amount (ABtv).

$$Atv = AE(ABtv) \quad (5)$$

The values of the lookup function AE, which indicates the number of individuals attracted for each budget amount allocated to advertising, are determined using a questionnaire distribution based on the prices of the year 2022 and presented in Table 2.

Table 11. Data used in the lookup function regarding the effectiveness of advertising based on expert opinion

Budget (Rials per year)	**1,000,000,000**	**5,000,000,000**	**10,000,000,000**	**50,000,000,000**
Number of individuals attracted	0 to 1,000	1,000 to 10,000	10,000 to 20,000	20,000 to 50,000

An age chain model is used to determine the number of individuals whose insurance premium payment is due since individuals in each group have different mortality rates. That includes individuals under 40, between 40 and 70, and over 70. According to insurance industry statistics, the mortality rates for these individuals are 2%, 10%, and 30%, respectively. Additionally, the transition rate from one stock to another takes an average of 15 years.

4.5. Simulating and validating the model

After determining the mathematical relationships of the model, validation is performed from 2011 and scenario analysis is carried out until 2031 with a time step of 0.03 years. The simulation model is shown in Figure 4.

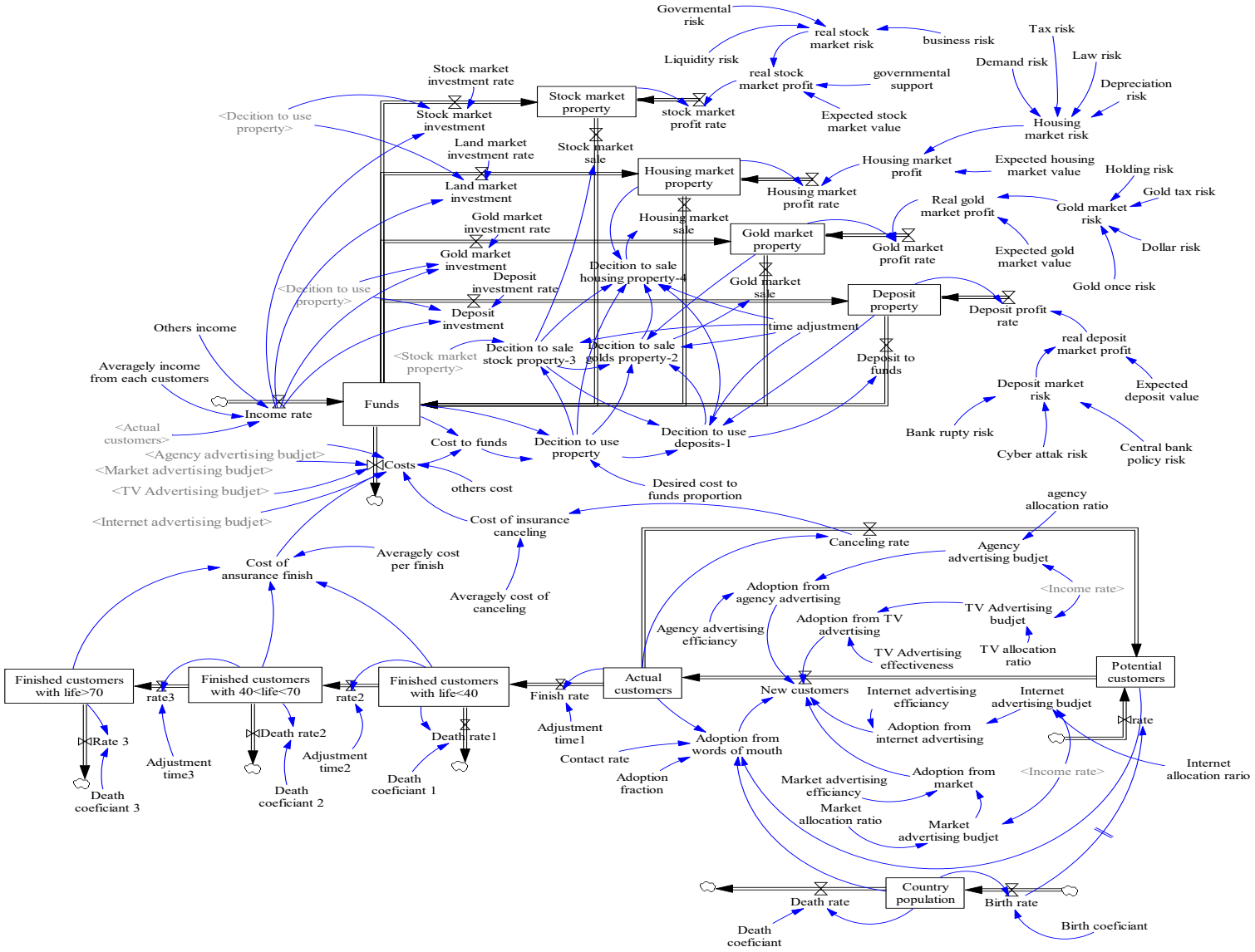


Figure 24. Stock flow diagram containing influential variables in the insurance industry

After simulating the model, its validation is carried out. In this study, the model's validity was assessed using various methods, including structural assessment, extreme condition tests, dimensional consistency tests, integral error tests, sensitivity analysis tests, and boundary adequacy tests, as Sterman (2000) introduced. The structural assessment of the model was evaluated using Vensim PLE software, and the model's validity was confirmed using this method (Fig.5).

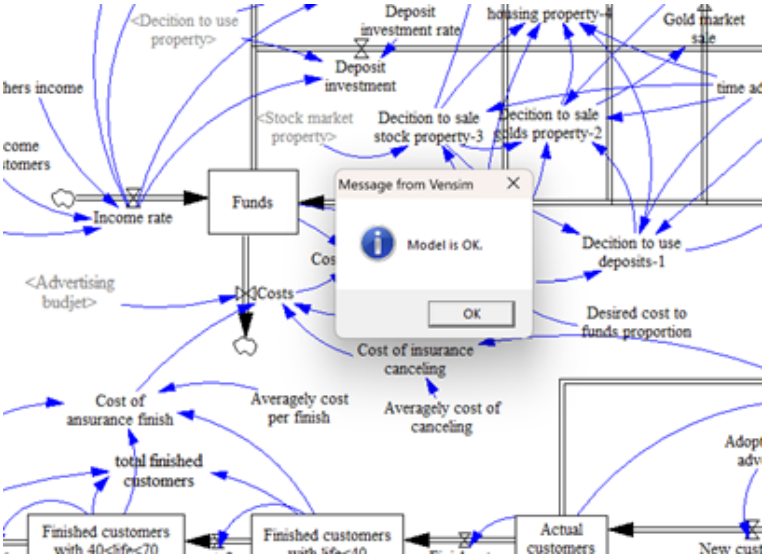


Figure 25. Structural evaluation of the model in Vensim software

Additionally, reducing the time step did not affect the model's outputs, and the model was validated in terms of integration error tests. For instance, Figure 6 illustrates the numerical results obtained from reducing the time step from 0.030 to 0.015 and its effect on the behavior of actual customers.

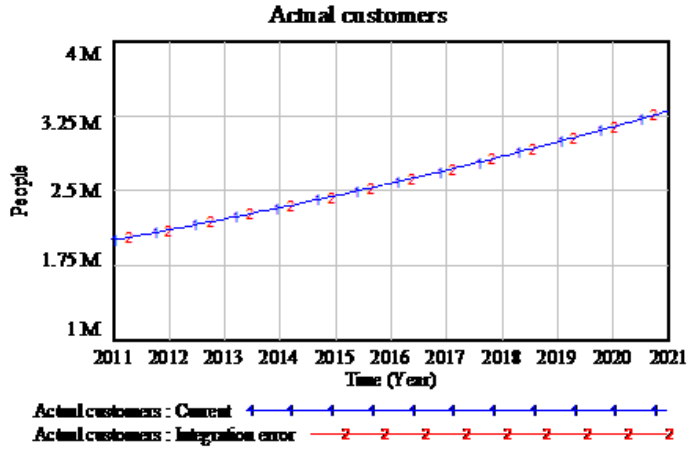
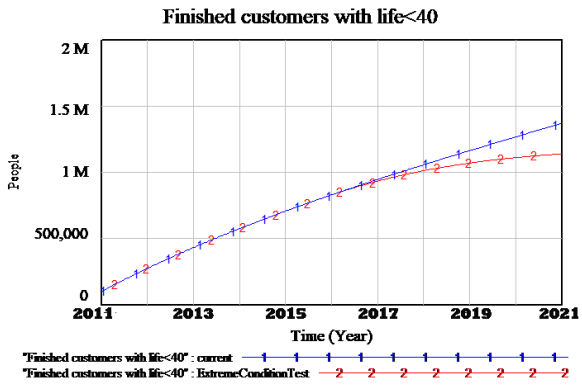
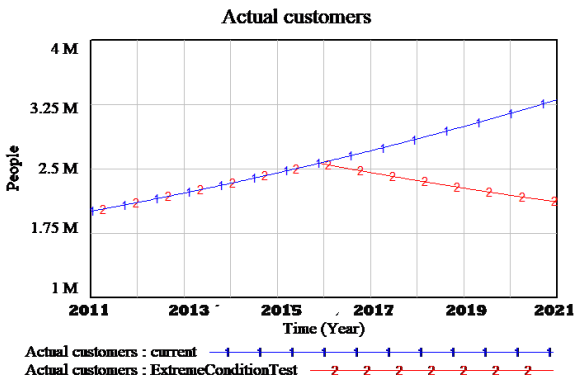


Figure 26. Behavior of the actual customers in the integration error test

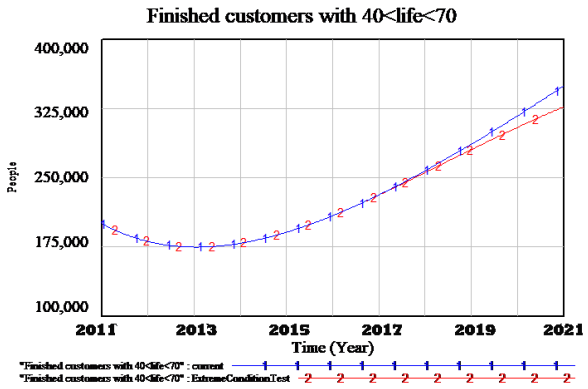
For the extreme condition test, many of the model's exogenous parameters were set to their extreme values, but the model did not exhibit any unreasonable or unexpected behavior. Therefore, the model's validity was also confirmed in terms of the extreme condition test. For example, assuming the insurance service withdrawal rate parameter increases tenfold from 2016 onwards, the behavior of variables such as the number of actual customers (Fig.5), policy expirations at different ages, and revenue and expenses are as follows. Figures 7 to 10 show, no unreasonable or uncontrolled behavior occurs in the model variables. This test was also applied to other model parameters, and the results confirmed the model's validity in other tests.



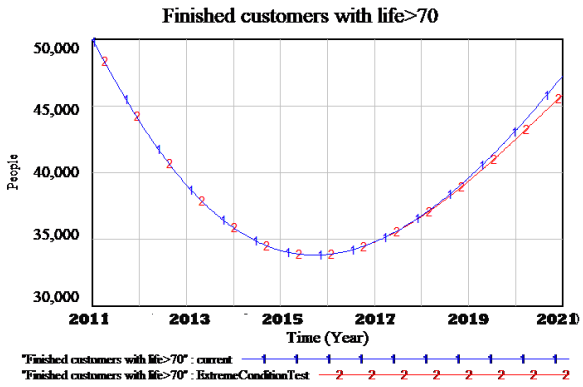
a: In the extreme test



b: With insurance policies completed before the age of 40 in the extreme test



c: With insurance policies completed between the ages of 40 and 70 in the extreme test



d: With insurance policies completed after the age of 70 in the extreme test

Figure 27. Behavior of the number of customers

The results from the sensitivity analysis test also confirmed the validity of the model. For example, Figure 8 illustrates the behavior of the company's financial inventory in response to a change in the parameter "Desired Cost to Funds Proportion." The value and behavior of this variable significantly change with variations in the specified parameter.

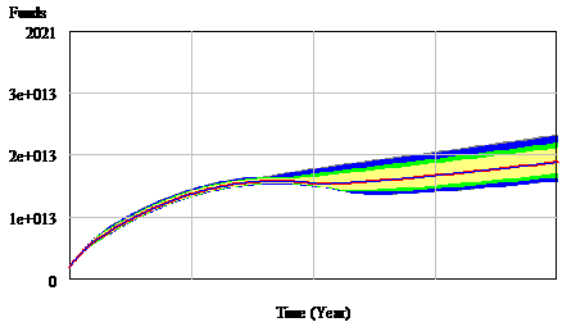


Figure 28. The result of sensitivity analysis test on the financial inventory

In the model boundary adequacy test, the question is whether the model's level of comprehensiveness is appropriate and includes all related structures, variables, and feedback effects necessary to examine the issue and align with the research objectives. The expert group's

response to this question was satisfactory, considering the dynamic hypothesis, the research objectives, and the results obtained from model execution.

4.6. Designing policies and scenarios

For the model analysis, three scenarios have been designed to examine various aspects of life insurance market dynamics in Iran, chosen based on the following criteria:

- Relevance to current industry discussions and strategies
- Potential for significant impact on market dynamics
- Feasibility of implementation within the Iranian context
- Ability to provide practical insights for policymakers and industry leaders

Analyzing these diverse scenarios leads to providing a comprehensive understanding of potential strategies for improving life insurance market performance in Iran

4.6.1. Scenario one: Continuation of current trends until 1410 (Base scenario)

The first scenario is crucial for identifying potential issues should current strategies remain unchanged. Its purpose is to establish a baseline for comparison and understanding the long-term implications of current strategies.

In this scenariothe model that was run until 2031 without changing the parameters. In this scenario, the rate of customer increase based on word-of-mouth advertising and other advertising methods (television, internet, marketing, and insurance agents) is presented as shown in Figure 9. As observed, the customer increase rate based on word-of-mouth advertising is significantly higher than that of other advertising methods.

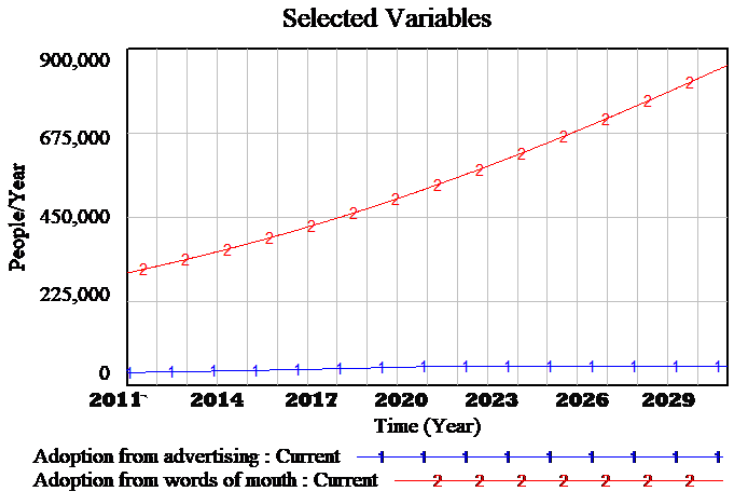


Figure 29. Rate of increase in actual customers through word-of-mouth advertising and other advertising methods

The rate of customers whose policies have expired is shown in Figure 10.

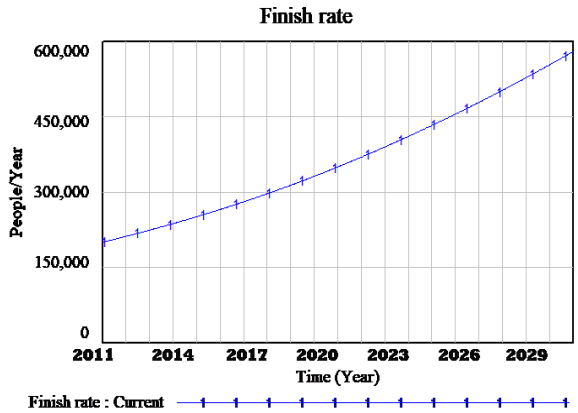


Figure 30. Rate of customers with completed insurance policies

Additionally, the number of actual customers compared to the total number of customers whose policies have expired is depicted in Figure 11.

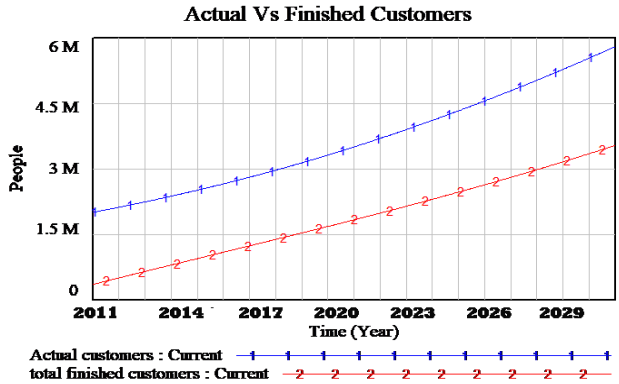


Figure 31. Trend of the number of actual customers and individuals with completed insurance policies

The chart below (Figure 15) also shows the behavior of revenue and expense variables. If current conditions continue similar to the trend that started in 2020, expenses will surpass revenue, leading to increased company losses.

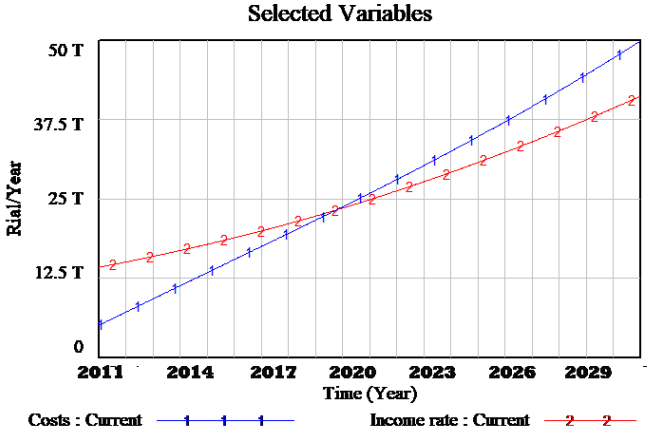


Figure 32. Comparison of costs and revenues in the first scenario

Given the increasing trend of expenses surpassing revenue (as shown in Figure 12), the behavior of the company's bank deposits, gold assets, housing assets, and stock market assets will also lose their growth trend to cover expenses. It will decrease accordingly, which is depicted in Figure 13.

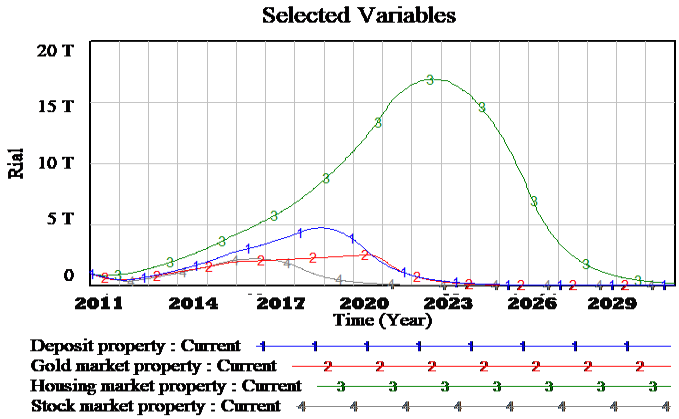


Figure 33. The behavior of various company assets in the first scenario

4.6.2. Scenario two: Impact assessment of increased advertising budget

This scenario is vital for industry decision-makers in determining advertising budget increases, and its objective is to examine the impact of intensive efforts on customer acquisition and revenue growth.

In the second scenario, it is assumed that the percentage of revenue allocated to the advertising budget will increase significantly from 2023 onwards, tripling the budget. Although the allocation percentage triples in this scenario, the advertising budget amount will increase more than threefold over time. This is because with increased advertising, the number of actual customers will increase, leading to higher revenue, and thus the advertising budget, according to Figure 14, will increase more than threefold through this feedback loop.

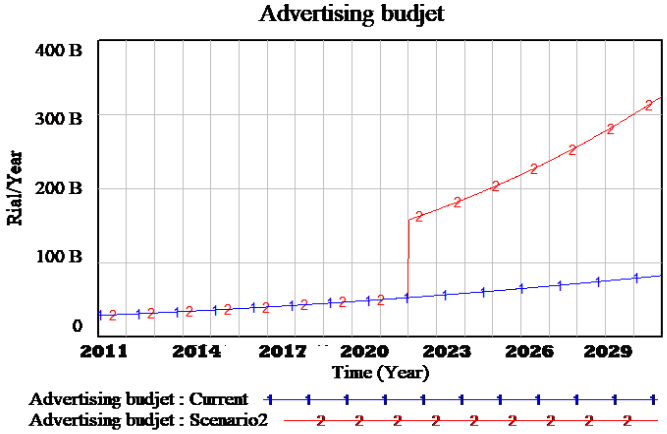


Figure 34. The advertising budget is allocated as a percentage of revenue

Implementing this scenario, the number of individuals attracted through advertising will increase, as shown in Figure 15.

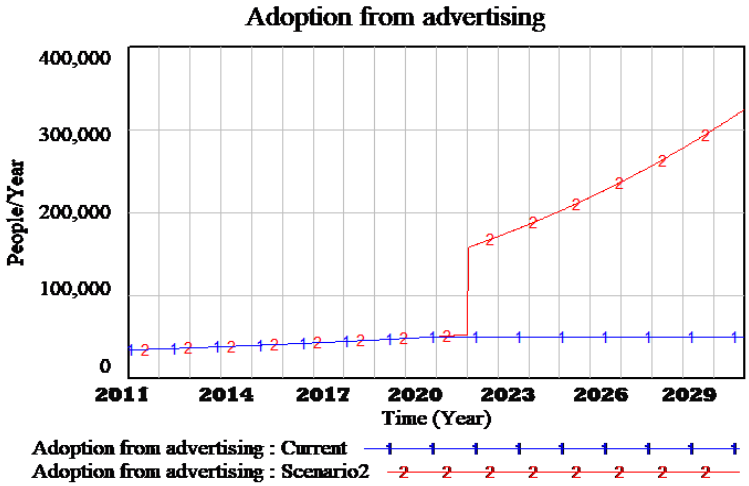


Figure 35. Rate of customers acquired through other advertising methods in the second scenario

Moreover, the increase in individuals attracted through this type of advertising will positively impact word-of-mouth advertising, increasing the number of individuals attracted through this method. This increase is due to the higher number of actual customers, which enhances the effectiveness of word-of-mouth advertising. In other words, according to Figure 16, with increased advertising through other methods, the word-of-mouth advertising loop is strengthened, attracting more customers.

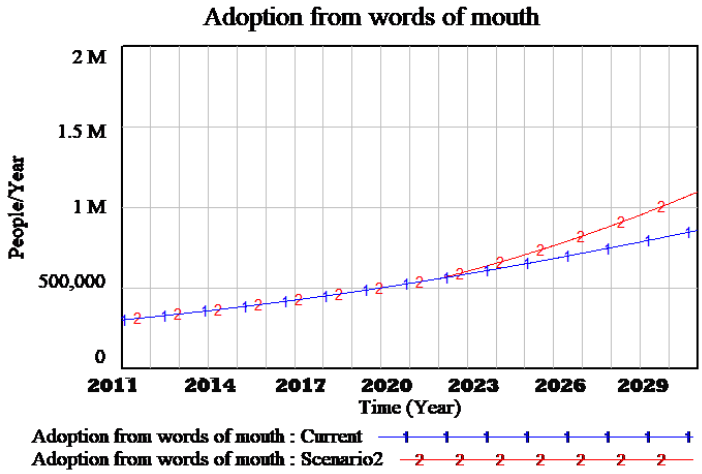


Figure 36. The rate of customers acquired through word-of-mouth advertising in the second scenario

The overall number of customers will follow the trend shown in Figure 17.

 DOI: 10.22067/JSTINP.2024.89580.1117

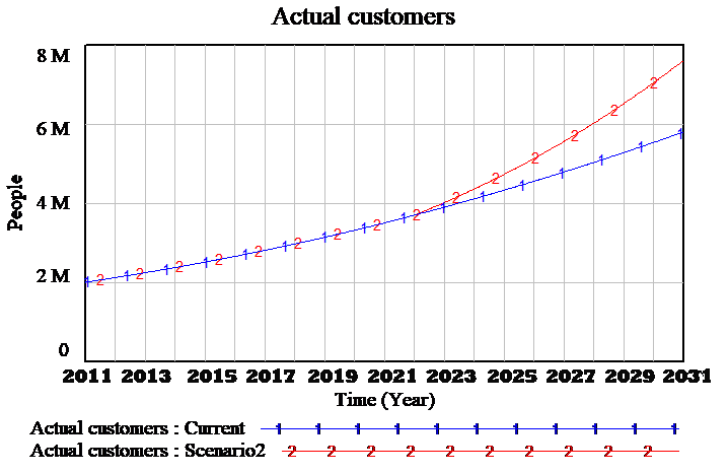


Figure 37. Number of actual customers in the second scenario

If the second scenario is implemented, the gap between revenue and expenses that emerged from 2020 in continuing current conditions will be somewhat mitigated with the increase in actual customers from 2023 onwards, reducing the company's life insurance losses observed in Figure 18.

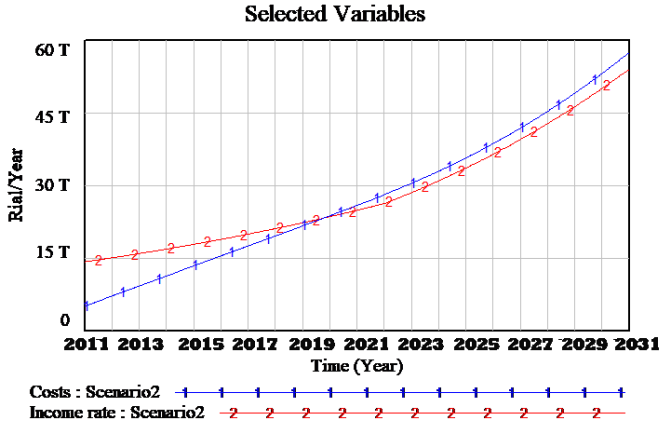


Figure 38. Comparison of costs and revenues in the second scenario

4.6.3. Scenario three: Customer acquisition through word-of-mouth advertising

Word-of-mouth advertising is a powerful yet often overlooked factor in the Iranian market. This scenario helps quantify its potential effects and examines the potential for improving customer satisfaction and referral rates. In this scenario, in addition to increasing the advertising budget, policies are implemented to improve the contagion rate parameter in word-of-mouth advertising by 10%. Under these conditions, the rate of individuals attracted through word-of-mouth advertising will follow the trend shown in Figure 19.

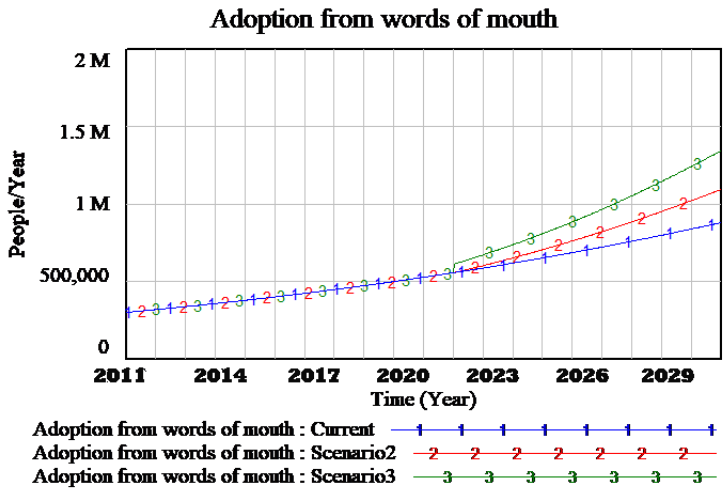


Figure 39. The number of individuals acquired through word-of-mouth advertising in the third scenario

Considering the increased number of individuals attracted through word-of-mouth and other advertising methods, Figure 20 shows the company's revenue and expense trend. As observed, only by increasing advertising can the revenue deficit be compensated, and even profitability can be achieved with more advertising.

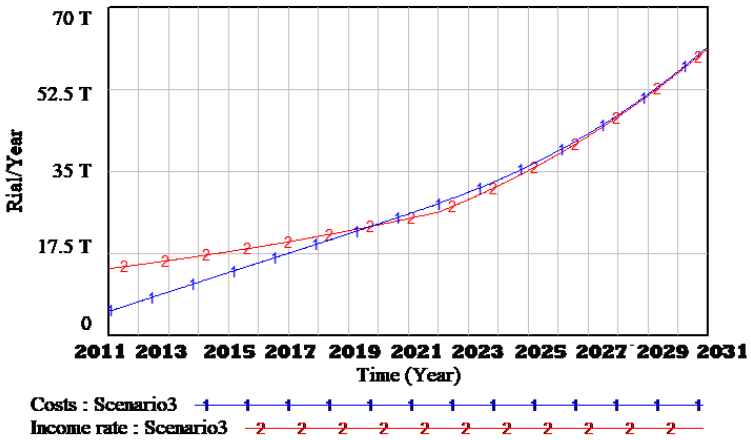


Figure 40. Comparison of costs and revenues in the third scenario

Figure 21 also compares the number of actual customers in the three scenarios. The results show that implementing different advertising scenarios will increase actual customers by 27% and 44%, respectively, by 2031, demonstrating the high impact of advertising on customer numbers and profitability.

 DOI: 10.22067/JSTINP.2024.89580.1117

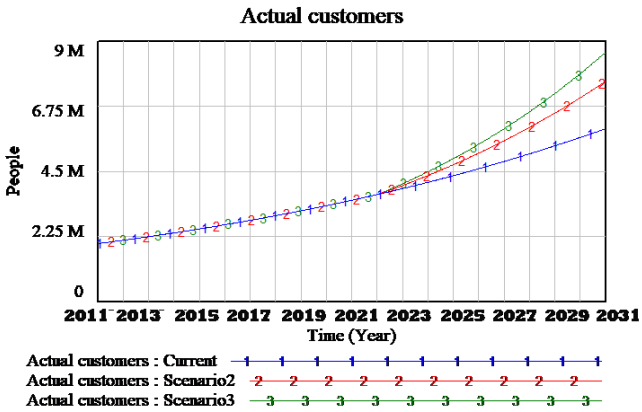


Figure 41. Comparison of the number of actual customers in all three scenarios

5. Conclusion

This article examines the application of system dynamics in the insurance industry. Given the complexity of insurance systems and the nonlinear, bidirectional interactions between various variables, system dynamics is introduced as a powerful method for modeling and simulating these systems. It addresses specific challenges faced by insurance systems, including risk management, adapting to changing market conditions, and, precisely, the impact of advertising on customer purchase behavior and its relationship with revenue and asset management.

The model presented in this research includes subsystems of the population, actual customers, financial resources, investments in various domains, and associated risks. The primary focus is on the impact of advertising, categorized into conventional advertising methods such as television, the internet, marketers, insurance agents, and word-of-mouth advertising. Simulation results suggest that increasing the advertising budget and employing customer-driven acquisition methods can help insurance companies make their advertising more targeted and effective, potentially leading to greater profitability. It aligns with broader marketing research that emphasizes the importance of strategic advertising in influencing consumer behavior.

Three scenarios were analyzed. The first scenario, based on the continuation of current trends until 2031, indicated that expenses would surpass revenue, increasing the company's losses. This underscores the importance of proactive strategy adjustment in changing market dynamics. The second scenario demonstrated that allocating a fixed percentage of revenue to conventional advertising methods could reduce the gap between expenses and revenue over time as customer numbers increase, thus potentially reducing the company's losses. The third scenario showed that combining a fixed percentage allocation to conventional advertising with a 10% increase in the diffusion parameter in word-of-mouth advertising could in the number of actual

customers over a ten-year horizon. This scenario suggested eliminating the gap between expenses and revenue and achieving profitability. The substantial impact of word-of-mouth advertising in this scenario aligns with general marketing principles that highlight the power of customer referrals and positive experiences.

This study indicates that system dynamics can help insurers achieve a shared mental model regarding the industry's variables, better assess the impact of policies and decisions through scenario analysis, and potentially enhance their market competitiveness. The model's ability to simulate different scenarios provides valuable insights for strategic decision-making, allowing insurance companies to test various strategies in a virtual environment before implementation. In addition, the present study offers a more comprehensive approach and precise modeling compared to previous research. For instance, Zhao et al. (2023) employed system dynamics in analyzing purchase decisions to examine the multi-level effects of factors such as advertising and government regulations. They demonstrated the effectiveness of advertising and education in enhancing customer understanding and purchasing behavior, which aligns with our research findings regarding advertising's key role in customer acquisition. However, unlike the present study, they did not address financial issues and specific risks in the insurance industry.

While utilizing system dynamics, this study confirms the effectiveness of word-of-mouth (WOM) advertising, similar to the research of England et al. (2022), which demonstrated WOM's crucial role in the insurance market. Moreover, our results align with the study by Kurnianingtyas et al. (2020), as both models indicate financial sustainability and the impact of long-term policies. Nevertheless, the present research addressing further addresses the complex interaction between advertising budgets and financial variables. Notably, our findings regarding WOM advertising effectiveness parallel the work of Yang and Peng (2020), who analyzed the impact of fear and natural risks on insurance purchases, as they also demonstrated that indirect motivations (such as personal advertising) could be influential. The research by Parviero et al. (2022) and Olmez et al. (2023) emphasizes the importance of social network effects and operational risks. Still, their focus is primarily on individual-oriented simulations and specialized functions.

In comparison, our research provides a more comprehensive analysis by integrating marketing and financial aspects, which is innovative and effective in a long-term simulation of life insurance customer behavior. The study by Nursiana et al. (2021) assessed the impact of product quality, company reputation, and perceived risk on insurance purchase decisions. Still, it did not analyze feedback dynamics and cumulative advertising effects. However, they showed

that company reputation and service quality positively influence purchase decisions, which aligns with our model, confirming customer increase through advertising strategies and improved customer experience.

Nevertheless, our distinction lies in analyzing complex feedback between advertising, financial management, and external variables, which previous studies have not comprehensively examined. This analytical integration introduces our use of system dynamics in Iran's insurance industry as an innovative approach that aids in evaluating long-term strategies while identifying findings and key distinctions similar to those of previous research.

Based on the presented model and scenario analysis, practical Suggestions can be provided that could benefit the life insurance market. According to the simulation model results, one of the influential variables is the cancellation of policies by existing customers. Therefore, reducing the life insurance policy cancellation rate is a significant challenge for industry players. Thus, customer retention is of great importance. Implementing a robust customer relationship management system can decrease policy cancellation rates and encourage customer loyalty, motivating them to retain their policies in the long term.

The low penetration rate of life insurance, often caused by a lack of public awareness about its benefits or immediate intangibility, reveals the need to implement product and market development activities. To this end, offering more diverse product combinations of life insurance with other financial products is recommended to increase the perceived value. Additionally, investing in training programs for insurance agents can improve their ability to explain the benefits of products. Furthermore, developing educational content for potential customers can increase awareness of life insurance benefits. From a macro perspective, engaging with regulatory bodies could also be considered to explore policy changes that could foster market growth, such as tax incentives for life insurance purchases, leading to increased market penetration. Developing a multi-company model to investigate competitive dynamics in the insurance industry is recommended for future research. The model could include more detailed customer segmentation to examine how different demographic groups respond to various marketing strategies. Conducting a comparative study that applies this model in other developing markets to identify common patterns and unique characteristics could also be, valuable and practical. Our model is based on the assumption of stability for certain macroeconomic variables, which may change in reality. Additionally, it does not fully cover external risks such as regulatory changes. Modeling these changes could be considered in future research. By implementing these suggestions and pursuing the mentioned research paths,

stakeholders in Iran's life insurance industry can move towards increasing market penetration, improving customer satisfaction, and ensuring long-term sustainability.

Disclosure statement

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

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Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir
Online ISSN: 2821-1669, Print ISSN: 2980-9460
Review Article
DOI: 10.22067/JSTINP.2025.89642.1118
JSTINP 2025; Vol. 4, No. 1

Decision Intelligence to Enhance Bank Profitability through Customer Promotion Path Design

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How to cite this article

Adibi, M. A., Pourghader Chobar, A. 2025. Decision Intelligence to Enhance Bank Profitability through Customer Promotion Path Design, *Journal of Systems Thinking in Practice*, *4*(2), pp.70 -.82 doi: 10.22067/jstinp.2025.89642.1118. URL: https://jstinp.um.ac.ir/article_46265.html.

ABSTRACT

Studying the behavior of a bank's customers over time to determine and monitor their position in a customer segmentation system (CSS) could be the basis for producing and proposing some paths to promote the customers to a preferred level in the CSS. It is mutually beneficial for both the bank and the customers. On the one hand, the bank increases its revenue by growing sales; on the other hand, the customers benefit from incentive allocation. In this research, with the help of the new concept of Decision Intelligence (DI) along with the machine learning modeling approach, customized paths were extracted that led to improving the level of the customers in the bank's CSS. These paths are designed according to the specific circumstances of each customer and the scope of its business, which ensures its feasibility. The proposed method was implemented for 422,264 customers in a private bank, and the results show that this method has been successful in achieving successfully achieved the predefined goals.

Keywords

Customer segmentation; Decision intelligence; Machine learning; Customized banking.

Article history

Received: 2024-08-30
Revised: 2024-12-13
Accepted: 2025-01-20
Published (Online): 2025-03-17

Number of Figures: 5 **Number of Tables: 1** **Number of Pages: 13** **Number of References:19**

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1. Introduction

Over the decades, organizations have focused only on their products and brands. However, the focus has been on establishing and maintaining an effective exclusive relationship with customers in recent years (Prasad and Aithal 2017; Mosa et al. 2023). The reason for this can be considered as the need to move to a higher level of customer service in competitive business environments. In this new level of service, the design and presentation of a product or service are tailored to the needs and position of any customer. Therefore, gaining knowledge from customers and identifying homogeneous groups of customers to design and offer appropriate products, services, and incentives to maintain and promote customer loyalty and profitability are current issues of both researchers and organizations, especially the marketing departments of organizations, including banks. Homburg et al. (2008) published a comprehensive survey on different customer prioritizing criteria and methods in marketing. In this regard, some newly published papers can be mentioned too; Gao et al. (2020) used Behavior Mining to establish a personalized recommendation system. Using precision marketing, Zhu and Gao (2019) provided a method based on big data analysis for personalized marketing. In 2020, Behera et al. presented a personalized recommender system based on data analytics. Gayathri and Arunodhaya (2021) presented a method for Personalized Marketing using K-means and Apriori Algorithms. Eslami et al. (2024) studied unveiling IoT customer behavior by segmentation to get insights to enhance IoT-CRM strategies. Adeniran et al. (2024) used segmentation methods to detect customer behavior in a customized manner. However, due to market dynamics, static cognition and segmentation cannot be sufficiently responsive. So, studying the behavioral patterns of customers over time and predicting trends can be very effective in maintaining or promoting the customers at a desired level of loyalty and profitability. In fact, instead of assigning one segment to each customer in terms of loyalty or profitability, the status of the customer in terms of loyalty and profitability is determined in the form of a trajectory over a relatively long period. These trajectories can generate some "paths" through which the customers can improve their position in the organization's customer segmentation system (CSS). It should be noted that due to resource constraints, providing incentives to all customers is not possible or even logical. Therefore, organizations almost use available resources for superior or potentially superior customers in the CSS. Improving the customer level in the CSS has economic returns for the organization by selling more products or services and also for the customer by benefiting from special privileges and rewards of loyal and profitable customers offered by the organization.

Among the methods for customer evaluation and segmentation based on customer lifetime value (CLV), loyalty, and profitability is the RFM analytical approach that uses only three criteria: Recency (R), Frequency (F), and Monetary (M) according to customer interaction with an organization to determine customer position in the CSS. One outstanding advantage of this approach is its reliance on the operational data stored in the organization's databases. So, it eliminates any need to collect new extra information. Therefore, RFM is an easy, low-cost, and fast way to estimate CLV, as well as a widespread basis for customer segmentation. A comparison of several methods of evaluating CLV is given by Borle et al. (2008). It must be noted that due to the type of customer interactions with banks, which distorts the importance of novelty of interaction, the criterion of continuity of interactions (C) is considered in such segmentation.

Regarding marketing context, organizations are faced with a decision-making challenge, including setting a threshold level of usage of products or services to benefit from incentives, which must be addressed specifically for each customer. Given the number of customers in organizations such as banks, where the number easily reaches millions of business and private customers, using a new approach in decision making, namely the Decision Intelligence (DI), has been proposed by Pratt (2019).

Decision intelligence is a new concept that many believe is part of the future of artificial intelligence-related technologies such as Business Intelligence (BI) and Decision Science. DI deals with how to match the technological needs of an organization in the field of Artificial Intelligence (AI) on the one hand and the needs of the organization's decision-making structure on the other hand. So, it enables organizations to make the best operational to strategic decisions by examining the outcome of each action resulting from their decisions in a volatile, uncertain, complex, and ambiguous environment. These decisions range from choosing a market to enter or entering an investment to incorporating a feature into a product or service to decisions in designing an operational process (Hasić et al. 2018; Ma et al. 2018; Moser et al. 2021; Nica et al. 2022, Haider & Tehseen 2022). Organizations will be able to see the results of their actions in advance. Hence, DI is also called Action Intelligence. According to the research conducted by the researcher of this paper, the concept of DI has not been used in the issues of customized banking methods. Therefore, this article can be considered a report on the first efforts in this field.

This research practically provides a method that if a customer wants to know what to do to be upgraded in the bank's CSS in terms of a set of behaviors, the answer is clear in a customized

manner. As far as we know, this issue has not been covered before in the related literature. The problem of this research includes classifying customers in terms of loyalty and profitability and then determining a customized path for each customer so that the customer gets a promotion in the CSS. It should be noted that these two issues are raised together, and the solution will be generated in an integrated manner. The necessity of solving this problem arises from the fact that organizations need to classify customers so that the resources allocated for promotion can be spent effectively to encourage customers to increase the use of services and products that are available.

On the other hand, customer segmentation doesn't meet all needs because a question always remains with customers and organizations: If a customer wants to move from an existing level to an upper one in a CSS, how do author do it? This question is difficult to answer because customer segmentation criteria generally comprise several factors. Therefore, there are several ways to improve the value of the factors. In banks, for example, customer segmentation may be based on criteria such as CLV, which is calculated or estimated in various ways (including using the RFMC analytical approach used in this study). It is generally a function of the level of customer resources in the types of deposit accounts and the credits. Each of these two groups of products includes a wide range of items that the banks can provide. Also, each customer needs some of them according to the type and scope of his/her business. Therefore, in such circumstances, the question arises: according to the customer's needs and conditions, which products or services and to what extent will improve the customer level in the CSS?

As a significant contribution, this article presents a method that uses the DI approach to determine a customized path for each customer. Through the path, the customer can grow in the CSS. So, the organization and the customer benefit together. In fact, to determine these customized paths, the data in the organization's database, artificial intelligence, and machine learning techniques will be rendered in terms of the DI. Also, the paths should be extracted way so that their implementation by the customers is feasible according to the specific conditions of its business and needs, while the organization benefits in developing the level of interaction with the customers, too.

Section 2 describes the proposed method based on Decision Intelligence and data analysis methods. Section 3 presents the results, followed by Section 4 describing the conclusions.

2. Decision intelligence for problem-solving

2.1. Decision intelligence approach

The problem mentioned in the introduction section will be solved according to the existing complexities and the necessity of generating a customized promotion path in CSS using the DI concept. The basis for the DI is creating a chart called the Causal Decision Diagram, or CDD for short. This diagram shows the process by which each decision or action ends in a result. Drawing this diagram provides a basis for building a model using artificial intelligence or machine learning, considering stored data. This model can be utilized to estimate the outcome of each action. The resulting model is then used reversely to identify the best action to achieve the desired result. Figure 1 shows the key elements of a CDD. According to a CDD, the link between the decisions and the outcomes is modeled mainly through Machine Learning (Pratt, 2019). A CDD shows intermediate elements (under the organization's control) and factors outside the organization's control (external) involved in turning a decision into an outcome. The task of DI is to find out how to influence and then adjust the best level of factors to achieve the goals.

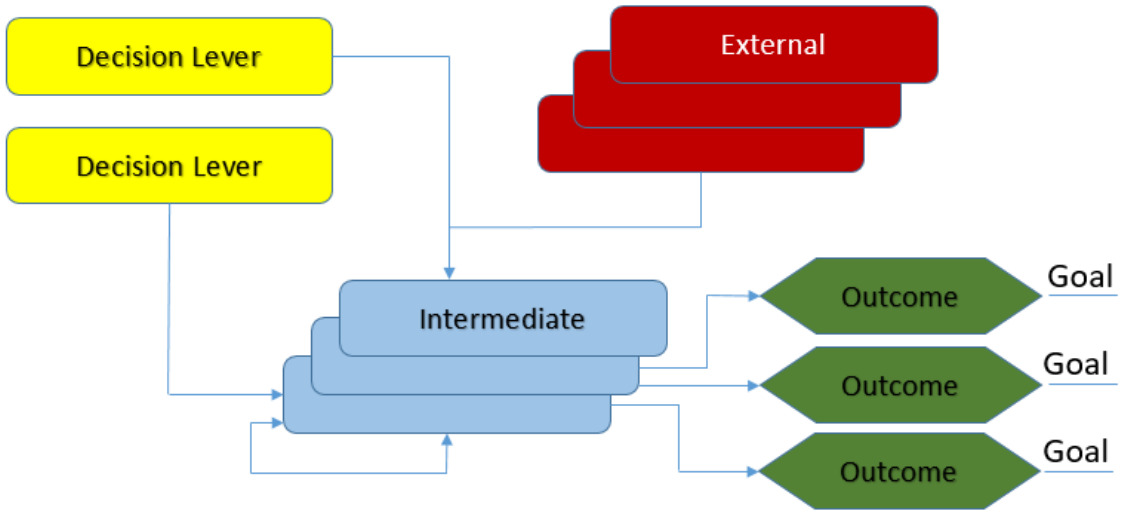

Figure 42. Key elements of a CDD

Figure 2 shows the factors and how the change in the four criteria R, F, M, and C affect the CSS's customer loyalty and profitability level. Considering a banking business, transaction date affects R and C, number of transactions affects F, and account average, loan, letter of guarantee, and letter of credit affect M. Regarding the CDD, in the action section, the threshold in the amount of bank account average, loan, letter of guarantee and letter of credit should be specified to determine the status of each customer in the segmentation system through RFMC-Score. This figure shows how customer interaction with a bank determines the customer segment in the

CSS based on RFMC-Score. With this chart and modeling its relations, the appropriate interaction thresholds to create the desired change in a particular customer segment can be determined.

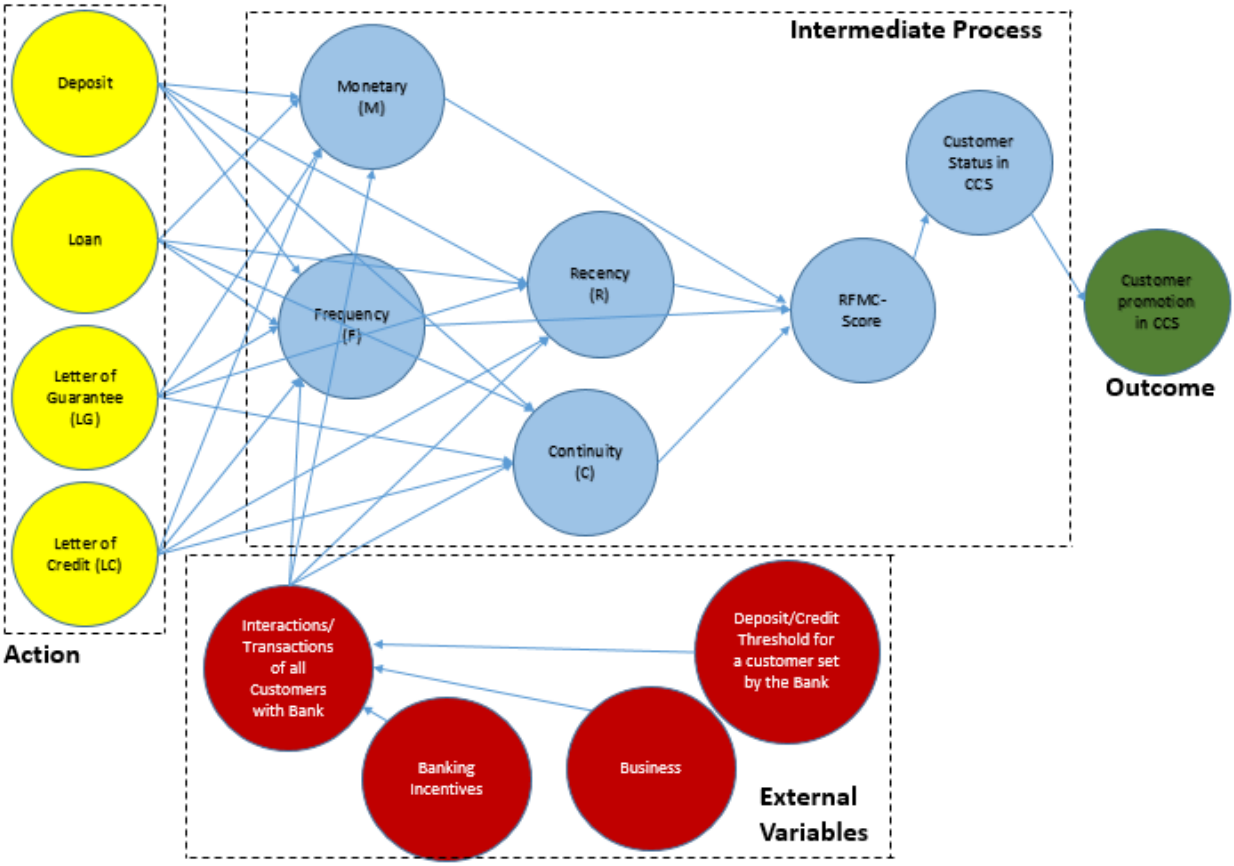

Figure 43. The CDD describes how elements affect customer level in a CCS considering RFMC-Score

It should be noted that any change in the customer segment is related to external factors and the bank's decisions in determining the thresholds. These thresholds are set specifically for each customer and are considered as a target for him/her that achieving it leads to a positive change in the customer's segment. Therefore, if a model that links each action to the result is achieved, it can be possible to determine the best action: the thresholds of the account average, loan, letter of guarantee, and letter of credit required for each customer. These thresholds or target levels will be a roadmap or path for each customer to be promoted to a higher loyalty or profitability segment in the CSS.

2.2. K-Nearest neighbors method

In this research, the similarity structure is obtained through the *k*-nearest neighbors or *k*-NN, one of the well-known methods in the machine learning (Tékouabou Koumétio and Toulni 2021). *k*-NN is often useful for considering more than one neighbor of an instance. Although the technique is more commonly called *k*-Nearest Neighbour Classification, the underlying

intuition can be used to construct a similarity system for a group of instances. So, one can call *k*-NN in a machine learning toolkit and easily get *k* nearest neighbors of any instance, which is named here Similarity Structure.

2.3. Problem solving methodology

For generating the customized promotion paths, the customers would first be placed in 4 classes over two six-month intervals using the RFMC-Score criterion. For this purpose, the information previously stored in the bank database is used. All the changes in customer segments over time will be analyzed. Here, two categories of customers will be given special attention; the first category is the customers who have moved from a specific level to a higher level of loyalty and profitability in two tandem intervals. It should be noted that this upgrade in the segment is necessary through increasing the level of product usage, which the bank provides. This category of customers is called Potential Reference Customers (PRC). The second category is the customers who have remained in a constant segment for two tandem intervals. These are called Potential Target Customers (PTC). Then, using the *k*-NN method, *the most similar customers for all PTCs will* be extracted.

The basis for calculating similarity can be the items such as the amount of bank account average, loan, letter of guarantee, letter of credit, number of transactions, and industry or business for a long time. After extracting *k* most similar customers for each PTC, if there are PRCs in the list of similar customers, the most similar one will be selected as the so-called Reference Customer (RC). In this way, the reference is identified only for a subset of PTCs. These subsets are called Target Customers (TC). For each TC, the level of the interactions associated with the assigned RC during the last segmentation time interval is determined as a target. So, if the TC reaches the thresholds, it is considered a customer in the upper segment in the CSS.

Since both the RC and the TC have been in the same segment in the previous period and, on the other hand, based on banking information, have had similar conditions, we can expect them to achieve the target thresholds specified for each TC. The combined use of information about the bank deposit accounts and the volume of use of credit products in the modeling process can ensure that both the TC and the RC have the same type of behavior in using deposit services or credits provided by the bank. This can ensure that the proposed path is appropriate for each TC.

also figure 3 presents the proposed method of problem-solving and shows the software and analytical techniques used in each step.

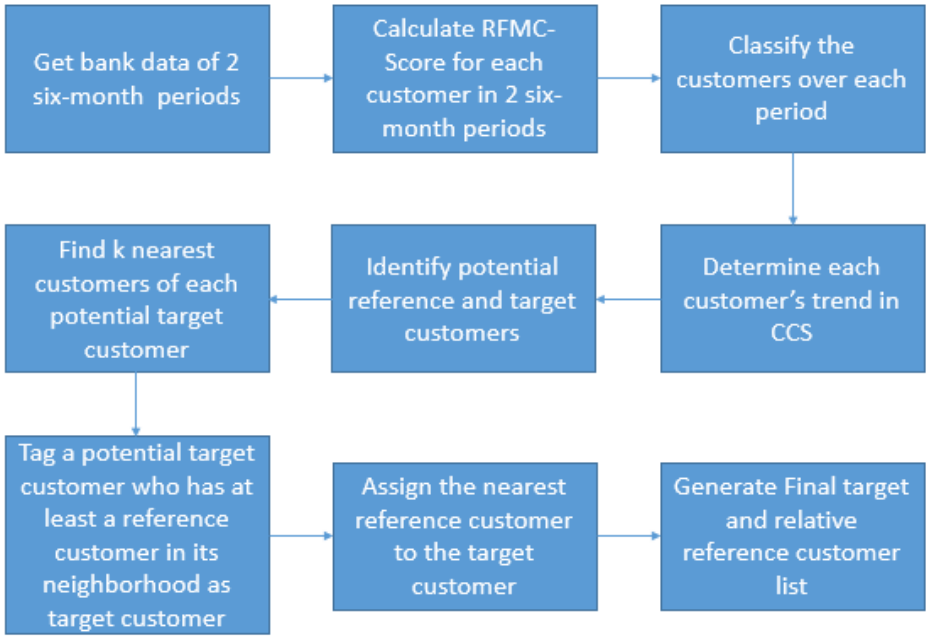

Figure 44. Main steps of the proposed method

3. Experiments

3.1. Data

- The proposed method was used for 422,264 corporates, which are commercial bank customers in three categories: big, medium, and small businesses. Information, including the following items over a 2-year period, was extracted from the bank database for these customers. Monthly average of the four deposits, including current, short-term, long-term, and saving in 2 years (96 variables)
- Amount and count of monthly transactions related to the four deposits over 2 years (192 variables)
- Amount and count of loans received during four 6-month intervals (8 variables)
- Amount and count of LGs received during four 6-month intervals (8 variables)
- Amount and count of LCs received during four 6-month intervals (8 variables)
- Customer category (1 variable)

3.2. RFMC-Score calculation

Segmentation of the customers in terms of profitability and loyalty was implemented with the help of RFMC-Score. For this, Equation (1) was used to integrate the factors R, F, M, and C. Relevant weights have been used based on the results of research by Zaheri et al. (2002) and Khajvand et al. (2011) on determining the relative importance of the factors.

$$\text{RFMC-Score} = 0.1R+0.1F+0.7M+0.1C \quad (1)$$

4. Results

The number of final RCs and TCs in each of the three studied categories when k equals 40 was obtained, as shown in Table 1. It should be noted that to ensure the feasibility of a proposed path, the similarity of an RC to a TC has been prioritized over the number of detected TCs. On the other hand, by changing the parameter k in the k-NN method, the number of final TCs can be controlled so that a higher k value leads to extracting more TCs, and a lower value leads to a smaller number of TCs. However, it should be noted that a high value of k suggests paths that may not be feasible.

Table 12. Frequency of target and reference customers

Customer category	All customers	Reference customers	Target customers
Big	4958	20	424
Medium	23148	238	2730
Small	394158	69	1756

Examples of the references for two target customers are shown in Figures 4 and 5. In Figure 4, for a target customer who, according to their past interaction with the bank, is of a depositor type, the reference customer is assigned intelligently from the same behavior using the proposed method. By comparing historical data of the target and the reference customers, it is clear that both customers in the former three 6-month periods of four examined 6-month periods had experienced similar deposit averages, so they were in the third segment or level in CSS. However, the reference customer increased the deposit average to 16.75 billion in the last 6-month period and entered the fourth segment (the highest segment). Therefore, if the target customer increases its deposit average to this point (16.75) by adding 16.45 billion, it can enter the fourth segment, too. On the other hand, we can expect this increase in the deposit average to be feasible due to the similarity of the situation in the past periods.

In Figure 5, for the target customer, which, according to the historical data, is a creditor-type customer, the reference customer of the same behavioral type is assigned. Regarding this case, the target and the reference customers were in the same situation in the first three 6-month periods and, therefore, were classified in the same segment (the third segment). However, in the last 6-month period, the reference customer increased its total deposit average to 42 billion and, on the other hand, got a loan of 45 billion. Therefore, the target customer can enter the fourth segment (the top segment) by increasing the level of interaction with the bank in terms of total deposit average and consuming loans and/or credits at the mentioned level by depositing 35.6 billion and receiving loans and credits up to the level of 45 billion.

Moving customers from the lower segment in the bank's CSS to a higher one leads them to benefit from incentives designed for loyal and profitable customers. Therefore, for the customers who have this motivation, with the help of the proposed method, a clear and wholly quantitative and, at the same time, customized path is generated according to its conditions, behavioral type, and business.

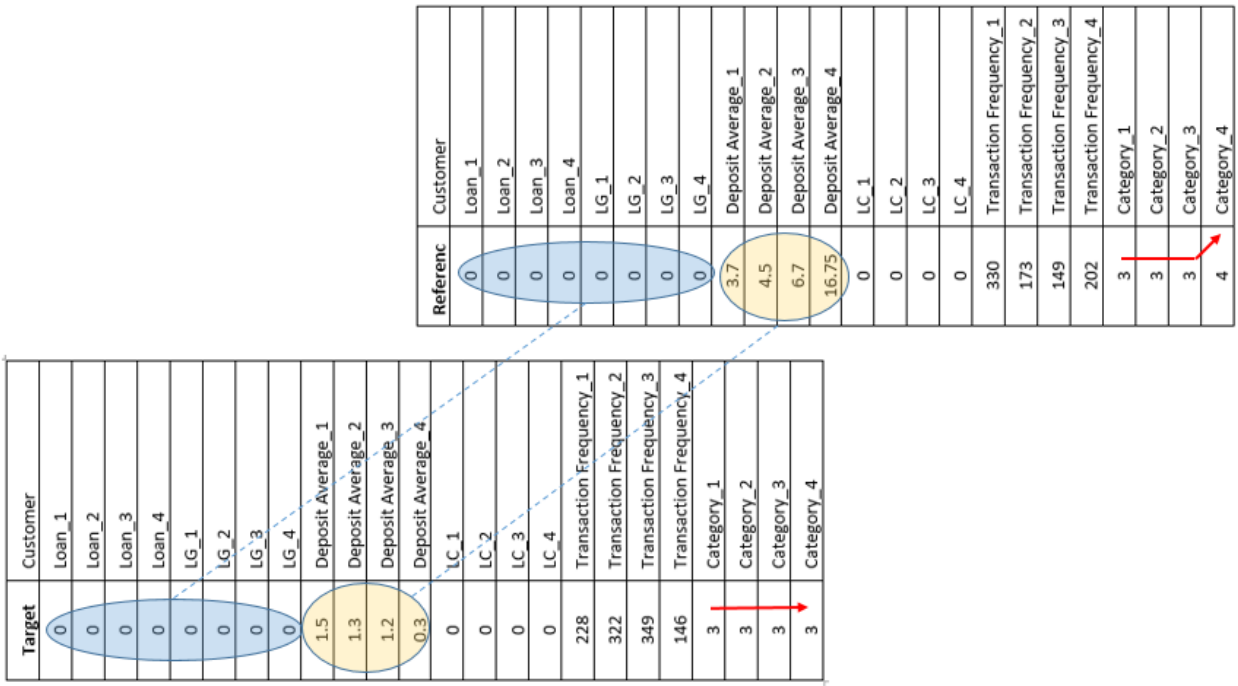

Figure 45. Information of a depositor target customer and the determined reference point

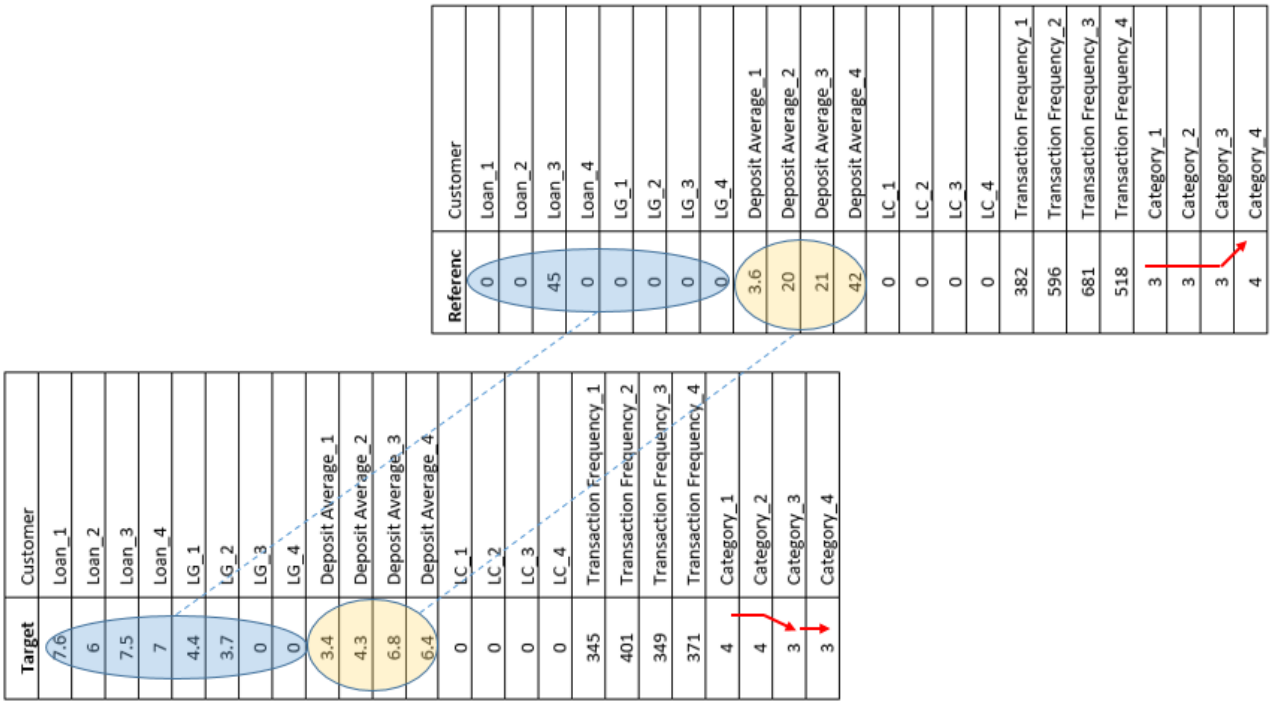

Figure 46. Information of a creditor's target customer and the determined reference point

Notably one of the main reasons for creating a CCS and then providing the proposed method is budget restrictions to provide incentives to promote the level of all customers. Therefore, the intention is to provide a promotion path for potentially valuable customers. Small values of k make the "promotion path" more attainable for a target customer; conversely, the chance of finding such a path will be low. On the other hand, large k increases the chance of finding the path but reduces its feasibility. Therefore, this value directly affects the number of customers the promotion path. Therefore, its value is determined based on the amount of the marketing budget. In this article, the number 20 has been chosen, which has led to the number of TCs identified in Table 1.

5. Conclusion

In this paper, the concept of Decision Intelligence (DI) was introduced to generate a customized path through which a customer can make purposeful changes in the level of interaction with a bank to improve the loyalty and profitability segmentation system. For this purpose, a proper CDD diagram was first developed. It demonstrated how each decision or action relates to a result. Then, using the k-NN method, the relationship between action and result was modeled to determine the best action to achieve the desired result, which is the positive change in the customer segment leading to determining the target levels for the customer interaction with the bank. The proposed method was used for the data of 422,264 corporate customers of a private bank. Finally, the customers who were prone to upgrade and the target levels were determined for each. In this research, the RFMC-Score criterion was used to classify the customers. Using the proposed method for these customers, 4,910 potential customers were identified to be promoted to a higher level at the Customer Segmentation System, along with targets for each in terms of deposit average and credit. A closer look at the results showed that the proposed method of setting targets for each customer according to the kind of customer behavior in both depositor and creditor worked intelligently. Due to the successful performance of the proposed method for bank customers, it can be utilized by other organizations. Also, using more accurate CLV evaluation criteria and customer segmentation based on such criteria is another research topic that can be mentioned in the context of the DI and the general framework presented in this research.

Disclosure statement

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

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Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir
Online ISSN: 2821-1669, Print ISSN: 2980-9460
Research Article
DOI: 10.22067/JSTINP.2025.89236.1121
JSTINP 2025; Vol. 4, No. 1

Integrated Systemic Modeling of Production Scheduling, Maintenance, and Quality Control in Closed-Loop Supply Chains

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How to cite this article

Rahim, J., Morovati Sharifabadi, A., Andalib Ardakani, D. 2025. Integrated Systemic Modeling of Production Scheduling, Maintenance, and Quality Control in Closed-Loop Supply Chains, *Journal of Systems Thinking in Practice*, *4*(1), pp. 83-106. doi: 10.22067/jstinp.2025.89236.1121

URL: https://jstinp.um.ac.ir/article_46239.html.

ABSTRACT

Closed-loop supply chains (CLSCs) are increasingly recognized as essential frameworks for achieving operational efficiency and sustainability in modern industries. This study focuses on optimizing production scheduling, maintenance strategies, and quality control within CLSCs, specifically tailored for the home appliances industry. The proposed model integrates preventive and corrective maintenance policies, scheduling, and quality management into a unified system that minimizes costs while enhancing reliability and sustainability. The Strategic Choice Approach (SCA) was employed to structure complex decision-making processes, leveraging the expertise of industry professionals to identify key uncertainties and variables. A Genetic Algorithm (GA) was utilized to optimize decision variables, including sample size, sampling intervals, control limits, and maintenance schedules, ensuring robust solutions under real-world constraints. The model categorizes machine failures into immediate and delayed modes, providing tailored strategies for each to maintain system performance. Comparative analyses highlight the integrated model's superior cost-effectiveness and operational benefits over traditional independent approaches. Sensitivity analyses further demonstrate the robustness of the model under varying operational conditions, validating its adaptability and scalability. By addressing the interconnected challenges of maintenance, scheduling, and quality control, this research offers a practical and holistic solution for CLSCs, contributing to improved operational resilience, customer satisfaction, and alignment with sustainability objectives. The decision-making process provides valuable insights and confident recommendations for future research.

Keywords

Integrated system, Production scheduling, Maintenance, Closed-loop supply chain, Strategic choice approach.

Article history

Received: 2024-10-15
Revised: 2025-01-16
Accepted: 2025-01-13
Published (Online): 2025-03-17

Number of Figures: 1 **Number of Tables: 5** **Number of Pages: 24** **Number of References:38**

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1. Introduction

Supply chains are the lifelines of modern industries (Taghipour et al., 2023b), underpinning the processes that deliver goods and services efficiently and sustainably. In recent years, the concept of closed-loop supply chains (CLSCs) (Foukolaei et al., 2024) has gained significant attention as industries recognize the importance of integrating forward and reverse logistics to manage resources more effectively (Gholian-Jouybari et al., 2024). CLSCs are particularly valuable in sectors such as the home appliances industry, where product lifecycles demand robust mechanisms for recycling (Ghaedi et al., 2024), remanufacturing, and waste reduction (Ramezani et al., 2024). This approach minimizes environmental impact and creates opportunities for cost savings and enhanced customer satisfaction (Taghipour et al., 2024), aligning with global sustainability goals (Taghipouret al., 2023). Scheduling and production planning are critical elements within supply chains, influencing resource allocation, production efficiency, and customer fulfillment (Shambayati et al., 2023). Effective scheduling ensures that production meets demand while minimizing delays and costs, whereas robust planning aligns operational strategies with long-term business goals (Scheller et al., 2023). These factors are even more complex in CLSCs, where production planning must accommodate uncertainties in reverse logistics, such as the timing and quality of returned products (Gholizadeh et al., 2023). Moreover, integrating maintenance strategies and quality control into scheduling processes becomes essential to ensure operational reliability and product integrity (Corsini et al., 2024). Balancing these interdependencies for industries like home appliances is key to maintaining competitiveness in increasingly dynamic markets (Bhattacharya et al., 2024).

Systems thinking provides a practical framework for addressing these complexities by emphasizing the interconnectedness of various elements in CLSC operations (Coenen et al., 2018). By viewing production scheduling, maintenance, and quality control as parts of a unified system, systems thinking enables organizations to identify feedback loops, dependencies, and potential trade-offs (León & Calvo-Amodio, 2017). This perspective is particularly valuable for CLSCs, where the flow of materials, information, and resources must be optimized across multiple stages (MahmoumGonbadi et al., 2021). Industries can move away from siloed approaches through systems thinking and develop integrated strategies that enhance overall performance, resilience, and sustainability (Jaaron & Backhouse, 2019).

This study is motivated by addressing these challenges in CLSC operations. Specifically, it focuses on developing an integrated model for production scheduling, preventive and corrective maintenance, and quality control in the home appliances industry. Using the Strategic Choice

Approach (SCA) to identify key decision variables and mathematical modeling to optimize them (Antweiler & Schlund, 2023), the study aims to provide a comprehensive solution that minimizes costs and enhances system performance. By bridging theoretical advancements with practical applications, this research contributes to the ongoing discourse on CLSC optimization and demonstrates the value of holistic decision-making frameworks.

The remainder of this paper is organized as follows. The literature review examines previous studies on CLSCs, production scheduling, and integrated maintenance strategies, highlighting existing gaps and opportunities. The methodology section details the use of SCA and the development of the mathematical model. The results section presents the findings, illustrating the effectiveness of the proposed model with numerical examples. The discussion provides insights into managerial implications, highlighting the advantages of integrated approaches over independent models. Finally, the conclusion summarizes the study's contributions and outlines directions for future research in advancing CLSC strategies.

2. Literature review

Recent advancements in closed-loop supply chains (CLSCs) have emphasized the importance of integrating innovative optimization methods to enhance efficiency and sustainability. Recent studies in the field of closed-loop supply chains are listed in the Table 1. Aliahmadi et al. (2023) developed a multi-echelon CLSC model that incorporated pricing decisions and queuing systems under uncertainty. Their approach utilized Flexible Robust-Fuzzy Optimization (FRFO) and meta-heuristic algorithms, such as G-HHO and PSO, to maximize net present value (NPV). Results showed that increasing the number of production lines reduced queue lengths and enhanced profitability, with the G-HHO algorithm performing best for large-scale problems. Similarly, Gholizadeh et al. (2023) proposed a closed-loop green supply chain network incorporating redundancy strategies for reliability and eco-friendliness. Their model, which applied hybrid heuristics and meta-goal programming, achieved notable cost reductions, increased eco-friendly part usage, and improved system reliability through active standby strategies. Scheller et al. (2023) analyzed CLSCs for lithium-ion batteries using a multi-stage, multi-product, multi-period production planning approach in the context of network structures. The study compared centralized, decentralized, and circular factory setups, demonstrating that circular factories outperformed others in reducing transportation costs and enhancing material flow in the short term. Corsini et al. (2024) extended the focus to production capacity and control policies, evaluating four production control strategies in CLSCs. Their findings

highlighted the Adaptive Hedging Corridor Policy as a practical approach for enhancing customer service levels and minimizing the bullwhip effect, with return flows and manufacturing operations playing critical roles in supply chain performance.

Multi-objective optimization models have also been pivotal in addressing CLSC challenges under uncertainty. Yousefi et al. (2021) presented a model for aggregate production planning, optimizing costs, customer satisfaction, and product quality through LP-metric and LINGO software. Applied to military industry data, the model effectively balanced conflicting objectives. Roshani et al. (2023) tackled capacitated lot-sizing and scheduling in CLSCs, incorporating sequence-dependent setup times. By leveraging large-bucket mixed-integer programming and Grey Wolf optimization algorithms, their model minimized costs across manufacturing, remanufacturing, inventory holding, and energy utilization, demonstrating the effectiveness of these algorithms in solving NP-hard problems. Emerging technologies like IoT and artificial intelligence (AI) are transforming CLSC operations. Shambayati et al. (2023) and Shambayati et al. (2022) explored IoT-enabled virtual CLSCs, revealing significant improvements in profitability and efficiency through advanced tracking and defect management systems. Meanwhile, Bhattacharya et al. (2024) provided a comprehensive review of AI applications in CLSCs, identifying ten popular techniques and proposing a framework with fifteen research questions for future exploration. Hussaini et al. (2023) contributed to CLSC viability by proposing a multi-period, multi-season model to manage fluctuations in demand and costs, emphasizing the importance of accurate cost forecasting and capacity adjustments.

Table 13. Summary of the related recent studies

Author(s)	Aim	Methods	Findings
(Aliahmadi et al., 2023)	To model a multi-echelon closed-loop supply chain with pricing decisions and queuing systems under uncertainty.	Flexible Robust-Fuzzy Optimization (FRFO) and meta-heuristic algorithms (G-HHO, PSO, ALO, GWO)	Maximized net present value (NPV), reduced queue lengths, and improved NPV with increased production lines. G-HHO algorithm provided the best performance for large sample problems.
(Gholizadeh et al., 2023)	To design a closed-loop green supply chain network with a redundancy strategy for eco-friendly parts and maximum reliability.	Multi-objective mixed-integer program with a hybrid heuristics algorithm and multi-choice meta-goal programming	Achieved a 15.3% decrease in total cost, 2.83% increase in eco-friendly parts, and 11.25% increase in reliability with active standby strategy.
(Scheller et al., 2023)	To develop a production planning model for closed-loop supply chains in lithium-ion batteries, analyzing different network structures.	Multi-stage, multi-product, multi-period production planning approach	Circular factories outperformed centralized and decentralized networks in the short term, improving material flow and reducing transportation costs.
(Corsini et al., 2024)	To analyze how production capacity and production control policies impact the performance of closed-loop supply chains.	Comparison of four production control policies using simulation	Adaptive Hedging Corridor Policy enhanced customer service levels and reduced the bullwhip effect. Sensitivity analysis highlighted the importance of return flows and manufacturing operations.

Author(s)	Aim	Methods	Findings
(Yousefi-Babadi et al., 2021)	To present a multi-objective model for aggregate production planning in a closed-loop supply chain under uncertain conditions.	LP-metric and LINGO software for multi-objective optimization	Optimized costs, customer satisfaction, supplier satisfaction, and product quality; solved through numerical examples and actual data in military industry.
(Roshani et al., 2023)	To address capacitated lot-sizing and scheduling with sequence-dependent setup times in a closed-loop supply chain.	Large-bucket mixed-integer programming, matheuristic, and grey wolf optimization algorithms	Minimized manufacturing, remanufacturing, setup, inventory holding, backlogging, and energy costs. The proposed algorithms demonstrated effectiveness in solving the problem.
(Shambayati et al., 2023)	To optimize a virtual closed-loop supply chain (VCLSC) using IoT under uncertainty.	Grey Wolf algorithm and Firefly algorithm for optimization	The Firefly algorithm outperformed others, leading to higher profit for the VCLSC. The use of IoT significantly increased profits by tracking defective parts and improving chain efficiency.
(Bhattacharya et al., 2024)	To review the applications of Artificial Intelligence (AI) in closed-loop supply chains (CLSC) and propose future research directions.	Systematic literature review of 303 peer-reviewed articles	Identified 10 popular AI techniques and 7 CLSC subfields where AI could bring significant benefits. Proposed a framework with 15 research questions for future research.
(Hussaini et al., 2023)	To develop a multi-period, multi-season model for ensuring supply chain viability under fluctuations.	Mixed-integer mathematical model solved with CPLEX solver	Highlighted seasonal supplier layoffs, capacity adjustments, and accurate cost forecasting as critical strategies for maintaining supply chain viability.
(Shambayati et al., 2022)	To optimize virtualization in closed-loop supply chains using IoT.	Grey Wolf and Firefly algorithms for optimization; sensitivity analysis	IoT integration significantly enhanced efficiency and profitability of the virtual supply chain by improving tracking, product delivery, and defect management.

While significant advancements have been made in optimizing closed-loop supply chains (CLSCs), gaps remain in fully integrating key aspects such as production scheduling, maintenance strategies, and quality control under uncertainty. Existing studies primarily focus on isolated components, such as pricing decisions (Aliahmadi et al., 2023), green supply chain design (Gholizadeh et al., 2023), or specific network structures (Scheller et al., 2023). However, the interplay between these elements, particularly in real-world constraints like fluctuating demand, multi-objective trade-offs, and operational disruptions, is less explored. The novelty of the current study lies in its holistic approach to optimizing CLSCs by integrating production, maintenance, and quality management using advanced optimization techniques. By addressing these interdependencies and incorporating dynamic factors such as machine reliability and system efficiency, the study bridges existing gaps. It offers a unified framework that enhances cost-effectiveness, sustainability, and decision-making robustness in complex supply chain environments.

3. Methodology

The study employed the Strategic Choice Approach (SCA) (Khazaei et al., 2021b) to design an optimized closed-loop supply chain model tailored for the home appliances industry. SCA, a methodology from the soft operational research category (Dehghan Nayeri et al., 2018), is a collaborative decision-making framework that emphasizes the incremental management of uncertainties and involves participants with diverse expertise (Khazaei et al., 2021a). For this research, nine home appliance industry experts were convened in structured workshops (Paucar-Caceres et al., 2020). These experts represented various domains: production, logistics, quality control, and sustainability. The workshops were designed to systematically identify the key decision areas, uncertainties, and comparison criteria essential for designing an effective closed-loop supply chain. The SCA process unfolded through its four strategic modes—shaping, designing, comparing, and choosing—enabling the group to build a commitment package for decisions to be implemented incrementally (Franco, 2007). The discussions focused on defining uncertainty boundaries, such as the working environment, guiding values, and interrelated choices, specific to the home appliances sector (DeCarolis et al., 2017). For example, uncertainties about product lifecycle, recycling processes, and customer return behaviors were identified and categorized. By navigating these uncertainties, the group collaboratively formulated assumptions about the structure and functionality of the supply chain, ensuring that the proposed model addressed practical challenges and aligned with industry needs.

The assumptions derived from the SCA workshops (Figure 1) were systematically converted into a mathematical model for optimization, which will be elaborated on in subsequent sections. This conversion involved translating qualitative insights into quantitative parameters, enabling precise modeling of production scheduling, maintenance strategies, and reverse logistics flows. The mathematical formulation integrated these assumptions into a robust framework to minimize costs and improve efficiency across the closed-loop supply chain. This integration of SCA with mathematical modeling provides a unique methodological approach, bridging expert-driven decision-making with quantitative optimization for practical implementation (Awasthi et al., 2018). Therefore, our model in this paper categorizes machine failures into two distinct modes (Bektur, 2020): 1) The first type of breakdown mode (FM_1): The breakdown of the machine is determined immediately. 2) The second type of failure mode (FM_2): Machine failure after production is determined by transferring the process average in the discussion of process quality.

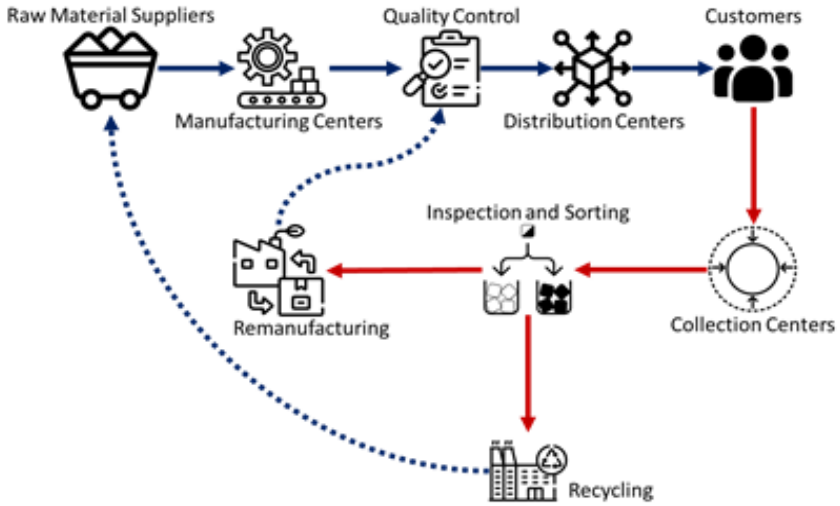

Figure 47. The designed flow of CLSC model after SCA employment

3.1. Assumptions and descriptions

Here are the assumptions the authors will examine:

1) Corrective maintenance and repairs are fundamentally minimal. Post-correction, the equipment's lifespan remains unchanged, and the duration of the corrective activity is included in its operational life.
2) Maintenance and repairs are inherently partial; they only partially address the issue, leading to potential recurring problems.
3) For quality control, the authors consider only one characteristic: CTQ[1].
4) The production process starts from the state under control. The mean and standard deviation of CTQ are μ and σ as follows.
5) A specific error that happens randomly and causes the process average to σ when it remains constant. It transfers from μ_0 to $\delta+\mu_0$ μ_1
6) The control chart monitors the process $\bar{x}$.

Table 2 shows the variables and parameters of the CLSC model.

Table 14. Variables and parameters

Variables / Parameters	Definition
$ARL2_E$	The average sample length is when the process is out of control for external and environmental reasons.
$ARL2_{M/C}$	The average sample length when the process is out of control due to machine wear.
ARL1	The average sample length when the process is under control.
K	Coefficient of control limit.
C_{lp}	The cost of stopping production.
C_{Rej}	The cost of returning the product.
$C_{resetting}$	The cost of restoring the process to the first state.
prd_E	Overall evaluated time.
$[C_{CM}]_{FM_1}$	Expected cost of maintenance and corrective repairs due to the first mode error.

[1] Critical to Quality

Variables / Parameters	Definition
C_{PM}	Expected cost of preventive maintenance and repairs.
$E\,[T_{Cycle}]$	Duration of the process.
T_1	The time required to determine the occurrence of the specified reason.
$E\,[T_{restore}]$	The time required to restore the process to the first state or to repair the machine if the process has gone out of control due to the environment or machine depreciation.
$[TCQ]_{process-failure}$	The cost of quality degradation due to process defects.
λ_1	Process failure rate due to environmental and external reasons.
λ_2	The machine breakdown rate due to machine depreciation.
C_{FCCM}	Fixed cost of maintenance operations and corrective repairs.
C_{FCPM}	Fixed cost of preventive maintenance and repairs.
LC	Cost of labor for maintenance and repairs.
MT_{CM}	Average time required for maintenance and corrective repairs.
MT_{PM}	Average time required for preventive maintenance and repairs.
N_f	Average number of failures.
t_{PM}	Interval of maintenance and repair activities.
β_E	The possibility of a second type of error due to an external reason.
$\beta_{M/C}$	The possibility of the second type of error due to the depreciation of the machine.
P_{FM_1}	Probability of occurrence of the first failure mode.
P_{FM_2}	Probability of occurrence of the second failure mode.
λ	Process failure rate.
PR	Production rate.
N	Sample size.
T_s	Sampling time.
α	First type error.
H	Time interval between sampling.

3.2. Model description

If FM_1 occurs, the machine stops immediately. Corrective operations are applied to repair it. Therefore, the cost of maintenance and corrective repairs ($[C_{CM}]_{FM_1}$) consists of the cost of idle time, the cost of repairing and restoring the machine to its original state (Bocken et al., 2019). The machine's condition influences the effects of FM_2 and results in an increased product return rate. In other words, FM_2 impacts the process's return rate. It is assumed that the process halts immediately upon detecting FM_2, and corrective measures are implemented to restore normal operating conditions. Additionally, the process may deteriorate due to external factors (E), such as environmental conditions, operator errors, or improper tool usage (Calabrese et al., 2019). The process transitions to an out-of-control state if an external event (E) occurs. Process monitoring accomplishes detection of FM2 or an external cause (E). In this article, a control chart mechanism is used for monitoring. The control chart design parameters include sample size (n), sampling interval (h), and coefficient (k) to determine the distance from the central line to the control limit. Therefore, the total cost of process failure due to E and FM_2, i.e.,

$[TCQ]_{process-failure}$, include the cost of machine idleness, product return due to process transfer, repair cost, sampling and inspection cost, and the deviation cost of CTQ target values (Centobelli et al., 2020).

The authors need to account that both parameters, FM_1 and FM_2, are flawed and diminished. Reducing FM_2 leads to increased costs due to out-of-control operations and quality issues. However, preventive maintenance requires resources and time that could be used for production. The cost of preventive maintenance (PM) includes the expense of process downtime (C_{PM}) and the costs associated with maintenance and repairs. This article discusses the problem of determining the optimal values of the decision variables (n, h, k, t_{PM}) to minimize the total cost per time unit ($[TCT]_{Maintenance*Quality}$) (Chaturvedi et al., 2017). It should be noted that the life of the equipment is reduced after preventive maintenance and repair according to the repair and return factor. The total cost per unit of time for maintenance and preventive repairs and control chart policy ($[TCT]_{Maintenance*Quality}$) is the ratio of the total cost of quality control ($[TCQ]_{process-failure}$), the total cost of preventive maintenance and repairs (C_{PM}), and the total cost of machine breakdown ($[C_{CM}]_{FM_1}$), to the evaluation time. The cost incurred due to FM_2 includes the cost of process quality control. Therefore, the total cost is as follows per unit of time for the integrated model (Chen et al., 2023) in Equation 1:

$$[TCT]_{Maintenance*Quality} = \frac{1}{prdE}([C_{CM}]FM_1 + C_{PM} + [TCQ]_{process\text{-}failure}) \quad (1)$$

Where $[TCT]_{Maintenance*Quality}$ = (n, h, k, t_{PM}) and prd_E. The time is planned and evaluated according to the analysis of what will be done. Therefore, the optimization problem can be Equation 2:

$$\begin{aligned} &\text{Minimize } [TCT]_{Maintenance*Quality} \\ &\text{Subject to} \\ &a_1 \le n \le b_1 \\ &a_2 \le h \le b_2 \\ &a_3 \le k \le b_3 \\ &a_4 \le t_{PM} \le b_4 \\ &n, h, k, t_{PM} \ge 0 \end{aligned} \quad (2)$$

Where α_i and b_i are decision variables and upper and lower limit values. Next, the authors will describe the three cost functions within the objective function. For the specified evaluation period, expected cost models are derived for preventive and corrective maintenance related to FM_1 and the cost of process failures due to external factors associated with FM_2. To calculate the costs associated with corrective and preventive maintenance for FM_1, the analyst needs the

following information (Chen et al., 2018): The amount of time required for corrective maintenance (CM) and preventive maintenance (PM) operations encompasses not only the actual maintenance and repair activities but also reasonable delays, such as waiting for labor, materials, or other necessary resources. These operations incur costs, including machine downtime, labor expenses, required materials, and associated fees. Additionally, equipment failure is always possible due to specific failure modes, highlighting the critical need for a comprehensive and proactive maintenance and repair strategy to ensure system reliability and operational efficiency (Chihambakwe et al., 2021). For the cost of maintenance and corrective repairs, the authors must have the following factors:

1) Average duration needed for maintenance and corrective repairs: MT_{CM}
2) System production rate: PR
3) The cost of stopping production during maintenance and corrective repairs: C_{lp}
4) Cost of labor for maintenance and corrective repairs: LC
5) Fixed cost of maintenance operations and corrective repairs: C_{FCCM}
6) The possibility of the first mode failure: P_{FM_1}
7) Average number of failures: N_f

The cost of maintenance and corrective repairs on FM_1 is calculated as Equation 3:

$$[C_{CM}]_{FM_1} = [[PR.C_{lp}+LC] + C_{FCCM}] \times P_{FM_1} \times N_f \quad (3)$$

where $[MT_{CM}$.$[PR.C_{lp}+LC] + C_{FCCM}]$ is the cost of machine failure due to maintenance and corrective repairs. The variable is t_{PM} in Equation 2-3 where N_f is a function that lies in it, discussed in the following.

The following should be considered to obtain a cost model for preventive maintenance and repairs:

1) Average time required for preventive maintenance and repairs: MT_{PM}
2) System production rate: PR
3) The cost of stopping production during preventive maintenance and repairs: C_{lp}
4) Cost of labor for preventive maintenance and repairs: LC
5) Fixed cost of preventive maintenance and repairs: C_{FCPM}
6) The possibility of the second mode failure: P_{FM_2}
7) Time of the entire evaluated course: prd_E

The expected total cost of preventive maintenance and repairs will be as Equation 4:

$$C_{PM} = [MT_{PM} . [PR. C_{lp}+LC] + C_{FCPM}] \times \frac{prd_E}{t_{PM}} \quad (4)$$

where $[MT_{PM} . [PR. C_{lp}+LC] + C_{FCPM}]$ is the cost of machine downtime is due to preventive maintenance and repairs and $\frac{prd_E}{t_{PM}} = N_{PM}$. The number of preventive maintenance and repairs is rounded to a smaller integer. Building on the work of Govindan et al. (2016), the authors have

developed a novel model that optimizes product return costs, a unique approach to maintenance and repair costs. In new studies, the number of maintenance and corrective repairs is obtained by simulating machine defects for the given evaluation period, explained in the next section.

Next, the total cost of the process defect of $[TCQ]_{process-failure}$ is calculated. Then, the authors calculate the length of the period E[T_{Cycle}]. The period length refers to the anticipated duration between successive controlled intervals. During these intervals, costs arise from process sampling, product defects, and false alarms. If the process deviates from control, it is presumed that it cannot revert to a controlled state without external intervention. There are costs such as upgrading the level of the produced product, sampling, repair and return, searching for the reason, and stopping the process to return to the controlled state. After this, one period ends, and the successive periods begin. This section breaks down the expected cost of process quality control into costs. These costs include:

1) Expected cost to find the specific cause,
2) Sampling cost,
3) Expected cost for out-of-control operations.
4) The expected cost of restoring the process in a state that goes out of control due to machine wear or external and environmental reasons.

It is assumed that C_F is the fixed cost of sampling and C_V is the cost of variable sampling. Therefore, the expected cost of sampling in one period, the sum of fixed and variable costs per unit of time, is as Equation 5:

$$E[C_{sampling}]=(C_F + C_V.n) \times \left(ARL2_{M/C} \times {}^{\lambda_2}/_{\lambda} + ARL2_E \times {}^{\lambda_2}/_{\lambda}\right) \quad (5)$$

Now, the authors calculate the expected cost due to the lack of quality in the out-of-control state, and in fact, the authors get the cost of the defective products produced when the process is in the out-of-control state. The cost of returning the product when the process is out of control due to machine failure is Equation 6:

$$E[c_o]_{M/C}=(PR\times P_{M/C} \times C_{Rej})\times [\ (h+n.T_s) \times (ARL2_{M/c} \times {}^{\lambda_2}/_{\lambda} + ARL2_E \times {}^{\lambda_1}/_{\lambda}\ ) - \tau+T_1)]\times ({}^{\lambda_2}/_{\lambda}) \quad (6)$$

Moreover, when the process goes out of control due to an external and environmental factor, the return cost is Equation 7:

$$E[c_o]_E=(PR\times P_E \times C_{Rej})\times [\ (h+ n.T_s) \times (ARL2_{M/c} \times {}^{\lambda_2}/_{\lambda} + ARL2_E \times {}^{\lambda_1}/_{\lambda}\ ) - \tau+T_1)]\times ({}^{\lambda_1}/_{\lambda}) \quad (7)$$

$P_{M/C}$ and P_E are the probability of producing a defective product due to machine depreciation, external and environmental reasons, respectively. It is obtained from the Equation 8 and 9:

$$P_{M/C}=1\text{-}Pr(LSL\leq X\leq USL)=1\text{-}Pr(\frac{LSL-(\mu+\delta_{M/C})}{\sigma}\leq N(0,1)\leq\frac{USL-(\mu+\delta_{M/C})}{\sigma}) \quad (8)$$

$$P_E=1\text{-}\ Pr(LSL\leq X\leq USL)=1\text{-}Pr(\frac{LSL-(\mu+\delta_E)}{\sigma}\leq N(0,1)\leq\frac{USL-(\mu+\delta_E)}{\sigma}) \quad (9)$$

where USL and LSL are high and low-quality specification limits (tolerance). It is assumed that $C_{resetting}$ is the cost of finding and restoring the original state. The expected cost amount is calculated for $C_{resetting}$ in Equation 10:

$$E[C_{resetting}]=[\ C_{resetting}\times T_{resetting}]\times(\lambda_1/\lambda) \quad (10)$$

The expected cost of the maintenance activity and corrective repairs due to the error, finding, and repairing the specific reason for the cause of the machine failure are show in Equation 11:

$$E[c_{Repair}]_{FM_2}=[(MT_{CM}).[PR.C_{lp}+LC]+C_{FCCM}]\times(\lambda_2/\lambda) \quad (11)$$

This cost includes stoppage of production, cost of labor, and fixed cost of maintenance and corrective repairs. Therefore, the expected cost of process failure in the desired period is according to Equation 12:

$$E[C_{process}]=\ E[C_{sampling}]+E[c_o]_{M/C}+E[c_o]_E+E[C_{resetting}]+E[c_{Repair}]_{FM_2} \quad (12)$$

It is assumed that the failure of the process is repeated naturally. The period will be the same whenever the process is transferred from the state under control to the state out of control and back to the first state. (The duration of the course will be fixed). If the authors have M periods of process failure in an evaluated time, the total cost is according to Equation 13:

$$[TCQ]_{process-failure}=[E(C_{process})]\times M \quad (13)$$

In Equation 14, M is:

$$M=\frac{prd_E}{E[T_{cycle}]} \quad (14)$$

The expected course time is the sum of the following terms:

1) the desired period for the specific cause to occur,
2) the desired duration for analyzing and examining a sample and the graph of the results,
3) the desired period until the chart gives us a sign of leaving the controlled state,
4) the desired period to discover and analyze the specific reason that occurred,
5) The desired period to return the process to the first state if the defect of FM_2 is due to an external reason or to repair the process if the defect is due to the reason.

It is assumed that the time of the controlled state follows an exponential distribution with a mean of $1/\lambda$. The failure rate value is independent in the statistical discussion. Therefore:

$$ARL1= 1/\alpha \quad (15)$$

In Equation 16, α is α = Pr $(out\ of\ control\ signal|process\ is\ in\ control)$ and it is based on the calculations in quality control:

$$\alpha = 2\ F(-k) \quad (16)$$

where F will be the cumulative normal distribution, Process failure rate: λ, Coefficient of control limit: k, and Sampling period: h. It is supposed that τ is the expected time of occurrence and a specific reason. When the specified reason occurs between the i and i+1 samples. Therefore:

$$\tau= = h/2 \quad (17)$$

Hence, is τ the independent of i. where ARL2 is the average length of the period when the process has moved to an out-of-control state. According to the quality control discussion, if the taken samples are independent, therefore:

$$ARL2_{M/C}=1/1-\beta_{M/C} \quad (18)$$

$$ARL2_{E}=1/1-\beta_{E} \quad (19)$$

$$\beta= Pr(in\ control\ signal\ |\ process\ is\ out\ of\ control\ ) \quad (20)$$

$$\beta_{M/C}=Pr(LCL \le \bar{x} \le UCL|\mu = \mu_1 = \mu_0 + \delta_{M/C}\sigma_p) \quad (21)$$

$$\beta_{E}=Pr(LCL \le \bar{x} \le UCL|\mu = \mu_1 = \mu_0 + \delta_{E}\sigma_p) \quad (22)$$

Since it is $\bar{X}\sim N(\mu, \sigma_P^2/n)$ and the upper and lower control limits are equal to Equation 22 and 24 :

$$UCL=\mu_0 + k\sigma_p/\sqrt{n} \quad (23)$$

$$LCL=\mu_0 - k\sigma_p/\sqrt{n} \quad (24)$$

Then we will have:

$$\beta_{M/C}=F(\frac{UCL-(\mu_0+\delta_{M/C}\sigma_p)}{\sigma_p/\sqrt{n}}) - F(\frac{LCL-(\mu_0+\delta_{M/C}\sigma_p)}{\sigma_p/\sqrt{n}}) \quad (25)$$

$$\beta_{E}=F(\frac{UCL-(\mu_0+\delta_{E}\sigma_p)}{\sigma_p/\sqrt{n}}) - F(\frac{LCL-(\mu_0+\delta_{E}\sigma_p)}{\sigma_p/\sqrt{n}}) \quad (26)$$

Where F is the indicator and the standard normal cumulative distribution function. The equation 25 and 26 can be simplified as Equation 27 and 28:

$$\beta_{M/C}=F(k-\delta_{M/C}\sqrt{n})\ -F(-k-\delta_{\frac{M}{C}}\sqrt{n}) \quad (27)$$

$$\beta_{E}=F(k-\delta_{E}\sqrt{n})\ -F(-k-\delta_{E}\sqrt{n}\ ) \quad (28)$$

For an n sample, the time is equal to n. T_s to analyze the samples and the graph result, where T_s is the sampling time. The expected time is out of control from the occurrence of a specific reason until the process. As described in Equation 29:

$$[\ (h+\ n.T_s)\times(ARL2_{M/c}\times{}^{\lambda_2}/_{\lambda}+ARL2_E\ \times{}^{\lambda_1}/_{\lambda}\ )]-\tau \quad (29)$$

Failure rate due to external and environmental reasons: λ_1

Breakdown rate due to machine depreciation: λ_2

The authors suppose that T_1 is the expected time to find specific a cause and $E[T_{restore}]$ is the expected time to restore the process to the first state due to external reasons or machine failure in an out-of-control state. A specific cause is searched for restoring the process. It depends on the type of error that occurred. For example, the process may have problems due to machine depreciation or external and environmental reasons. ($E[T_{restore}]$) is the expected time for return or repair. As described in Equation 30::

$$E[T_{restore}]=(T_{resetting}\times{}^{\lambda_1}/_{\lambda}+MT_{CM}\times{}^{\lambda_2}/_{\lambda} \quad (30)$$

Therefore, the time of a period becomes Equation 31:

$$E[T_{Cycle}]=[(\ h+n.T_s)\times(ARL2_{M/c}\times{}^{\lambda_2}/_{\lambda}+ARL2_E\ \times{}^{\lambda_1}/_{\lambda}\ )]\ -\tau+T_1+E[T_{restore}] \quad (31)$$

3.3. Process and machine failure rate

A model for integrating and consolidating maintenance repairs and quality control has been presented. Now, the relationship between these two issues should be addressed. Maintenance, repairs, and quality control relationships can be related, and the total cost function can be integrated. Therefore, these two issues can be related to the objective function by obtaining a mathematical relationship for the process failure rate (λ). In this research, machine breakdowns are considered in two ways. One type is that the machine's performance is gradually depreciated, and the other is immediately affected. The probability of machine breakdowns is taken from previous information. Similarly, the process may fail due to machine wear or external and environmental reasons. The failure rate is supposed to be due to the machine's depreciation (λ_2), erosion, and external and ecological reasons (λ_1). Therefore, the failure rate of the process (λ) will be the sum of the failure rate due to the machine's wear and tear and the

failure rate due to external and environmental reasons (Equation 32).

$$\lambda = \lambda_1 + \lambda_2 \quad (32)$$

The authors consider the breakdown rate due to machine tear as Equation 33:

$$\lambda_1 = \frac{1}{prd_E}(N_f) \quad (33)$$

And the failure rate will be determined due to external and environmental reasons:

$$\lambda_2 = \frac{1}{MTTF} \quad (34)$$

Where MTTF is the mean time between failures. N_f and MTTF are calculated based on the data for each problem. The MTTF will be calculated by the data of each problem, information about the time intervals of maintenance operations and preventive repairs, and the number of failures occurring between intervals. Obtaining $\mathbf{N_f}$ is the number of failures analytically and accurately for a short impossible planning period. Different ways and models have been proposed to do this, but they have often been time-consuming and complicated. $\mathbf{N_f}$ is known as t_{PM} function. The regression approximation method is used. The authors obtain according to the equation 35 an approximate amount by having the time intervals of preventive maintenance and repairs and the number of breakdowns in each interval in different intervals of a period.

$$N_f = \text{a } (t_{PM})^b \quad (35)$$

N_f and t_{PM} are predicted by regression, and the values a and b. To solve the mathematical model derived from the SCA, the authors employed a Genetic Algorithm (GA), a widely used meta-heuristic optimization technique suitable for addressing complex, multi-objective problems. GA was chosen for its robustness in exploring large solution spaces and its ability to find near-optimal solutions efficiently through evolutionary processes, such as selection, crossover, and mutation. The algorithm was configured to optimize decision variables—including production scheduling parameters, preventive maintenance intervals, and quality control thresholds—to minimize the total cost and enhance overall supply chain performance.

4. Implementing and results

Recently, the use of integrated models compared to independent models has attracted the attention of many researchers. Researchers engage in integrated and consolidated modeling by studying and examining the characteristics of different subjects because this type of modeling has shown better results than independent modeling of subjects. The critical point is whether

the proposed model will be more efficient and suitable than the independent model. Based on this, the integrated model is compared with two independent models of maintenance and repairs and quality control, and using a numerical example in both models will determine which model provides a better answer. For this purpose, the authors must first analyze the problem into two independent models of quality control and maintenance and repairs and then compare the performance of two integrated and independent models with a numerical example to see which model will provide a more optimal solution. Article model is specifically designed to address the critical areas of maintenance and repairs within a system. The primary goal is establishing an optimal time interval for implementing preventive maintenance and repairs directly influenced by the associated costs.

In this model, quality control is not considered. The possibility that the quality of the produced products may decrease is ignored. Therefore, the cost of maintenance and corrective repairs is considered in Equation 36:

$$C_{CM}=[MT_{CM}.\ [\mathrm{PR}.C_{lp}+\mathrm{LC}]+C_{FCCM}]\times N_f \tag{36}$$

Also, the cost of preventive maintenance and repairs is according to equation 37.

$$\mathrm{C_{PM}}=[\mathrm{MT_{PM}}.\ [\mathrm{PR}.\mathrm{C_{lp}}+\mathrm{LC}]+\mathrm{C_{FCPM}}]\times\frac{\mathrm{prd_E}}{\mathrm{t_{PM}}} \tag{37}$$

The cost of maintenance and repairs in a planned period will be the total cost of corrective and preventive maintenance and repairs (Equation 38).

$$\mathrm{C_{MP}}=\frac{1}{\mathrm{prd_E}}(\mathrm{C_{CM}}+\mathrm{C_{PM}}) \tag{38}$$

The optimal time interval for preventive maintenance and repairs ($\mathrm{t_{PM}}$) is obtained by minimization of C_{MP}. In this model, only the aspect of quality control in the existing system is considered, and maintenance and repairs are ignored. Therefore, the model has a different period. That is $\mathrm{E}[T_{cycle}]$ changes to compare to the integrated model. The reason for these changes is apparent. In this model, the issue of machine tear and breakdowns related to the machine requiring repairs is no longer discussed, and the breakdown rate depends only on external and environmental reasons. If the issue of machine maintenance and repairs is not considered, the only things that affect the quality of the produced products are external and environmental factors. The length of the period obtained in the quality control model is almost similar to the size of the period in the integrated model. The failure rate is only specific to

external and environmental factors, which is shown by λ_E.So the length of the period in the quality control model is according to Equation 39:

$$E[T_{cycle}]_{SPC}={}^{1}/_{\lambda_E}+[(h+nT_S)\ \times(ARL2)_E]\ -\tau+T_1+T_{reset} \tag{39}$$

The cost function of quality control is equation 41 considering maintenance and repairs.

$$C_{SPC}=\frac{(C_F+C_V.n).({}^{1}/_{\lambda_E}+T_0\times\frac{S}{ARL_1})+[h\times(ARL2)_E]-\tau+nT_S}{h}+(\alpha.\ PR.C_{Rej}).({}^{1}/_{\lambda_E}+(PR\times\frac{(R_\delta)_E}{1-\beta_E}\times C_{Rej}).\ (h.\ (ARL2)_E)-\tau+nT_S+(C_{resetting}\times T_{resetting}) \tag{41}$$

Therefore, the total cost of quality control per time unit is according to Equation 42:

$$CPUT_{SPC}=\frac{C_{SPC}}{E[T_{cycle}]_{SPC}} \tag{42}$$

4.1. Numerical data

This part implements a numerical example of the model to obtain optimal decision variables. First, a single-component device is considered part of a single-machine system. Let's assume the machine works three seven-hour shifts six days a week. The time for preventive maintenance and repairs is 7 times units, and the time for maintenance and corrective repairs is 12 times. Suppose the process is under control. The value of the parameters of the given problem is shown in Table 3.

Table 15. The value of the parameters of the given problem

Data	C_v	C_F	$T_{resetting}$	T_1	T_0	T_s	$\delta_{M/C}$	δ_E
value	50	100	2	1	1	$\frac{20}{60}$	0.6	1.5
data	PR	C_{reset}	LC	C_{Lp}	C_{FCPM}	C_{FCCM}	$C_{false-Alare}$	C_{Rej}
value	10	5000	500	400	1000	10000	1200	2500

Based on the data related to the problem, the authors implement this data in our model, and the proposed model is solved using MATLAB 2021 software. The optimal variables were obtained as follows:

$(n^*, k^*, h^*, t_{PM}{}^*)=(11,1.90,5.8,643)$

$f^*(11.8,1.76,5.73,648)=112$

In this part of paper two increments of 10 and 20 percent for each of the data C_V, C_F C_{rej}, $T_{resetting}$, T_0, T_1, δ_E,$\delta_{M/C}$ are implemented.

Table 16. The amount of changes in some problem parameters at +(10%) and +(20%) levels

Data	First value	+(%10)	+(%20)
δ_E	1/5	1/65	1/8
$\delta_{M/C}$	0/6	0/66	0/72
T_0	1	1/1	1/2
T_1	1	1/1	1/2
$\mathrm{T}_{\mathrm{resetting}}$	2	2/2	2/4
C_{Rej}	2500	2750	3000
C_v	50	55	60
C_F	100	110	120

Table 17. The proposed method objective functions

Data	N	h	k	t_{pm}	$f(n,h,k,t_{pm})$
$\delta_E = 1/65$	11	7	1/90	653	118
$\delta_E = 1/8$	10	6	1/92	655/5	120/5
$\delta_{M/C} = 0/66$	12	8	1/85	654	119
$\delta_{M/C} = 0/72$	11	8	1/9	654	117
$T_0 = 1/1$	12	6	1/8	652	112
$T_0 = 1/2$	12	6	1/8	652	112
$T_1 = 1/1$	12	6	1/8	652	112
$T_1 = 1/2$	12	6	1/8	652	112
$\mathrm{T}_{\mathrm{resetting}} = 2/2$	12	6	1/95	651	113
$\mathrm{T}_{\mathrm{resetting}} = 2/2$	12	6	1/9	652	114
$C_{Rej} = 2750$	13	6	1/85	650	113
$C_{Rej} = 3000$	13	5/5	1/85	651	115
$C_F = 110$	12	6	1/8	652	112/5
$C_F = 120$	13	8	1/85	652	114/5
$C_v = 550$	11	9	1/8	651	113
$C_v = 600$	11	9	1/8	650	114

Table 4-5, shows that when δ_E and $\delta_{M/C}$ increase by 10 and 20 percent of the data. The values of the objective function and decision variables exhibit significant changes, yet our model remains largely unaffected by variations in other data. It underscores the critical importance of maintaining process control. Additionally, changes in the average standard deviation of the key qualitative characteristic are highly significant.

4.2. More analysis

Now, the question is raised: If the independent model is not used and the integrated model is not used, what difference will occur in the value of the optimal objective function? For this purpose, the data is put into the independent quality control cost function and solved by MATLAB software using GA. The result is as follows:

(n^*, k^*, h^*)=(11,3.44,9)

f^*(11 ,3.44 ,9) =359.8

As can be seen, the value of the cost function in the quality control department alone is higher than the total cost in the integrated model, where maintenance, repairs, and quality control are considered together. Monitoring the production equipment and machines is essential, considering the maintenance and repairs of a quality control model. The manufactured products are produced according to acceptable quality with the maintenance and repairs of the equipment and machines. Production of products with the expected quality reduces the costs related to quality control. In this model, implementing preventive maintenance and repairs reduces the number of out-of-control states in the system, resulting in a higher percentage of products within control limits. By optimizing the intervals for preventive maintenance, repairs, and quality parameters, the total cost function can be minimized. The example illustrates that this approach significantly lowers the cost function compared to scenarios where maintenance and repairs are neglected. Therefore, integrating preventive maintenance and repairs with quality control proves to be much more effective.

5. Discussion

This study underscores the significance of integrating production scheduling, maintenance strategies, and quality control within CLSC. By addressing the interconnectedness of these elements, the proposed model aims to achieve both cost efficiency and operational sustainability. Leveraging the SCA in tandem with mathematical modeling, the study navigates the complexities of real-world systems, particularly in the home appliances industry. Categorizing machine failures into two modes and utilizing a GA for optimization, the model provides a robust framework for decision-making that accounts for uncertainties and variable constraints. Integrating maintenance and quality control highlights the importance of managing interdependencies to minimize production downtime and enhance system reliability. Decision variables such as sample size, control limits, and maintenance intervals emerge as critical factors in balancing operational costs with system performance. Preventive and corrective maintenance integration reduces costs while aligning operations with sustainability objectives, positioning the model as a valuable tool for industries aiming for eco-friendly practices and long-term resilience. Managers can leverage the integrated model to establish cost-effective maintenance schedules and elevate product quality, improving customer satisfaction and reducing return rates. By embedding sustainability into the supply chain framework, organizations can bolster their competitive edge while adhering to eco-friendly practices. The model's adaptability, supported by its capacity to handle uncertainties, ensures its relevance

across diverse manufacturing contexts that demand precise quality and maintenance management. This discussion underscores the study's contribution to advancing supply chain strategies and offers actionable insights for optimizing operations.

6. Conclusion

The challenge of production scheduling has long been a critical focus for engineers and researchers, with considerable advancements aimed at optimizing the process. Scheduling in single-machine systems has emerged as a particularly significant subfield involving the precise allocation of resources to ensure production efficiency. Concurrently, preventive maintenance (PM) and corrective maintenance (CM) have gained prominence as researchers aim to determine the optimal timing for such activities to reduce costs and prevent operational disruptions. In parallel, quality control has become a central concern, ensuring that products meet expected standards and that the production system remains within control limits. When deviations occur, identifying root causes and implementing corrective measures becomes essential to restoring order and maintaining productivity.

Production managers are pivotal in aligning maintenance and quality control efforts to minimize costs and optimize system performance. The integration of these two aspects is critical, as failure to do so can lead to machine depreciation, increased product return rates, and customer dissatisfaction. Numerous models have been proposed to address these challenges, focusing on determining optimal intervals for maintenance and repairs while designing effective control charts to manage quality. These efforts aim to mitigate costs related to machine downtime, workforce repairs, and deviations from quality standards. The significance of these interconnected processes underscores the need for integrated approaches that consider the dependencies between maintenance and quality control rather than treating them in isolation.

Recent studies have highlighted the synergistic benefits of combining maintenance, repairs, production scheduling, and quality control into integrated models. Integrated approaches consistently outperform independent models by addressing the dependencies between these elements, resulting in reduced costs and improved operational outcomes. The model presented in this study exemplifies this integration, encompassing maintenance, repairs, and quality control in a unified system. By optimizing four key decision variables—sample size, sampling interval time, control limit coefficient, and preventive maintenance intervals—, the model minimizes total costs while maintaining high standards of reliability and quality reliability and quality standards. A comparative analysis with independent models demonstrated the

superiority of the integrated approach, with significant cost reductions validating its effectiveness.

Future research could explore extending the proposed integrated model to account for dynamic and stochastic variations in real-time production environments. Advanced technologies such as machine learning and IoT could enhance the model's adaptability, allowing for predictive maintenance and real-time quality monitoring. Additionally, the model could be applied to more complex, multi-machine systems and diverse industries to evaluate its scalability and versatility. Investigating the environmental and sustainability impacts of such integrations, particularly in closed-loop supply chains, could also yield valuable insights for industries aiming to align operational efficiency with eco-friendly practices. Future studies can further refine integrated models and provide comprehensive solutions for modern manufacturing challenges by addressing these areas.

Disclosure statement

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

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Journal of Systems Thinking in Practice
JSTINP, *QUARTERLY*
Homepage: jstinp.um.ac.ir
Online ISSN: 2821-1669, Print ISSN: 2980-9460
Research Article
DOI: 10.22067/JSTINP.2025.89938.1123
JSTINP 2025; Vol. 4, No. 1

A Reference Model of GaaP Readiness Indexes Using Systematic Review and Meta-Synthesis Method

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How to cite this article

Razavi, S. M., Balounejad Nouri, R., Kousari, S., Saghafi, F. 2025. A Reference Model of GaaP Readiness Indexes Using Systematic Review and Meta-Synthesis Method, *Journal of Systems Thinking in Practice*, *4*(1), pp.107-134. doi: 10.22067/jstinp.2025.89938.1123.

URL: https://jstinp.um.ac.ir/article_46230.html.

ABSTRACT

In the traditional way of governance, people pay taxes and receive services but do not participate in government. The government creates capacity as a platform so that people can innovate in a partnership ecosystem, and the content produced is considered a national asset. This study presents a reference model for the Government as a Platform readiness index. This is a qualitative study and a systematic review of the literature in which the meta-synthesis method is used to analyze and analyze the data extracted from selected sources. Finally, and 58 out of 961 sources are selected and used for qualitative analysis and coding in the systematic review process. The articles and research studies reviewed were extracted from major scientific databases, including Google Scholar, Scopus, and Web of Science, and cover the period from 2011 to 2023 to ensure the inclusion of the most recent and relevant findings. According to code classification, there are 75 indexes, including three categories, seven themes, 32 main codes, and 33 subcodes formed into four layers and categorized into the following categories: 1- creating a change mindset and being prepared for the change, 2- being prepared for innovation, 3- being prepared for economic growth. The present research, which analyses data from more than 30 countries, indicates that there is no agreed model around the world for the government as a platform readiness index. However, each of the governments in the world, with its specific components, such as digital transformation, digital culture, budget and credits, digital privacy, and the community's digital talent, formulates a custom model to realize its Government as a Platform. Since the current model comes from the combination of the available information in this field, it can be helpful and applicable as a reference model in any country of the world world country to initiate action.

Keywords

Government as a platform, Digital transformation, Good governance, Systematic review, Meta-synthesis method.

Article history

Received: 2024-09-25
Revised: 2025-01-06
Accepted: 2025-01-11
Published (Online): 2025-03-17

Number of Figures: 3 **Number of Tables: 3** **Number of Pages: 28** **Number of References:58**

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1. Introduction

Although some countries worldwide strive to realize and implement Government as a Platform (GaaP), a comprehensive reference model for this concept has not yet been developed. However, several studies have explored different definitions and conducted systematic reviews. For instance, (Cordella and Paletti, 2019) analyze the Italian GaaP initiative, emphasizing the importance of orchestrating GaaP characteristics to enhance coordination among public agencies and enable co-production of services with external actors, ultimately delivering more excellent public value. Similarly, (Styrin et al., 2022) highlight that GaaP has been advocated in several countries, with most research focusing on national-level collaboration. In the Russian Federation, the participation of regional and city authorities in the Gosuslugi.ru public service platform is prioritized to address regional disparities and improve efficiency. Furthermore, (Margetts and Naumann, 2017) examine the case of Estonia, where underlying data registries, information exchange systems, secure identification, and front-end portals form a robust platform for digital services, earning Estonia global recognition for digital government. Their study applies the seven principles of GaaP proposed by Tim O'Reilly—openness, simplicity, participation, learning from hackers, data mining, experimentation, and leading by example—to evaluate Estonia's success. Additionally, (Brown et al., 2017) The Platform Appraisal Framework (PAF) is proposed as an assessment tool to ensure consistency in GaaP initiatives. The authors apply this framework to the UK Government's platform initiatives over two distinct periods, 1999–2010 and 2010 onward, deriving practical insights into implementing platforms in the complex public sector environment.

One of the problems faced by countries, especially developing countries, is the failure of information technology projects in electronic government. This lack of success is due to the complexity, largeness, time consumption, and high cost of such projects (Mukhopadhyay et al., 2019). budget budget and capital has been spent and locked in such massive IT systems (Fujitsu, 2015). The reason for the emergence of this problem has been the existence of a silo view on the issue of transformation (Bracken, 2015). Being a silo of electronic government means that instead of creating a unique digital government in the country, modernization efforts have led to the creation of many silos within the government. Each of the silos has security flaws, inflated costs, and different user experiences. As a result, a labyrinth of databases and applications has been scattered at the level of government organizations, which are unable to or can hardly integrate and work together (Pope, 2019).

In the last decade, an idea and philosophy called Government as a Platform was proposed, which claims to be able to solve the mentioned issues. In this idea, instead of having unique and customized systems that cannot interact with each other, they can be replaced with small, suitable, and reorganizable parts (Copeland, 2016). The philosophy of Government as a Platform is based on the fact that the application of platform thinking can lead to a transformation in the government's approach to public services and, as a result, improve the quality of public services and, at the same time, reduce costs (Accenture, 2016). In line with the global efforts to realize the concept of Government as a Platform, examples of such initiatives can be observed in countries like India. For instance, India's Aadhaar authentication platform has successfully integrated services across government sectors for over one billion people. The Estonian government is devising new services for "life events", such as having children, that go beyond the boundaries of government agencies. They can do this because of the common intergovernmental data infrastructure they have built over the past decade. Common standard components in the UK, Italy, and Argentina solve public issues for the whole government (Pope, 2019).

Platform technologies can influence the services and relations of intergovernmental institutions (Styrin et al., 2022). Platforms build our digital infrastructure more than ever, and society increasingly relies on them (Srnicek, 2021). Government as a Platform provides a new path for greater citizen participation, which should be implemented from a governance perspective (Seo and Myeong, 2020). Government as a Platform allows citizens to benefit from user-friendly services while the government also benefits from increasing efficiency and reducing costs (Poliarus, 2022). In this case, instead of being the first initiator of a civil action, the government integrates people and empowers them (O'Reilly, 2011). This type of government presents a new paradigm, which is not the continuation of gradual improvement in the current government system (Pope, 2019). If governments want to be considered actors, they must first design a comprehensive platform approach centered on public values and collective goals (Van Dijck et al., 2018).

If each of the ministries covers the existing gap in the implementation of cooperation to optimize the processes, the Government as a Platform is achieved with more cooperation (Llanos Guillen, 2022), and the degree of its success depends on the desire of the government organizations to overcome the silos of their departments and this approach is a social and economic opportunity (Bharosa, 2022). To achieve this concept, all government officials should get used to applying Intelligent Information Technology (IIT) in their jobs (Seo and Myeong,

2022), and its implementation requires cooperation and coordination at the national level (Styrin et al., 2022).

In this research, the present study seeks to identify the readiness indexes and components of Government as a Platform. Existing research on platforms focuses on the modularity, openness, ecosystem leadership, and governance of the platforms, as well as on the impact of the platforms on government innovation, scale, and agility (Mukhopadhyay et al., 2019). The functions of implementing Government as a Platform include: improving the efficiency of public services, reducing silos, improving the evolution of public services, and facilitating coordination between government agencies (Cordella and Paletti, 2019). From another point of view, the elements required to implement this concept are an entrepreneurial culture, transformational leadership, open innovation, citizen participation, data transparency, and knowledge sharing (Kato, 2021). This government aims to develop efficient and user-friendly services by exploiting the platform principles, such as openness, modularization, and co-creation. However, success depends on the context and culture of a country (Kuhn, et al., 2022a).

Accordingly, by studying the experiences of more than 30 countries in the field of Government as a Platform, the current research attempts to provide a reference model of Government as a Platform readiness index. As a result, this research will seek to answer the question, "What are the Government as a Platform readiness indexes, and what is the Government as a Platform reference model?" In this article, the generality of the subject and the empirical literature are stated. Then, the research method, based on a systematic review, is described. Further, findings, model descriptions, and research results are presented.

In this research, the reference model for Government as a Platform readiness index is presented based on a systematic review and meta-synthesis research method. What distinguishes the current research is a meta-synthesis approach to the achievements of the leading countries in this field. Since there is no agreed model for the Government as a Platform readiness index worldwide, this model can be used as a basic model in different countries. Also, the findings of this research determined that each Government as a Platform readiness index has been extracted from the experiences of which country or countries.

2. Research literature

2.1. Theoretical background

In 2011, Tim O'Reilly proposed the concept of Government as a Platform for the first time. He referred to successful companies like Wikipedia, Amazon, and Google to explain how platform-

based organizations improve their services through customer behavior and feedback data. He believes this is also possible for the government and criticizes the old model of the government in which people pay taxes and receive services, but they do not contribute. Moreover, he believes that the government should create a capacity for the people to innovate in an ecosystem of participation. In this regard, the information produced by citizens or on their behalf is like blood for the economy and the country, and the government is responsible for treating it like a national asset (Brown et al., 2017). Government as a Platform seeks to answer two key questions: first, how to turn the government into an open platform so that people inside and outside the government can innovate, and second, how to design a system where the results (solutions) are not predetermined but formed in the interaction between the government and people (Brown et al., 2017).

As mentioned in the introduction, in recent years, some countries have gained experience from implementing Government as a Platform and obtained the components and requirements for its implementation.

Shami Zanjani (ShamiZanjani, 2022) says that governance means managing all management, that is, phenomena at the highest possible level. Digital governance is the highest level of decision-making about digital issues in the organization. Hassani (Hassani, 2023) considers platform governance as a concept that relates to the layers of governance relationships that structure the interactions between key parties in the current platform society. Digital transformation's role in realizing Government as a Platform is crucial. In this regard, Kane believes that companies must address three business issues if they are going to manage digital transformation effectively. These issues include navigating digital disruption, rethinking leadership and talent, and becoming a digital organization (Kane, 2019). In this regard, Venkatraman believes that for the Government as a Platform, the country country's ecosystems should be harmonized, and the government should be agile (Venkatraman, 2017). Al-Ani considers open governance to be one of the components and indexes of Government as a Platform (Al-Ani, 2017).

Government as a Platform allows coordination of various institutions to achieve a common goal (Bender and Heine, 2021). The overall concept of this government model focuses on using digital technologies to integrate different services. It is worth mentioning that a single platform coordinates the portfolio of public services. By that, the government provides a platform with powerful components to provide various services (Bender and Heine, 2022). This approach sees the government as an open platform where people inside and outside the government can

innovate and create better public services (Kuhn,et al., 2022b). The development of an intersectional electronic interaction system should be considered one of the introduction mechanisms of this concept (Olegovna, 2022).

When government processes become as transparent, responsive, flexible, user-friendly, and innovative as a platform that has good management and design, a great gift is offered to the country (Parker et al., 2017). In the government model of Government as a Platform, its role is brought to an irreducible core of essential and important infrastructure, allowing public and private developers to innovate based on it (Peña-López, 2020). According to Tim O'Reilly, just as companies like Google, Facebook, Apple, Amazon, and Microsoft establish rules and regulations to manage their platforms, appropriate laws should be established for the Government as a Platform, which is implemented to ensure the success of our society (Van Dijck et al., 2018).

Through Government as a Platform, the public sector realizes the well-known advantages of the platform economy (Bender and Heine, 2021). Additionally, for the implementation of Government as a Platform, the approaches of the private sector need to be transferred to the public sector, and the processes need to be continuously improved (Brown et al., 2017).

Web 3.0 is one of the requirements for the realization of Government as a Platform. Participation based on Web 3.0 technology, which encourages participation and has a participatory feature, is the basis of the design of Government as a Platform, and this idea is based on civil participation (Neverov, 2020). Accordingly, governments should actively mine new open data that can create added value for innovation. Governments must create an environment of easy collaboration with other stakeholders, especially non-governmental participants (Seo and Myeong, 2021).

2.2. Experimental background

In this research worldwide was reviewed based on meta-synthesis research.

As a result of the search for the two terms Government as a Platform and "Case Study" in Web of Science, Scopus, Elsevier (Science Direct), and Google Scholar databases found related studies from more than 30 countries. Among these studies, those related to Slovenia, Germany, America, England, Italy, Peru, Russia, Japan, Singapore, France, Finland, South Korea, Norway, India, Spain, Austria, Belgium, Ecuador, China, and South American countries (Argentina, Brazil, Bolivia, and Uruguay), which have described the experiences of Government as a Platform preparation in more detail, were selected.

Gil-Garcia et al., (2019) refer to the existence of different conceptualizations regarding Government as a Platform by researchers and executives and mention that this model of government can be the next stage in the digital government. They extract several features of Government as a Platform, including state-wide architecture, modularity, citizen-centered design, open participation, cooperation network, flexible cooperation model, programmability, open standards, and encouragement to experiment. Considering the limitations of their research, they examined the first three characteristics in England, America, and Australia. Mukhopadhyay et al., (2019) seeks to find the role of government platforms in solving the problem of efficiency in providing government services to the poor, especially the need to scale services given to a large population of these recipients in India, by introducing some features "through a case study", and investigated the role of the government platform in increasing the scalability of electronic services in the "Aadhar" authentication platform. Their findings show successful practical experiences. Mukherjee, (2013) compares technological platforms to the railway system: "Look, it's just like a railway platform. Various trains stop on the same railway platform. Each has different destinations, and people get on and off depending on where they go. Similarly, the state technology platform is a central place where various state governments, institutions, and citizens can unite. All government services are provided on this platform, and citizens can apply for all services provided on it".

The UK is a leader in implementing and realizing this concept. The UK government's Digital Services Centre explains: "It is thought that there is a simpler and easier way. The same public service but with a different design and presentation, an idea called Government as a Platform. This idea divides everything into smaller pieces, such as building blocks. Each block is responsible for an activity. Blocks can be easily connected, and the scale can be increased in case of increased demand. If part of the service delivery system breaks down, it can be easily repaired or upgraded. Also, platforms can be open so that the use of government data for third-party services is allowed" (Pope, 2019).

The Organization for Economic Co-operation and Development[2] (Peña-López, 2020) has outlined models of Government as a Platform in several countries of the world according to Table 1, identifying several important issues that can be explored through Government as a Platform thinking. This shows that an ecosystem of service teams to meet needs (Model 1)

[2] OECD

 DOI: 10.22067/JSTINP.2025.89938.1123

provides the foundations that can facilitate the creation of a market for public services (Model 2) and a way to rethink the relationship between citizens and state (Model 3).

Table 18. Examples of elements in a government as a platform ecosystem

Problem solved by a government as a platform ecosystem	Government as a platform model	Country example
Transforming procurement to improve supplier relations	1	Digital Outcomes and Specialists Framework, United Kingdom
Training and equipping of in-house capability	1	Canada School of Public Service Digital Academy, Canada; Academia Digital, Chile; Digital Academy,-United Kingdom
Internal tools for civil servant users such as authentication	1	GOV.UK Signon, United Kingdom
Standards and controls for spending	1	Spend controls model: Denmark, Norway, Portugal,-United Kingdom
Guidance on "what good looks like"	1, 2	Arquitectura TI, Colombia; Service Manual, United Kingdom
Reusable common components that respond to common user needs	1, 2	Digital Identity: Austria, Canada, Denmark, Estonia, Italy, Korea, Norway, Portugal, Spain, United Kingdom,-Uruguay Digital Mailbox and notifications: Australia, Canada, Denmark, Norway, United Kingdom Hosting: United Kingdom, United States Payments, Italy, United Kingdom
Reusable designs and patterns that respond to common needs	1, 2	Design systems: Argentina, Australia, Brazil, Canada, Singapore, United Kingdom, United States
Standards and controls for spending	1, 2	Spend controls model: Denmark, Norway, Portugal,-United Kingdom
Standards for ensuring the design of services	1, 2	Service standards: Australia, Canada, Germany, New Zealand, Singapore, United Kingdom
Standards for technology	1, 2	Secure Cloud Strategy, Australia; Open Source Contribution Policy, France; IT Architecture Principles,-Norway; Technology Code of Practice, United Kingdom
Canonical, discoverable data	1, 2	Public registers: Denmark, Italy, Norway,-Sweden
Standards for publishing and handling data	1, 2	Standards on APIs, Canada; Common Public Digital- Architecture, Denmark
Cross-governmental networks for delivering services that avoid silos of delivery	1, 2, 3	Service communities, United Kingdom
Interoperability of data	1, 2, 3	X-road, Estonia; TRAY, Slovenia
Transparency of access to personal data and effective models of citizen consent for their reuse	1, 2, 3	NemID, Denmark; Carpeta Ciudadana, Spain

Very few countries have proposed that governments could create centralized add-ons to implement sector-specific infrastructure or platforms. Estonia is often highlighted as a leading example of a government prepared to establish its platform community Margetts and Naumann, 2017). A literature review reveals that while numerous studies have explored the characteristics and requirements of Government as a Platform (Yakhchali et al., 2020), there is still a lack of a

comprehensive reference model specifically aimed at evaluating governments' readiness to adopt this concept. This study aims to fill this gap by proposing a conceptual framework to assist governments in assessing their readiness.

A reference model for Government as a Platform readiness indexes index is provided hereinafter using the meta-synthesis research method.

3. Research method

This research is a fundamental study using a qualitative method based on a systematic review of the literature using a meta-synthesis approach. Library and documentary study methods were used to gather information, and appropriate resources were refined and selected through a systematic review of the literature. Finally, by analyzing data using the meta-synthesis and coding method, a reference model was obtained and formulated.

Meta-synthesis is a type of qualitative study that examines information and findings extracted from other qualitative studies related to the subject and provides a systematic approach for researchers to explore new topics. Therefore, meta-synthesis is an exploratory research method for creating and extracting a common reference framework for previous studies' results that combines separate qualitative research projects by translation and synthesis processes at an abstract level. In other words, meta-synthesis is the process of searching, evaluating, combining, and interpreting qualitative studies in specific contexts (Ludvigsen et al., 2016). The most common method of meta-synthesis is the seven-stage model of Sandelowski and Barroso (Sandelowski et al., 2007), which is used in this research (Fig. 1). The research findings are presented here based on the steps of the meta-synthesis method.

Figure 48. Successive steps of the meta-synthesis method (Ludvigsen et al., 2016)

Step one – Setting the research question: The parameters of what, who, or the studied community and the timeframe were used to set the research question according to Table 2. The timescale was chosen from 2011 to 2023 because research on Government as a Platform began in 2011.

Table 19. *Setting the research question*

Components of the Question	Answer to Question
Studied Community	All fields, branches, and research and scientific fields in the Web of Science, Scopus, Elsevier (Science Direct), and Google Scholar databases on GaaP related to more than 30 countries around the world, as well as related theses and book chapters.
Timeframe	From 2011 To 2023

Step two—Systematic background review: In this step, the authors systematically searched articles and books that included related keywords.

Systematic review research is mainly used to combine initial research and create an image of the existing knowledge on a specific topic, as well as to find differences and variations in the results of various studies and explain the reasons for these differences. A critical issue in a systematic review is comprehensiveness and ensuring proper resource coverage. To analyze and summarize the research results for the combination of qualitative data, meta-synthesis can be used.

This study, based on the problem and the objective set, seeks to answer the following questions:

1. What are the Government as a Platform readiness index?
2. What is the Government as a Platform readiness reference model?

Step three - Searching and selecting appropriate articles: in the identification stage, to realize search comprehensiveness regarding Government as a Platform readiness indexes, efforts are made to consider a broader scope of the search resources (databases) so that most digital libraries and online databases are used. Thus, Scopus, Web of Science, and EBSCO indexing databases and JSTOR, Elsevier, Wiley, Sage, Springer, and Proquest databases were searched. Moreover, articles and books published in the last two years were identified and collected using manual Google Search and automatic Researchgate and Google Scholar notifications by searching “Government as a Platform”. Then, the researcher saved and categorized the results as an Endnote library.

Since the concept of Government as a Platform was first proposed in 2011, the results of searches related to the period from 2011 to 2023 were examined. It should be noted that most of the articles that focused on the Government as a Platform as a case study in one or more countries were published in 2020, 2021, and 2022. In this step, 961 sources were identified and recorded.

The process of evaluating and selecting from the resources collected in Endnote software and the resources obtained from searching databases were screened in several stages. In the screening stage, duplicated search results in each database were removed from Endnote library

and the results of previously searched databases. Resources that could not be evaluated and used in later stages due to the lack of access to their full text were also removed. In addition to English articles in Korean, Chinese, Portuguese, German, Russian, and Italian were also used. The identified sources were reduced to 306 after the screening stage, shown in Fig. 2 inspired by (Moher et al., 2009).

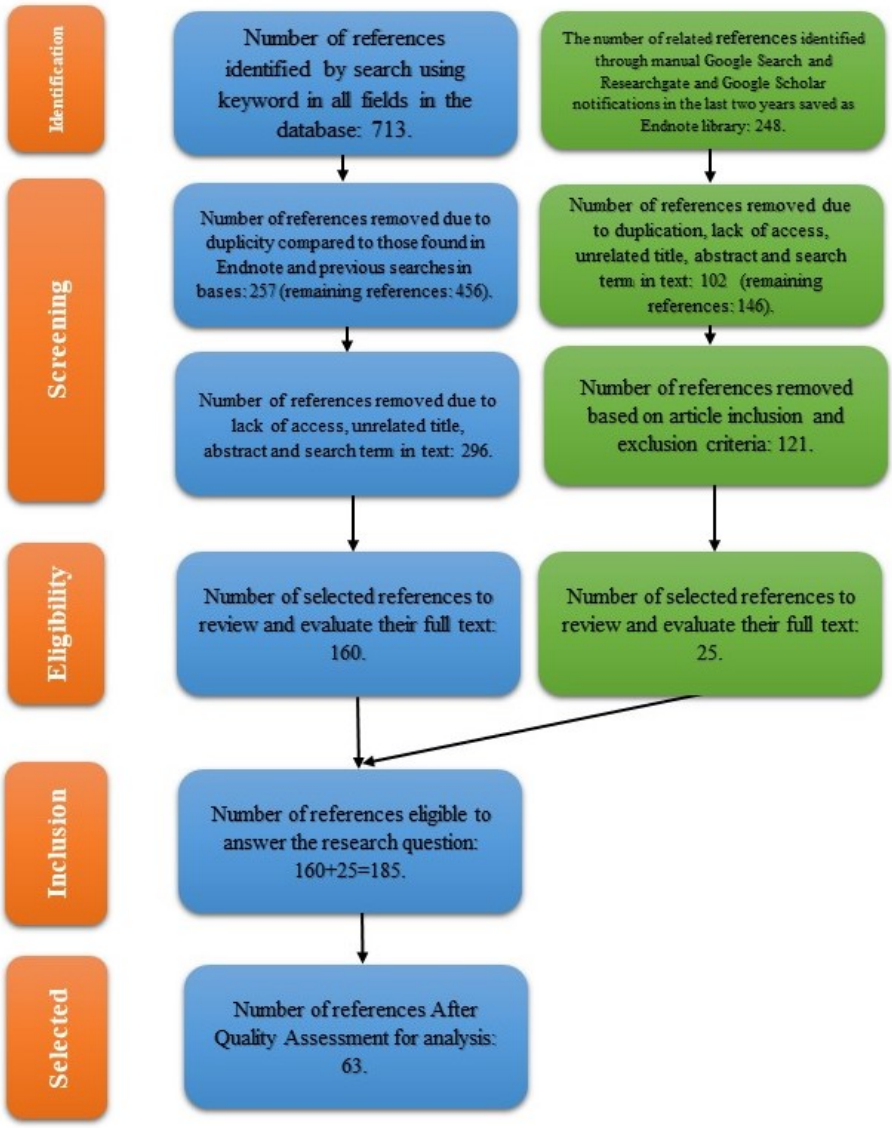

Figure 49. Information flow of the systematic review process

In the eligibility (inclusion) stage, the full text of the sources selected in the screening stage was reviewed, and several sources, especially those unrelated to the research question, were removed due to non-compliance with the inclusion criteria. At this point, the number of resources was reduced to 185.

In the final stage of the systematic review, the following quality assessment indexes were considered:

- Database validity (indexed in authoritative databases),
- Credibility of the publisher's journal (CS and IF) and number of references (citation) to articles,
- Author and publisher credit for the book,
- The credibility of the international institution or organization about official and international reports,
- The university's credibility about theses, and
- Clarification or assignment of the subject to a case study of the Government as a Platform.

The information required for quality assessment in data mining tables in Excel was individually entered and recorded for each resource and scored at three levels[3]: good, average, and poor. Consequently, among 185 sources that were deemed eligible based on inclusion criteria, 58 were finally selected and used for qualitative analysis and coding.

The selected sources[4] include 32 journal articles with high citations published in prestigious international journals with high impact factor, nine books by leading researchers in this field,

[3] The sources were selected based on the following criteria:

1. Relevance to the research topic: Sources that are directly related to the concept of Government as a Platform and governments' readiness in this domain.
2. Scientific quality and credibility: Sources that were scientifically reliable and published in reputable journals and specialized conferences, offering comprehensive and thorough content for analysis and coding.
3. Methodological rigor: Sources that employ valid research methodologies for data collection and analysis.

After evaluating these criteria, 58 out of 185 eligible references were selected for analysis and coding.

[4] The selected references were taken from the following databases:

- ScienceDirect: For scientific articles published in reputable journals.
- SpringerLink: Including articles and books published by reputable publishers.
- Wiley Online Library: For credible articles across various scientific disciplines.
- Google Scholar: To identify and evaluate highly cited and credible articles.
- JSTOR: For access to scholarly articles and reputable journals.
- IEEE Xplore: For articles and proceedings from international conferences in the fields of technology and e-government.

six theses from prestigious universities, seven papers published in prestigious conferences in the field of e-government, and four official and international reports including reports from the Organization for Economic Co-operation and Development (OECD), international companies, such as Fujitsu and Accenture, and reports from national institutions of the United Kingdom (the list of references is given in the bibliography).

Step four - Extracting the results: Following the transcription methodology, selected articles were studied to achieve relevant content. Due to the focus of the research question on "identifying Government as a Platform readiness index", the mentioned features were extracted from the text of the articles. Open coding means assigning code to sentences, creating concepts from the combination of codes, and forming categories and themes from the combination of concepts to obtain a general and macro image of the concept under study. This study transferred selected sources (58) to MaxQDA Analytics Pro 2020 to extract, analyze, and combine content data. First, each source's sentences and phrases related to the research question were selected, and each was encoded. These codes were gradually modified and optimized after being categorized and combined over several stages, and the research concepts were formed. Typically, research groups conduct systematic review research, and resource assessment and data extraction are performed in the interaction between research team members. The results are compared, and disagreements are resolved through discussion.Therefore, in this research, the research team members discussed and reviewed all stages, from resource review and screening to code extraction and analysis of the findings. They agreed on them and approved the processes that were undertaken. In the coding process, hundreds of codes were extracted, and during the analysis process, several codes were deleted, combined, or separated, and eventually, 670 extracted codes were verified. After classifying and aggregating the codes, 75 concepts were formed. The reference model of the Government as a Platform readiness index was further classified by gender index was further classified by gender, as shown in Fig. 3. This model was derived from MaxQDA Analytics Pro 2020.

Step five - Analysis and integration of research findings: In meta-synthesis methodology, topics that have emerged in studies on meta-synthesis are searched. To do this, the themes or topics are first identified, and then a thematic classification is formed, and then similar themes are placed under the topic or category that describes it in the best possible way (Ludvigsen et al., 2016).

Step six - Quality control: Validation of meta-synthesis qualitative studies can be done in two ways: first, using the opinion of experts to correct and confirm the findings, and second,

presenting the final results of studying the theoretical foundation (Campbell et al., 2012). This study used the first method to confirm the research achievements. To assess the foundations of the research, Cohen's kappa coefficient (Ludvigsen et al., 2016) was calculated (0.72), and the above agreement between the two coders and the acceptable reliability was confirmed. After obtaining the validation results, interviews were conducted with 15 experts in digital transformation and e-government fields. The basis for the selection was the availability of the experts in question, the ability to write authoritative articles in the field of research for university professors, and the availability of suitable management backgrounds for managers.

Step seven—Presentation of findings: Based on concepts, similar codes were categorized into a single concept (research themes), and finally, by combining the themes, categories were extracted (Table 3).

Table 20. GaaP readiness indexes according to the countries under study

No	GaaP Readiness Index	References
1	Good Governance	Margetts and Naumann (2017), Peters and Billert (2021), Mukhopadhyay et al. (2019), Cordella and Paletti (2019), Neverov (2020), Smorgunov (2021), Olegovna (2022)
2	Citizenship Rights	Peña-López (2020), Gil-Garcia et al. (2019), Brown et al. (2017), Margetts and Naumann (2017), Poliarus (2022), Cordella and Paletti, 2019., Peters and Billert (2021), Kuhn et al. (2022a), Styrin et al. (2022), Neverov (2021), Kato (2021), D'Silva and Norway (2018), Chung (2017), Seo and Myeong (2021) , Linders (2012), Mergel et al. (2018)
3	Political Stability	Neverov (2021), Geliskhanov Islam et al. (2018), Mergel et al. (2018)
4	Responsible Government	Styrin et al. (2022)
5	Rise of Public Value	Cordella and Paletti (2019), Neverov (2020), Smorgunov (2021)
6	Justice in Distribution	Neverov (2020), Geliskhanov Islam et al. (2018), Styrin et al. (2022)
7	Rule of Law	Margetts and Naumann (2017), Neverov (2020), D'Silva and Norway (2018), Llanos Guillen (2022), Styrin et al. (2022), Bharosa (2022), Seo and Myeong (2022), Mergel et al. (2018), Peters and Billert (2021)
8	Citizens' Interaction with the Government	Peña-López (2020), Neverov (2021), Kato (2021), Kuhn et al. (2022b), D'Silva and Norway (2018), Styrin et al. (2022), Seo and Myeong (2021) , Seo and Myeong (2020) , Linders (2012), Gil-Garcia et al. (2019)
9	Explanation of Procedures and Rules	Bender and Heine (2021), Cordella and Paletti (2019), Neverov (2020), D'Silva and Norway (2018), Bharosa (2022), Seo and Myeong (2021), Gil-Garcia et al. (2019)
10	Identifying the Needs of Citizens	Peña-López (2020), Kuhn et al. (2022b), Cordella and Paletti (2019), Neverov (2020), Llanos Guillen (2022), Geliskhanov Islam et al. (2018), Styrin et al. (2022), Gil-Garcia et al. (2019), Seo and Myeong (2021)
11	Citizen-Centric Design	Gil-Garcia et al. (2019), Al-Ani (2017), Kuhn et al. (2022b), D'Silva and Norway (2018), Llanos Guillen (2022), Linders (2012), Peña-López (2020)
12	Predicting People's Expectations	Gil-Garcia et al. (2019)
13	Digital Literacy	Margetts and Naumann (2017), Kuhn et al. (2022b), D'Silva and Norway (2018)
14	Sharing Successes	Peters and Billert (2021), Cordella and Paletti (2019), Neverov (2020), Seo and Myeong (2020), Bender and Heine (2021)
15	Portal Content Creation	Margetts and Naumann (2017), Peña-López (2020), Boschetti (2022)
16	The Government Shifting Paradigm from Service Provider to Ecosystem Leadership	Boschetti (2022), Brown et al. (2017), Reponen (2017), Mukhopadhyay et al. (2019), Cordella and Paletti (2019), Kato (2021)
17	The Pervasiveness of New Technologies	Peña-López (2020), Al-Ani (2017), D'Silva and Norway (2018), Llanos Guillen (2022), Seo and Myeong (2020), Neverov (2021)
18	Minimal Government Management	Neverov (2020)

No	GaaP Readiness Index	References
19	Platform Ecosystem	Peña-López (2020), Bender and Heine (2021), Neverov (2020), Cordella and Paletti (2019), Mukhopadhyay et al. (2019), Kuhn et al. (2022b), Reponen (2017), D'Silva and Norway (2018), Styrin et al. (2022), Bharosa (2022), Seo and Myeong (2021), Seo and Myeong (2020), Margetts and Naumann (2017)
20	Existing Comprehensive Approach to the Concept of GaaP in Government	Peña-López (2020), Gil-Garcia et al. (2019), Chaobing and Tian (2022), Margetts and Naumann (2017) , Kuhn et al. (2022b), Mukhopadhyay et al. (2019), Cordella and Paletti (2019), D'Silva and Norway (2018), Chung (2017), Trček (2022), Mergel et al. (2018), Bender and Heine (2022), Bender and Heine (2021)
21	Architectural Principles of Information Technology	Gil-Garcia et al. (2019), Kollara (2017), Mergel et al. (2018), Peña-López (2020)
22	Compatibility of Government Platforms	Styrin et al. (2022)
23	Modular Government (Modular Architecture)	Cordella and Paletti (2019), D'Silva and Norway (2018), Mukhopadhyay et al. (2019), Styrin et al. (2022), Mergel et al. (2018), Chaobing and Tian (2022)
24	Single Platform for the Provision of Services	Gil-Garcia et al. (2019), Boschetti (2022), Cordella and Paletti (2019), Kollara (2017), Styrin et al. (2022), Seo (2021), Chung (2017), Trček (2022), Bender and Heine (2021)
25	Decentralized Governance	Neverov (2020), D'Silva and Norway (2018), Bender and Heine (2021), Seo (2021), Bharosa (2022), Styrin et al. (2022)
26	The Approach of Federal Governments	Styrin et al. (2022), Bender and Heine (2021)
27	Top-Down Platform Model	Brown et al. (2017), Styrin et al. (2022), Neverov (2020)
28	Nurturing th Entrepreneurial and Startup Community	Peña-López (2020), Al-Ani (2017), Peters and Billert (2021), Kuhn et al. (2022b), Reponen (2017), Seo and Myeong (2021), Seo and Myeong (2020), Cordella and Paletti (2019), Kollara (2017)
29	Digital Talent	Kollara (2017), Kuhn et al. (2022b)
30	Elite and Expert Human Resources	Peña-López (2020), Kollara (2017), Kuhn et al. (2022b), Brown et al. (2017)
31	Education of Citizens	Peña-López (2020), Kollara (2017), Seo and Myeong (2020), D'Silva and Norway (2018), Al-Ani (2017)
32	Transformative Leaders in Organizations	Kato (2021)
33	Integrating the Information Systems of Organizations	Jeannot (2020), Peña-López (2020), Neverov (2020), Mergel et al. (2018), Bender and Heine (2021), Seo and Myeong (2021), Seo and Myeong (2020), Cordella and Paletti (2019)
34	Government Sponsorship	D'Silva and Norway (2018), Kollara (2017)
35	Budget and Investment	Cordella and Paletti (2019), Neverov (2020), Bharosa (2022), Gil-Garcia et al. (2019), Peña-López (2020), D'Silva and Norway (2018)
36	Knowledge Management	Bender and Heine (2021), McBride (2017), Reponen (2017), Margetts and Naumann (2017), Kuhn et al. (2022b), Kato (2021), Neverov (2020), Peña-López (2020), D'Silva and Norway (2018), Seo (2021), Styrin et al. (2022), Seo and Myeong (2021), Bender and Heine (2021), Gil-Garcia et al. (2019) , Mergel et al. (2018), Brown et al. (2017)
37	Modeling of Private Sector Platforms	Bender and Heine (2021), McBride (2017), Reponen (2017), Seo and Myeong (2020), Neverov (2020), Bender and Heine (2022), Mergel et al. (2018), Gil-Garcia et al. (2019),
38	Stakeholder Experiences	Seo and Myeong (2021), Seo (2021)
39	Digital Trust	Peña-López (2020), Bharosa (2022) D'Silva and Norway (2018), Mukhopadhyay et al. (2019), Kollara (2017)
40	Development of Digital Government Infrastructure	Peña-López (2020), Boschetti (2022), Peters and Billert (2021), D'Silva and Norway (2018), Llanos Guillen (2022), Geliskhanov Islam et al. (2018), Bharosa (2022), Seo and Myeong (2021), Styrin et al. (2022), Kollara (2017)
41	Cyber Security	Peña-López (2020), D'Silva and Norway (2018) , Kollara (2017)
42	Web 3.0 Technologies	Neverov (2021)
43	Security of Information	Peña-López (2020), Mukhopadhyay et al. (2019) , D'Silva and Norway (2018)
44	Digital Privacy	Mukhopadhyay et al. (2019), Peña-López (2020), D'Silva and Norway (2018)
45	Blockchain	Viano et al. (2022), Geliskhanov Islam et al. (2018)
46	Electronic Authentication	Kollara (2017), Peña-López (2020), Mukhopadhyay et al. (2019) , Gil-Garcia et al. (2019)
47	Providing Growth and Development in the Community	Bender and Heine (2021), Bharosa (2022) , Bender and Heine (2022), Trček (2022), Smorgunov (2021), Neverov (2020) , Geliskhanov Islam et al. (2018), Al-Ani (2017)
48	Inter-Organizational Networks	Peña-López (2020), Jeannot (2020), Cordella and Paletti (2019), Llanos Guillen (2022), Styrin et al. (2022), D'Silva and Norway (2018), Kollara (2017), Bharosa (2022), Bender

No	GaaP Readiness Index	References
		and Heine (2022), Mergel et al. (2018), Reponen (2017)
49	Data-Driven Governance	Peña-López (2020), Seo and Myeong (2020)
50	Data Collaboration and Interaction	Mergel et al. (2018), Peña-López (2020)
51	Participation of all Ministries at the National Level	Cordella and Paletti (2019), Reponen (2017), Peña-López (2020), D'Silva and Norway (2018), Llanos Guillen (2022), Styrin et al. (2022), Bender and Heine (2022, 2021)
52	The Existence of Development Thinking in the Government	Reponen (2017), Cordella and Paletti (2019), Neverov (2020), D'Silva and Norway (2018), Styrin et al. (2022), Mergel et al. (2018), Peña-López (2020)
53	Model of Continuous Improvement in Governance	Gil-Garcia et al. (2019)
54	Cooperation with International Organizations	Peña-López (2020)
55	Digital Transformation	Brown et al. (2017), Reponen (2017), Kuhn et al. (2022b), Kuhn et al. (2022a), Peters and Billert (2021), Mukhopadhyay et al. (2019), Llanos Guillen (2022), Cordella and Paletti (2019), Kato (2021), Neverov (2020), Geliskhanov Islam et al. (2018), Bharosa (2022), Mergel et al. (2018), Peña-López (2020)
56	Moving from e-Government to Platform Government	Smorgunov (2021), Chung (2017)
57	Agile Organizations	Mukhopadhyay et al. (2019), D'Silva and Norway (2018), Styrin et al. (2022), Seo and Myeong (2020), Mergel et al. (2018), Cordella and Paletti (2019)
58	Open Data	Kato (2021), Seo and Myeong (2021), Seo and Myeong (2020), Mergel et al. (2018), Neverov (2020)
59	Optimizing the Processes of Government	Kollara (2017), Boschetti (2022), Peters and Billert (2021) , Kuhn et al. (2022b), D'Silva and Norway (2018), Neverov (2020), Llanos Guillen (2022), Styrin et al. (2022), Peña-López (2020), Seo and Myeong (2020), Reponen (2017)
60	Digital Culture	Eom and Lee (2022), Mergel et al. (2018), Seo and Myeong (2020)
61	Human-Technology Interaction	Neverov (2020), Geliskhanov Islam et al. (2018)
62	Open Government and the Smashing of Silos	Peña-López (2020), Al-Ani (2017), Kollara (2017), Reponen (2017), McBride (2017), Jeannot (2020), Peters and Billert (2021), Cordella and Paletti (2019), D'Silva and Norway (2018), Kato (2021), Bharosa (2022), Trček (2022), Seo (2021), Seo and Myeong (2020), Seo and Myeong (2021), Mergel et al. (2018), Chaobing and Tian (2022)
63	Preferring Audacity Over Caution	Mergel et al. (2018)
64	Inter-Organizational Collaborations	Zeng et al (2023), Reponen (2017), Kuhn et al. (2022b) , Jeannot (2020), Cordella and Paletti (2019), D'Silva and Norway (2018), Llanos Guillen (2022), Bender and Heine (2022), Eom and Lee (2022), Mergel et al. (2018), McBride (2017)
65	Big Data Management	Peña-López (2020), Margetts and Naumann (2017), McBride (2017), Peters and Billert (2021) , Geliskhanov Islam et al. (2018), Trček (2022), Chaobing and Tian (2022)
66	Creating an Open Mindset of Change and Innovation	Zeng et al (2023), Kuhn et al. (2022b), Peters and Billert (2021), Jeannot (2020), Mukhopadhyay et al. (2019), Cordella and Paletti (2019), Kato (2021), Seo and Myeong (2020) , Margetts and Naumann (2017)
67	Participatory Governance	Zeng et al (2023), D'Silva and Norway (2018), Styrin et al. (2022), Bharosa (2022), Trček (2022), Seo (2021), Seo and Myeong (2020), Seo and Myeong (2021), Eom and Lee (2022), Gil-Garcia et al. (2019), Mergel et al. (2018), Linders (2012), Neverov (2020)
68	Public-Private Cooperation	Reponen (2017), Mukhopadhyay et al. (2019), Cordella and Paletti (2019), Kuhn et al. (2022b), Neverov (2020), Kuhn et al. (2022a), Seo and Myeong (2021), Gil-Garcia et al. (2019), Mergel et al. (2018), Seo and Myeong (2020), Peters and Billert (2021)
69	Governing Together and Making Joint Decisions in the Government	Bender and Heine (2021) , McBride (2017), Cordella and Paletti, 2019, Neverov (2020), D'Silva and Norway (2018), Styrin et al. (2022), Bender and Heine (2022), Linders (2012),
70	Entrepreneurial Development	Kato (2021), Mergel et al. (2018)
71	Data Transparency	Peña-López (2020), D'Silva and Norway (2018), Mergel et al. (2018), Kato (2021)
72	Development in APIs	Trček (2022), Peña-López (2020), Mergel et al. (2018)

4. Research findings

The results of the experiences of countries around the world and the analysis and composition of data in this study, including subcodes, main codes, themes, and categories, led us to a

comprehensive understanding of the concepts necessary for implementing the Government as a Platform. This leads to a new and more comprehensive description, image, and formulation of the basic concepts, readiness indexes, and background necessary for implementing the Government as a Platform. According to the reference model of Government as a Platform in Fig. 3, by classifying the obtained codes, 75 indexes, including three categories, seven themes, 32 principal codes, and 33 subcodes, were formed and classified into four layers. The topics were categorized into three categories: 1- creating the mindset of change and preparing for change; 2- preparing for innovation; and 3- preparing for economic growth.

Table 3 shows indexes, including subcodes, main codes, and contents, as well as the identified sources and the country discussed in the source. It should be noted that a code may be mentioned in several places in an article.

Also, Table 3 and Fig. 3 present Government as a Platform readiness indexes based on codes, categories, and themes.

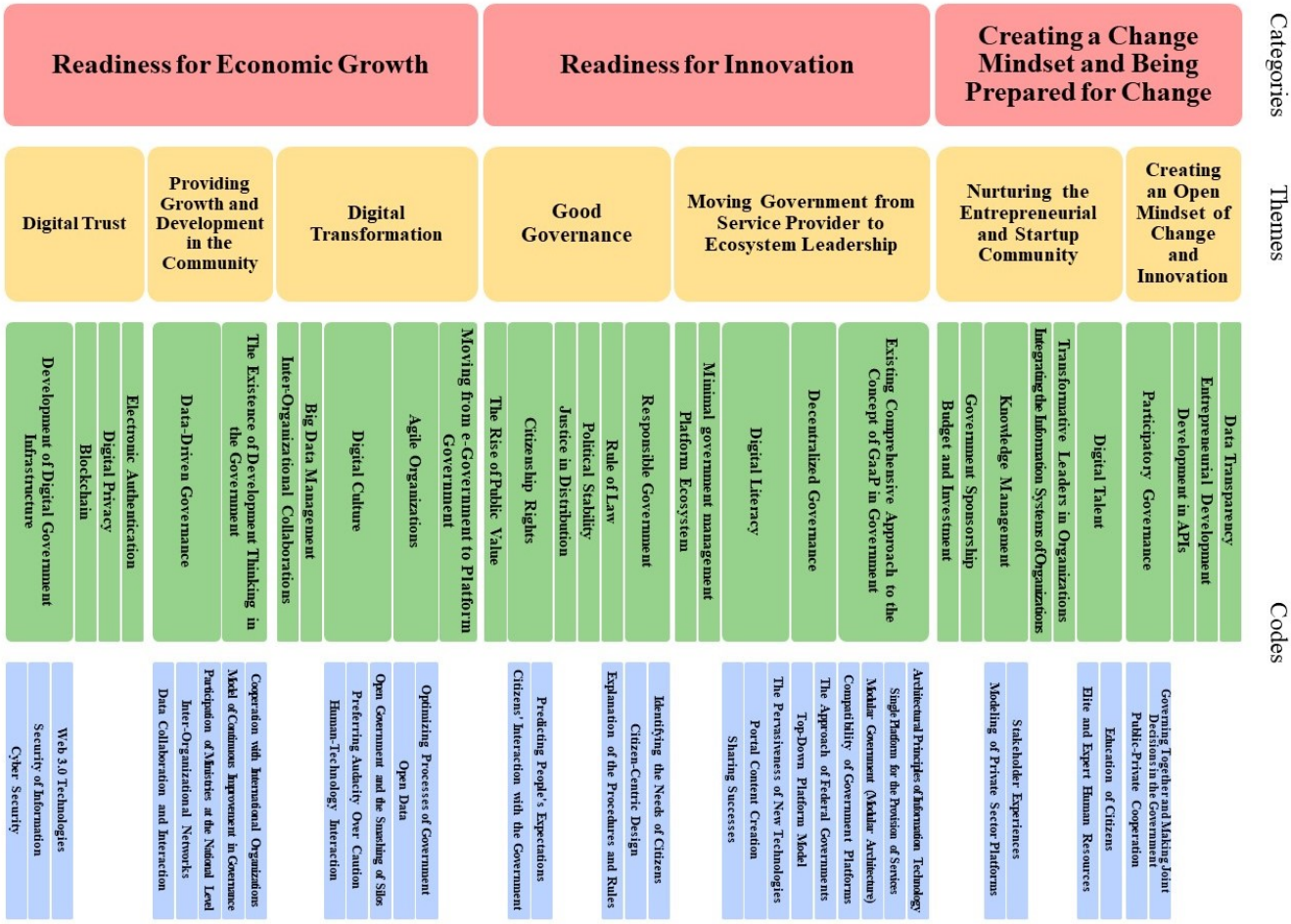

Figure 50. Infographic reference model of GaaP readiness indexes

The following are broader descriptions of the categories.

Table 21. *Mining GaaP readiness indexes based on codes, themes, and categories (Classification of extracted categories and themes)*

Categories	Themes	Codes	
Creating a Change Mindset and Being Prepared for Change	Creating an Open Mindset of Change and Innovation	Data Transparency	
		Entrepreneurial Development	
		Development in APIs	
		Participatory Governance	Governing Together and Making Joint Decisions in the Government
			Public-Private Cooperation
	Nurturing the Entrepreneurial and Startup Community	Digital Talent	Education of Citizens
			Elite and Expert Human Resources
		Transformative Leaders in Organizations	
		Integrating the Information Systems of Organizations	
		Knowledge Management	Stakeholder Experiences
			Modeling of Private Sector Platforms
		Government Sponsorship	
		Budget and Investment	
Readiness for Innovation	Moving Government from Service Provider to Ecosystem Leadership	Existing Comprehensive Approach to the Concept of GaaP in Government	Architectural Principles of Information Technology
			Single Platform for the Provision of Services
			Modular Government (Modular Architecture)
			Compatibility of Government Platforms
		Decentralized Governance	The Approach of Federal Governments
			Top-Down Platform Model
		Digital Literacy	The Pervasiveness of New Technologies
			Portal Content Creation
			Sharing Successes
		Minimal Government Management	
		Platform Ecosystem	
	Good Governance	Responsible Government	Identifying the Needs of Citizens
			Citizen-Centric Design
		Rule of Law	Explanation of the Procedures and Rules
		Political Stability	
		Justice in Distribution	
		Citizenship Rights	Predicting People's Expectations
			Citizens' Interaction with the Government
		The Rise of Public Value	
Readiness for Economic Growth	Digital Transformation	Moving from e-Government to Platform Government	
		Agile Organizations	Optimizing Processes of Government
			Open Data
		Digital Culture	Open Government and the Smashing of Silos
			Preferring Audacity Over Caution

			Human-Technology Interaction
		Big Data Management	
		Inter-Organizational Collaborations	
	Providing Growth and Development in the Community	The Existence of Development Thinking in the Government	Cooperation with International Organizations
			Model of Continuous Improvement in Governance
		Data-Driven Governance	Participation of Ministries at the National Level
			Inter-Organizational Networks
			Data Collaboration and Interaction
	Digital Trust	Digital Privacy	
		Electronic Authentication	
		Blockchain	
		Development of Digital Government Infrastructure	Web 3.0 Technologies
			Security of Information
			Cyber Security

4.1. Category 1- Creating a change mindset and preparing for change

If the results are to be changed to prepare for the Government as a Platform, there is no choice but to change the mindset. According to the artistic definition of Henry Chesbrough, open innovation is the "targeted use of external and internal knowledge flows to accelerate internal innovation, and market development for external use of innovation". This definition refers to the use of knowledge resources by companies. Any organization that relies solely on its internal knowledge resources for innovation uses closed innovation, which generally has its characteristics and limitations, and any company that uses internal and external knowledge resources has an open innovation approach. The prerequisites for popularizing governance as the basis for Government as a Platform are: empowering people, data transparency, analytical dashboards, mass platforms, and maintaining security and privacy through digital and intelligent systems and platforms. Researchers believe there must be a lot of change in sharing practices to ensure data transparency. Scientists contend that information should be made public while no one's security and privacy are threatened. Data transparency as an important Government Platform index can lead to the reproduction of science and be the basis for improving decision-making at micro and macro levels. Transformative leadership style increases team morale and leads to innovation, improved conflict resolution, reduced costs, and an increased sense of team members' ownership. Entrepreneurial development is an important index that governments take steps towards by designing and implementing programs and policies. Although in each country, according to its requirements, certain goals are considered in the interests of that country in the development of entrepreneurship, governments pursue

similar goals overall. The most important of these goals are to increase employment and economic development, increase competition in the economy and develop market efficiency, increase innovation and development of technology dissemination, help increase exports, achieve regional development, reduce the monopoly of large companies, and decentralization, and increase private sector participation in the economy (which is one of the important goals of the Government as a Platform). The development of APIs (Application Program Interfaces) has become an important element in Government as a Platform, as it allows developers to build new applications faster and with fewer development resources. The Government, as a Platform, uses APIs to make its data available to independent software developers. This allows them to communicate with other systems and create new applications that perform better than previously available ones. Implementing Government as a Platform is the prerequisite to implementing participatory governance. The implementation of participatory governance includes: 1- Strengthening the participatory process through innovative solutions and models and improving the common cognition of problems and outcomes of society. 2- Strengthening the interaction between policy and policy making and service delivery. 3- Integration of public services with an organizational and inter-organic attitude. By modeling private sector approaches in the field of platform strategy, Government as a Platform transfers the experiences of the private sector to the public sector. As competition is increasing internationally, many organizations invest huge amounts of their funds and resources in information and communication technology to gain a competitive advantage. Knowledge management, information systems integration, and the way of managing digital talent so that they become long-lasting play an effective role in the readiness of Government as a Platform. Organizations that manage digital talent need to replace a business with the usual mindset and outdated talent management practices with customized strategies to attract and develop talent way that persuades the talent to stay. Also, integrating information systems as a vital index offers a high capacity for disseminating information across the organization's borders and helps to make better decisions. Increasing productivity, making better decisions, reducing costs, increasing revenue, and providing integrated services are among the benefits of integrating information systems. Knowledge management is the use of individual and collective experience and knowledge through the process of knowledge production, sharing knowledge, and applying it with the help of technology to achieve the goals of the organization and, consequently, the government. Knowledge management is one of the infrastructures of Government as a Platform readiness, i.e., the creative and efficient use of all knowledge and information available to the

organization for the benefit of the customer and, therefore, for the benefit of the organization's benefit.

4.2. Category 2- Readiness for innovation

One of the main foundations of the Government as a Platform is exploiting private sector experiences. Today, the most critical issue in many countries is the economy, and economic conditions can be improved through interaction and cooperation between the public and private sectors. Public-private sector interaction is essential for boosting production in the economy. The central role of government in fostering innovation is an important topic analyzed in this article, based on evidence from other countries regarding Government as a Platform. The government is a crucial element of the Government as a Platform ecosystem. The government's support, policy, and leadership in this ecosystem can empower small- and medium-sized enterprises to enter international markets successfully. Through legal incentives, tax concessions, amnesty, financial support, and the reduction of customs barriers, the Government as a Platform can increase incentives for small- and medium-sized enterprises to enter international markets. Good governance represents a paradigm shift in the role of government by enabling equal participation of all citizens in the decision-making process and reflecting the reality that governance belongs to the people and is shaped by them.

Additionally, the Government as a Platform can effectively reduce waiting times and improve the delivery of public services, as well as enhance effectiveness, productivity, transparency, accountability, and the government's ability to carry out key activities. It is important to note that the transparency and accountability of the government in providing services are crucial outcomes of establishing a Government as a Platform for governance. Regarding the relationship between the Government as a Platform readiness index and the rule of law, it is important to note that without order, law, and societal regulations, force and fraud dominate interpersonal relations, leading to chaos and disorder. Centralized control over processes (both governmental and non-governmental), the acceleration of overall societal activities, and increased citizens' satisfaction with governance are examples of the benefits governments can gain from realizing Government as a Platform. Category 3- Preparation for economic growth

Digital transformation as the foundation of Government as a Platform is one factor contributing to the increase in economic growth of governments. Also, digitization increases entrepreneurship and creates new businesses. This, in turn, increases economic growth due to

increased profits and reduced business costs. In the digital age, two elements of transparency and building trust in citizens are important, with the focus on Government as a Platform. Trust is a prerequisite for the digital economy. Cybersecurity should be such that it can cover different layers. Data are the assets of the public and private sectors, so the optimal use of these valuable assets is important. Many countries have also adopted various institutions and laws on data control and storage, all of which reflect changes in data governance in the age of cyberspace. There are major issues around the important index of "data-driven governance" and ignoring them slows down the development of the "digital economy" in governments. Topics such as data ownership, data exchange, aggregation, data quality, data dissemination, and data security are among the root issues of data governance. The World Values survey indicates that high-income countries show the highest trust in people. Low-income countries have the lowest level of trust in people, indicating a possible link between digital trust and the digital economy. The digital trust index is a factor that measures the value of digital trust, quantifies the opportunity cost of digital trust loss, and shows that the global economy can be dramatically improved by increasing digital trust. Many economists have accepted that cultural institutions are important in economic outcomes. Today, works by Nobel laureates such as Douglas North and Gary Becker emphasize the role of cultural and institutional factors in building a more comprehensive and realistic theory of economic behavior. Several studies by management consulting firms show that digital culture and skills are the most important obstacles to the success of "digital transformation" and, consequently, Government as a Platform. As an important index, digital culture grants a sense of identity to members of the organization. Digital culture in the Government as a Platform creates commitments in people beyond personal interests. In this regard, to prepare the Government as a Platform for developing digital government infrastructure, including Web 3.0, is necessary. Web 3.0 is the current generation of the Internet and a paradigm shift towards a democratic and decentralized Internet. Web 3.0 is concerned with building people's Internet, which means that people own the Internet, and all its tools are designed to serve the people. The necessary condition for communicating services with real people on the topic of Government as a Platform readiness is creating a common language and, in other words, a "virtual cornerstone" called "digital identity". The formation of the data and information cooperation ecosystem in the Government as a Platform seems to result from the "digital identity" concept. Transformation requires eradicating obsolete systems and practices and replacing them with new models of government, such as Government as a Platform. In order to create new forms of government, the need for adaptive and timely changes is strongly

felt by governments. In a world of constant change, governments need to be more intuitive to immediately feel and respond to new technology opportunities, social challenges, and needs of citizens. Moreover, to serve citizens, governments need to act more integrated. Breaking down silos, integrating connections, and streamlining data and process flow are essential to finding new solutions, strengthening security, and creating personal and interesting experiences for citizens. Open government data is one of the important pillars of the readiness of Government as a Platform. Developers build smartphone applications based on the data that are available to the public sector, and activists in this field have realized the value of open government data. Implementing continuous improvement methods in organizations is one of the Government as a Platform readiness indexes. When employees of an organization engage in a single goal, they feel more belonging in their work. This increases their participation and ultimately increases productivity. The fact is that everything is progressing and changing day by day. Organizations and institutions should adapt to positive change to remain competitive. In this regard, optimizing government processes Government as a Platform readiness index means systematic methods and strategies to create coordination and order and, in general, improve specific processes within a specific set of parameters. In Government as a Platform, by improving the work process, costs can be minimized, and maximum efficiency can be achieved in the government. As an agile government, Government as a Platform can respond to environmental challenges and adapt to the new business world by offering a new approach to serving the people. Agility is linked to the ability of organizations to overcome unexpected changes, address unprecedented threats to the workplace, and use change as an opportunity. Therefore, survival in such an environment is only possible by changing and adapting to dynamics such as Government as a Platform.

5. Conclusion

The Government as a Platform (GaaP) concept represents an emerging paradigm in e-government and digital transformation, emphasizing the role of governments in delivering services through platforms and fostering open, participatory ecosystems. While the literature has explored various aspects of GaaP, it remains fragmented. It lacks a comprehensive framework that integrates the diverse dimensions necessary for evaluating governments' readiness to adopt this paradigm. This gap constitutes the central theoretical issue addressed by this study. This research identifies and addresses the critical absence of a consolidated reference model for GaaP readiness. Most existing studies focus on isolated dimensions, such as

technological or policy-related factors, while overlooking the holistic interplay of other essential dimensions, including organizational, socio-economic, and political readiness. By synthesizing these fragmented insights, this study introduces a comprehensive and integrative framework that is robust for assessing governments' readiness to embrace the GaaP model.

The platform approach in government enables the effective implementation of public functions and services (Smorgunov, 2021), and the link between government databases increases the speed of realizing the platform approach (Jeannot, 2020). The main goal of the Government as a Platform is to provide the ground for civilian institutions to communicate with the government or participate in country's administration through cooperation (Chung, 2017). The realization of Government as a Platform requires mutual trust between people and government, legislation, and transparency (D'silva & Norway, 2018). To implement this concept, the rapid growth of the platform economy must be realized (Geliskhanov Islam et al., 2018).

To achieve Government as a Platform, citizens' interaction with the government is more important than the architecture of infrastructure (Gil-Garcia et al., 2019). Every information system in the public sector is connected to an integrated platform to implement this concept, so the quantity and quality of open data should be increased (Seo, 2021). This study concluded that digital transformation is the cornerstone for realizing Government as a Platform. Digital transformation in the public sector not only involves processes and technology but also requires the creation of a digital society with the skills and culture necessary to embrace this change (Albanese and Bettoni, 2020). It was found that open data initiatives are necessary for the realization of Government as a Platform. The idea emerged as an industry, leading to the notion that data needs to be published openly by the government. If the data is published, citizens use it immediately (Bender and Heine, 2021). Open government, participatory government, automated decision-making, and data-driven policy-making lead to many advances in integrating new technologies in the future (Trček, 2022). In this regard, governments should actively extract new open data that can add value to innovation. Therefore, governments must create an easy collaborative environment with other stakeholders, especially non-governmental participants (Seo and Myeong, 2021).

As mentioned in the research background, despite the steps taken in several countries wordwide for the Government as a Platform readiness indexes, no reference model for the government's readiness to implement Government as a Platform has yet been provided. The lack of such a model has caused a conceptual disintegration, a lack of a single attitude, and,

most importantly, a delay in fully implementing this concept. In order to eliminate this research gap, the present article attempts to provide a reference model of Government as a Platform readiness index using the experiences of more than 30 countries worldwide in implementing the concept of Government as a Platform. This is a qualitative study that analyzes the data extracted from selected sources using the meta-synthesis method. In the systematic review process, 58 out of 961 sources were selected and used for qualitative analysis and coding. By classifying the obtained codes, 75 indexes were formed and classified into three layers: 1—create a change mindset and prepare for change; 2—prepare for innovation; and 3—prepare for economic growth. In conclusion, it should be noted that these three categories have priority and posteriority, so the category of "being ready for innovation" does not occur before the category of "creating a change mindset and being ready for change", and the category "readiness for economic growth" is not completed before the completeness of the category "readiness for Innovation".

The present work was a qualitative fundamental study, and it is suggested that researchers interested in Government as a Platform, digital transformation, and e-government examine the functions, consequences, and obstacles of realizing Government as a Platform. It is also suggested that the subjects of this study be categorized for each country of the world on a regional basis and following the culture of different nations so that new categories can be obtained and introduced.

Disclosure statement

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

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