



Agent-based modeling of banking service supply chain in Industry 4.0: A case study of Resalat Qard al Hasan Bank

Vahid shahabi^{a1}, Reza Radfar^b, Peter Wanke^c, Ali shahabi^d, Yong Tan^e

^a Department of Management and Economics, Islamic Azad University Science and Research Branch, Tehran, Iran

^b Department of Management and Economics, Islamic Azad University Science and Research Branch, Tehran, Iran

^c COPPEAD Graduate Business School, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

^d Department of Technology Management, Faculty of Management, Science and Research Branch, Islamic Azad University, Tehran, Iran

^e School of Management, University of Bradford, Bradford, West Yorkshire BD7 1DP, United Kingdom

ARTICLE INFO	ABSTRACT
<p><i>Received: 21 October 2023</i></p> <p><i>Reviewed: 28 November 2023</i></p> <p><i>Revised: 5 January 2024</i></p> <p><i>Accept: 9 March 2024</i></p>	<p>Purpose: Industry 4.0 has profoundly impacted the structure of businesses and organizations worldwide, and the digital revolution has led to the transformation of the supply chain of various industries, including the supply chain of banking services. Therefore, it is necessary to redesign the supply chain in the new era.</p> <p>Methodology: This study investigated the supply chain of banking services of Industry 4.0 and its simulation based on agent-based modeling. This research model simulates the profit flow and other important financial variables related to agents such as customers, banks, fintechs, and other players in the supply chain of digital banking services.</p>
<p>Keywords: <i>supply chain, Industry 4.0, Agent-based Simulation</i></p>	<p>Findings: The simulation results in different time periods show the amount of changes in important parameters in the face of digital transformations in Industry 4.0. Factors such as the connection of organizations and fintechs to the supply chain of banking services, as well as the removal of physical branches and the use of digital tools, change the structure of the chain in terms of information evolution, service evolution, and financial evolution.</p> <p>Originality/value: This paper is one of the first studies to analyze the effects of Industry 4.0 on the banking service supply chain and can be considered a starting point for digital banking supply chain studies.</p>

¹ Corresponding Author: vahid.shahabi@srbiau.ac.ir

1. Introduction

Research on Industry 4.0 is expanding as digitalization becomes a priority for manufacturing and service companies [1]. Deloitte's (2014) report found that the possibility of using Industry 4.0 would lead to greater competition in digital supply chain activities [2]. The digital tools can be used to share common data, information, and knowledge across the supply chain [3] [4].

Industry 4.0 is creating intelligent production systems by changing the mode of operation, design, product service, and structure of production systems. This new technological and forward-looking approach aims to increase the effectiveness and efficiency of the entire supply chain in the industry [5]. Digital transformation reduces deviations in the supply chain and improves the quality of banking services, ultimately leading to the integration of the supply chain and profitability [6].

The birth of Industry 4.0 has caused the supply chain of various industries, especially service industries, to face extensive changes and to have greater integrity. About two-thirds of the world's advanced economies have moved towards service industries, indicating that most future jobs will be service-oriented with more integration [7].

Despite the importance and increase of services in the world economies, research on the service supply chain has been neglected compared to production. The emphasis on supply chain management is still seriously focused on the manufacturing sector, and hence, the service supply chain, which has services at its core, has been neglected [8].

Service companies' supply chain design and development have many problems; therefore, little research has been done to develop the service supply chain model [9]. The reason for these problems is the different nature of the services. Services have different Attributes, such as Not being tangible, not homogeneous, not being storable, simultaneous production, distribution, and consumption, customer participation in production, etc. [10]. More specifically, in the banking industry, the growing cost of the cash supply chain is the issue or problem managers face.

The high cost of the traditional banking supply chain is focused on the cost of equipment or services required to receive, transfer, and distribute cash. This traditional and long chain starts from the central bank, moves to the branches/ATMs, and finally, goes to the customers. The growing and high cost of the cash supply chain is mainly attributed to the rising demand for cash and the use of complex technology in the supply chain. Therefore, although Industry 4.0 has certain benefits, it will also cause bank fees to grow. Thus, it is necessary to redefine the supply chain for service industries, including the banking service industry, which has had the largest share in digital developments due to changes in customer needs. This study designed and simulated the banking service supply chain model in Industry 4.0. we contribute to the literature and fill in the literature gap by investigating the supply chain of banking services of Industry 4.0 and its simulation based on agent-based modeling. More specifically, we aim to provide more insights into the detailed influence of Industry 4.0 on various aspects of banking operations, including the impact on bank's digital investment, banks' retained profit, and revenue from digital services, the number of customers, banks' ability to attract more customers as well as customers' use of digital banking services. We are the pioneer in providing this detailed analysis based on the innovative method and would be able to provide concrete policy implications. In summary, we are faced with the following questions:

- 1). What is the effect of the advent of Industry 4.0 on bank's investment in digital development?
- 2) what is the effect of the advent of Industry 4.0 on the retained profit of digital banking?
- 3) what is the effect of the advent of Industry 4.0 on the number of bank customers?
- 4) what is the effect of the advent of Industry 4.0 on revenues from digital banking services?
- 5) what is the effect of the advent of Industry 4.0 on the bank's ability to attract customers digitally?
- 6) what is the effect of the advent of Industry 4.0 on customers' use of digital banking tools?

2. Theoretical Basis

2.1. The concept of Industry 4.0

Industry 4.0 is a growing research field and an attractive keyword in the industry [11] [12]. This can be introduced as emerging convergence and new technologies such as artificial intelligence, big data, the Internet of Things, and robotics [13]. Industry 4.0 is a new concept that researchers and executives use to explain how the world's industrial systems will improve shortly, using Internet-based tools to increase added value for companies [8].

Progress towards Industry 4.0 is currently significantly impacting the manufacturing industry. This is based on establishing intelligent factories, smart products, and intelligent services embedded in the Internet of Things and services, also called the Industrial Internet of Things [14]. In addition, new business models are evolving based on Industry 4.0. Advanced technologies in Industry 4.0 have great potential to increase production efficiency dramatically. For instance, according to McKinsey, a change from conventional production towards automatic production in Industry 4.0 can increase productivity by 45%-55% [5].

Industry 4.0 includes the entire product life cycle and supply chain, from design, sales, inventory, planning, and quality to engineering, and it even changes the way people work [3]. Industry 4.0 emphasizes using digital technologies to collect and analyze data and provide industries with vital and practical information [15]. One of the largest industries that has significantly changed in recent years is the banking services industry. Therefore, investment in the IT sector of banks and using digital tools such as artificial intelligence, the Internet of Things, cloud services, and big data has increased. This has increased the bank's costs in the short term [16]. All these tools and concepts can transform the business models of the banking industry; thus, understanding these effects on banking supply chain evolution is very important.

2.2. Banking Supply Chain

The supply chain of traditional banking services includes supply and demand related to the supply chain of banking services. The supply chain is an interconnected process for financing, managing resources, disbursing loans, and receiving and disbursing cash to customers. Physical cash transfer includes logistics and delivery mechanisms and monitoring of this process. The banking supply chain is affected by issues such as financial statements, financial management, information technology management, customer relationship management, and bank process improvement management [17].

Also, bank supply chain management includes cash flow management and optimization and helps banks extend their payment terms to their suppliers according to banking standards [18].

Banks are one of the most important, complex, and reliable supply chains among industries that move large amounts of cash daily with low risk. The costs associated with these supply chains include all the equipment and services needed to process transfer and store information related to liquidity in the banking network. The operating expenses of this chain are very high. This is when customer demand for liquidity and increased use of more advanced technology throughout the supply chain are growing. Figure 1 is related to the main activities of the banking supply chain, including liquidity management and lending activities. Bank supply chain management includes lending, deposit, and investment activities [17].

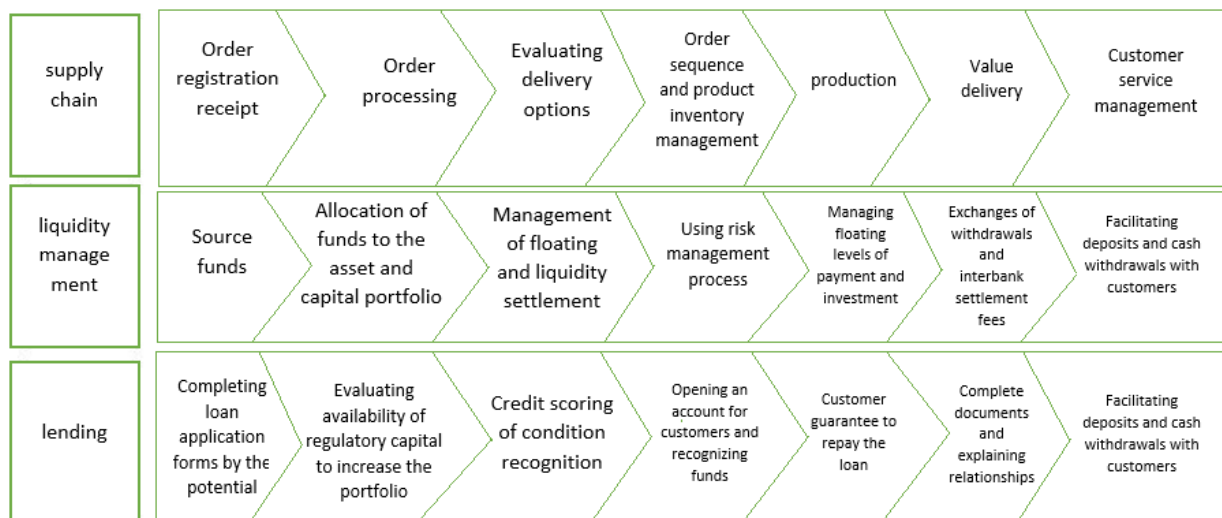


Figure 1. Comparison of supply chain activities with liquidity and lending management in banking [19]

2.3. Banking service supply chain in Industry 4.0

The digital revolution has recently changed production and service paradigms by migrating from the tangible world to the digital space. Industry 4.0 has become a big revolution in eliminating old jobs and creating new ones. The emergence of Industry 4.0 in the financial sector, including the banking industry, is also growing faster than other industries.

With the advancement of technology, customers' expectations of service quality are increasing, and they are constantly evaluating the trust and personalization of banking services. This issue changes the service strategy of banks in using advanced technologies. Therefore, it is necessary to redesign the operational processes of the banking sector, especially the banking supply chain, in the path of the digital revolution [20]. The empirical literature has attempted to investigate the relevant issue of the application of Industry 4.0 in the banking sector, including the examination of technology quality management of Industry 4.0 and cyber security risk management [21], and using fuzzy techniques to model Industry 4.0 on the banking supply chain [22].

The significant evolution in digital bank branches is related to customer interactions and the relationship between banks and customers. In today's world, customers receive banking services through tablets and computers. Also, one of the other essential conditions of the Digital Bank branch is innovation in providing services. This is related to a continuous process of innovation that offers different activities in the Digital Bank branch besides services. Other new services are no longer included in the traditional supply chain of banks. Banks could attract more customers not individually but through collaboration with other financial institutions by providing these activities using technologies. Therefore, from this perspective, industry 4.0 would increase banks' ability to attract customers digitally. This is an important issue, in line with our hypothesis 5. Future digital bank branches must provide attractive and up-to-date banking services to customers based on interactions and innovations that allow customers to quickly receive banking services without being in a branch. Therefore, we expect that Industry 4.0 would increase the number of customers, which aligns with our hypothesis 3. In addition, Industry 4.0 can facilitate the design and implementation of digital banking, from which, as argued previously, the banking customers benefit from cost reduction in terms of saving time and transportation costs. This is supposed to increase the number of customers using digital banking tools. This aligns with our hypothesis 6.

Previously, we mainly emphasized the impact of Industry 4.0 on banking customers. Concerning banking operations and bank performance, industry 4.0 would be able to create profitable business models and improve the staff working conditions through incorporating relevant technologies, running the business and providing the services online would significantly reduce the staff cost, energy costs as

well as the cost regarding the fixed assets, therefore, it would increase the retained profit. This aligns with our hypothesis 2. Furthermore, revenue is supposed to grow by attracting more customers digitally and increasing the number of customers using digital technologies, which accords with hypothesis 4. Finally, in terms of the impact of Industry 4.0 on the investment in digital development, although we can see that banks adopting Industry 4.0 are supposed to benefit from the retained profit and revenue, this will depend on the specific condition of a particular bank in terms of its volume of capital and ability to invest into technology-based services and operational mode. Therefore, the impact of Industry 4.0 on digital investment will be determined based on individual bank. This aligns with our hypothesis 1.

In today's banking world, the speed of digitization of banks has dramatically increased, and traditional models must be constantly redesigned.

In addition to providing services on a secure platform, customers' demands for speed and efficiency must also be met. Security and trust are critical, and banks have developed innovative banking products and services over the past few years to protect customers' assets fully. However, like any industrial revolution, Industry 4.0 can have positive and negative implications for the banking industry.

The digitization of banking processes is being carried out with total capacity. Other aspects of Industry 4.0 are expanding using blockchain, artificial intelligence, the Internet of Things, biometrics, and the cooperation of banks with fintech companies [23].

Several studies have been conducted on the digital development of banks. The results are shown in Table 1, which is based on a comparison of traditional and modern supply chains of banking services.

Table 1. Previous studies conducted on the digital transformation of banking service

Topic	Agent	aim	Methodology	findings	Supply chain Traditional	Supply chain In Industry 4.0	Source
Interaction with customer	Customer	Examining the role of electronic banking on the profitability of a bank's	single-layer neural network (perceptron).	With the development of electronic banking, many costs are imposed on the bank, but in the long run, costs are reduced, and profitability increases.	Receiving services by going to banks	There is minimal need to interact directly with the customer through digital tools.	[16]
Variety of services	Bank	Examining the relationship between banks and customers in the digital world	a descriptive qualitative research design	Communication with customers is personalized, and the satisfaction of digitally oriented customers has increased.	Providing services within a fixed framework for all customers	Customizing services based on big data analysis and customer behavior	[24]
Information flow	FinTechs	The impact of Industry 4.0 on supply chain performance	A Systematic Literature Review	Applied technologies in Industry 4.0 will improve supply chain performance	Information circulation	Systematic sharing of customer information among members of the participatory supply chain	[25]
Chain members	FinTechs	Investigating the applications of the Internet of Things in finance and analyzing digital trends	hierarchical classification analysis based on fuzzy Jaccard dissimilarity	Crowd-based financial fintechs will disrupt the tranquility of legacy institutions and grow.	Customer and bank	Connecting various actors to the supply chain, including fintechs	[26]
Environmental impacts		Evaluate the service supply chain environmental performance	grey-based hybrid MCDM approach	This method is superior compared to other MCDM models, which have drawbacks such as the inability to capture realistic fuzziness in decision-making (human judgment), inadaptability to different levels of measurement, complexity in calculation, and requirement of intricate details	Customer commute to banks and the use of paper tools	Eliminating paper and no need to visit banks	[27]

Availability	Customer	Examining the role of frontline teams in the preferences of using banking channels	Review of literature	Frontline teams are very decisive in the preferences of using banking channels for customers.	Limited access in the city at limited times	Permanent availability	[28]
Infrastructure	Central bank	A theoretical literature review on the development of digital technology in the Indian banking industry	Review of literature	Competition in the banking industry forces banks to use new digital models that create significant value.	Required infrastructure for traditional banking	Developing central bank infrastructure in the digital age to create local and global opportunities	[29]
Cost	All	Knowledge of supply chain 4.0 and global value chains	Review of literature	Industry 4.0 reduces costs, makes production more responsive to consumer demand, boosts employment, and saves consumers' time.	Excessive costs of buying property and rental and staff costs	Reducing branch costs and coordination and compliance costs	[30]
Synergy	FinTechs	Understanding the practical applications of Banking 4.0 in Industry 4.0	A systematic literature review	The new generation of banking has a wide impact on improving the customer experience, using artificial intelligence, and the emergence of databases, identification algorithms, machine learning methods, and data analysis.	Lack of inter-organizational cooperation and added value	Joint cooperation, particularly sharing knowledge and expertise and intellectual property	[31]
Resource sharing	FinTechs	Analysis of drivers of adoption of advanced digital production technologies	one-to-one nearest neighbor matching method	Companies' involvement with fintechs is positively related to the adoption of Industry 4.0 technologies	Lack of resource-sharing	Chain members share their resources to avoid unnecessary rework on matters and resources such as expensive assets such as transportation and maintenance network equipment.	[32]

Although these studies have examined the digital transformations of banking services, changes in the banking supply chain in Industry 4.0 have received less attention. Thus, in this study, the banking services supply chain model was designed in Industry 4.0 and simulated with an agent-based simulation approach.

2.4 Hypotheses development

Few studies address the impact of Industry 4.0 on digital investment and argue that there is a lack of clarity regarding the cost-benefit analysis and the monetary benefits of digital investment when applying Industry 4.0 to the supply chain context [33]. This argument is also supported by Nagy et al. (2018) [34]. Digital investment requires a reasonable amount of costs, the impact of Industry 4.0 on the volume of digital investment will depend on the benefits/profits that the companies or industries can gain from incorporating technology into the manufacturing and distribution of products and services. Regarding the impact of Industry 4.0 on profit Muller et al. (2018) argue that the application of technology in the operation and manufacture derived from Industry 4.0 would create profit business models, improve efficiency and product quality, and improve work conditions [35].

Industry 4.0 has an international approach and is different from traditional banking services provided by branches, and customers worldwide can use it [31]. This is considered to increase the number of customers. In addition, Industry 4.0 is geared towards increasingly individualized customer requirements. Therefore, it is considered that Industry 4.0 could attract more customers [36]. Dutta et al. (2020) argue that Industry 4.0 can reduce costs by providing customer-tailor production concepts, and additional revenue can be earned from providing new digital products, services, and solutions [37]. Fatorachian, and Kazemi (2020) argue that digital transformation in the financial sector increases the loyalty of existing customers [25]. This indicates that customers like to use digital tools in the services provided by the banking industry. In summary, we form the following hypotheses:

H1: We do not have a priori expectation of the impact of Industry 4.0 on digital investment.

H2: there is a positive impact of Industry 4.0 on retained profit

H3: Industry 4.0 increases the number of customers

H4: Industry 4.0 would be able to more attractive to potential customers

H5: there is a positive impact of Industry 4.0 on the revenue from digital banking services

H6: Industry 4.0 increases the use of digital banking tools

3. Methodology

3.1. The Agent-Based Modeling Approach

The Agent-Based Modeling Approach is a new computational method for modeling dynamic and complex systems in which humans play a crucial role [38]. There are generally four approaches of applications of this modeling, including flow simulation, organizational simulation, market simulation, and diffusion simulation [39]. This method of modeling creates an artificial community of individuals. It enables the modeling of two vital things that exist in most systems: people are different (society is heterogeneous), and people interact and influence one another.

In such systems, each agent is recognized as an independent, autonomous, and intelligent computational unit that can think and make decisions and social interaction [34]. The agent behavior can be modeled in the stock market, supply chain, and consumer market/marketing [40]. It can also be used to predict the spread of the epidemic [41].

Agent-based modeling has the following capabilities that make it one of the most popular methods in modeling [42].

1. Modeling dynamic and complex interactions among system elements in other methods is impossible, but agent-based modeling can quickly do this.

2. Creating heterogeneous agents with different characteristics and large numbers is possible in agent-based modeling, while other methods have severe limitations.

3. The possibility of using complex learning and reasoning mechanisms in agents in the agent-based method is much simpler than other methods.

Thus, considering the complexities in the banking service supply chain, adopting agent-based modeling based on its benefits would bring more benefits than other modeling approaches. Table 2 shows the studies done on supply chain simulation using agent-based modeling.

Table 2. Previous studies on supply chain simulation using agent-based modeling

No.	Author	Topic	Modeled agents or parameters
1	[43]	DESIGNING SUPPLY CHAIN MANAGEMENT-BASED MODELS IN DIGITAL ECOSYSTEMS	EXTERNAL AGENTS (WEATHER FORECASTING, TRAFFIC FORECASTING, SOCIAL MEDIA MONITORING, WEB TRACKING) / INTEGRATION AGENT (SERVICE TRANSFER) / MESSAGING AGENT (SUBSCRIPTION DISSEMINATION MODEL) / DATA LAKE AGENT (BACH MODEL) / PREDICTIVE MODELING AGENT (REAL-TIME) / VISUALIZATION AGENT (MANAGEMENT AND CONTROL, SUPPLIER COLLABORATION, CUSTOMER COLLABORATION, CUSTOMER AND SUPPLIER ENGAGEMENT, ONLINE ALERT, NEW SERVICES)
2	[44]	ANALYSIS OF FLEXIBILITY STRATEGIES AND THE EFFECT OF RIPPLE ON BLOCKCHAIN-COORDINATED SUPPLY CHAIN	SUPPLIER/MANUFACTURER/WHOLESALE/RETAILER
3	[45]	AGENT-BASED SUPPLY CHAIN OPTIMIZATION ALGORITHM	PHYSICAL OBJECTS (RECEIPT, PRODUCTION, TRANSPORTATION, ISSUANCE, STOCK)/LIQUIDITY (DEPOSIT, WITHDRAWAL, PAYMENT, SAVINGS ACCOUNT)/ INFORMATION (DECISION-MAKER, INFORMATION)
4	[46]	REDUCING THE RISK OF SUSTAINABILITY IN THE SUPPLIER POPULATION: AN AGENT-BASED SIMULATION STUDY	NUMBER OF BUYER/SUPPLIER PURCHASES/ POSSIBILITY OF SELLER-MISCONDUCT/ SUPPLIER MISCONDUCT/ RISK IMPACT/ BUYER'S POWER/ LACK OF BUYER RESOURCES/ NUMBER OF PERIODS
5	[47]	DATA-DRIVEN DECISION-MAKING FOR SUPPLY CHAIN NETWORKS WITH AN AGENT-BASED APPROACH	A NETWORK OF SUPPLIERS/ A NETWORK OF MANUFACTURERS/ A NETWORK OF DISTRIBUTORS
6	[19]	SERVICE-BASED SIMULATION OF THE SERVICE SUPPLY CHAIN IN BANKING BASED ON SERVICE DOMINANT LOGIC	BANK/ CUSTOMER/ OTHER BANKS/ CENTRAL BANK/ SUBSIDIARIES
7	[48]	A SERVICE-ORIENTED FRAMEWORK FOR AGENT-BASED SIMULATION OF SHARED SUPPLY CHAINS	SUPPLIER/ SHIPPING/ CUSTOMER
8	[49]	USING AN AGENT-BASED SUPPLY CHAIN TO REDUCE SUPPLY CHAIN DISRUPTIONS	SUPPLIERS/ DISTRIBUTORS/ SHIPPING/ CUSTOMER

Considering that none of the studies have dealt with the function of the banking services' supply chain in Industry 4.0, the primary purpose of this study was an agent-based simulation of banking service supply chain management in Industry 4.0. Therefore, first, the effect of Industry 4.0 on the supply chain of banking services was identified. Resalat Qard al Hasan Bank was selected because it is a leading bank in digital banking in Iran, and data related to the bank's financial statements were collected. The simulation was done in NetLogo, and coding stages were performed to introduce the factors and their

interactions. In the final stage, after validating the model and confirming its validity, a virtual experiment was performed based on real data, and the results were explained.

In this study, it was assumed that in the traditional supply chain and digital supply chain, the following steps are taken:

1. In the traditional supply chain, customers go to the bank to receive banking services and request their order, but in the digital supply chain, since physical branches are removed, customers receive their services digitally without the need to go to the bank.

2. In the traditional supply chain, all banking services are performed through the bank itself, but in the digital supply chain, the bank provides its services as cooperation networks of other members of the chain by outsourcing services such as validation, management of guarantee documents, etc.

- In the traditional supply chain, all services are limited to bank branches, but in the digital supply chain, through information sharing in the network, organizations provide many services to customers and complete this chain.

4. Because the model dynamics are primarily related to the four factors, such as banks, customers, FinTechs, and other organizations, factors that create little dynamism in the model (such as the central bank, bank companies, and other banks) were removed.

5. The model focuses on the revenue of banks, FinTechs, and other organizations in network collaboration and the number of customers.

In the agent-based simulation, the data in the reports and financial statements of Resalat Qard al Hasan Bank and related FinTech companies were used to simulate the supply chain of banking services for 2016-2021. The data used for simulation in NetLogo was extracted from <https://www.codal.ir> for 2016-2021. The study's statistical population included all banks in the Iranian banking industry. Considering the transparency and access to financial reports and statistics of variables about the status of the banking industry and also the leading status of Resalat Qard al Hasan Bank in providing digital services by completely eliminating its physical branches by the end of 2020, this bank was selected as a sample, and its supply chain was simulated. The subject area was the banking service supply chain. The present study was conducted on digital banking services in Resalat Qard al Hasan Bank, and the research results focus on the banking industry in terms of generalizability to other similar service sectors. This study can be the basis for further research. Temporally, this study simulated the supply chain of banking services for 2016-2021.

4. Data Analysis

The beginning of simulation with an agent-based approach is to "**identify**" a phenomenon that one intends to identify. Thus, the present study examined a phenomenon called the banking services industry and Industry 4.0. The parameters in this simulation and the relationships and interactions among agents are within a bank supply chain framework (Figure 2)

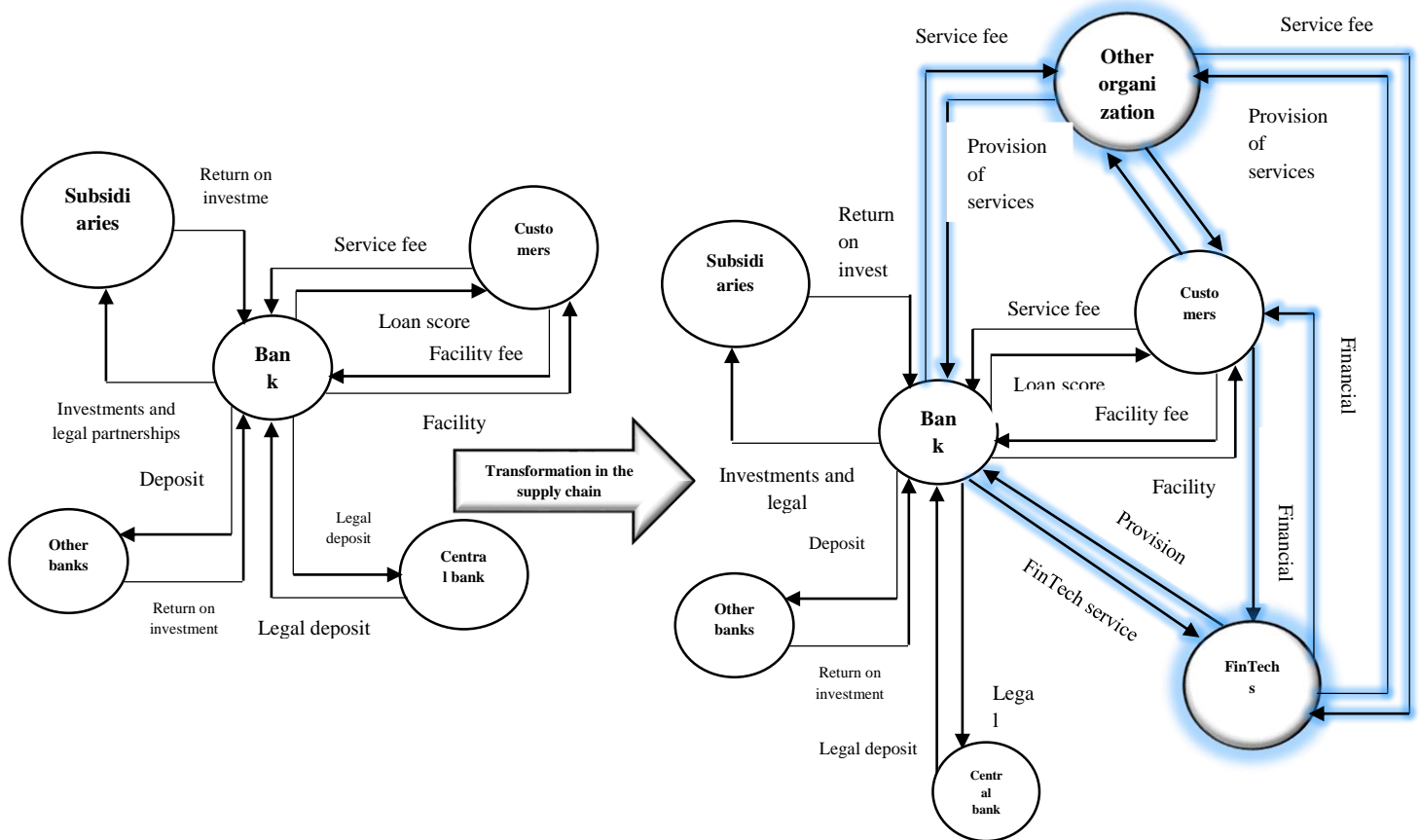


Figure 2. The framework of the supply chain of banking services in Industry 4.0 (researcher-made)

The next step in the agent-based research methodology is to "**define the domain**" of the model. Here, researchers need to clearly identify all the hypotheses used in the model. This model can start with a simple model that is easy to implement. The scope of the model in this research is the Iranian banking industry, which was measured by considering the data in the annual reports and financial statements accessed at <https://www.codal.ir>. The behavior of the main performance indicators for the banking supply chain, namely "profit" and "other important parameters," was simulated for 2016-2021. To this end, Resalat Qard al Hasan Bank was selected and simulated because it is the first bank in Iran without physical branches.

The next step is to determine the "**simulation scheme**". In this step, the type of objects is defined in the simulation. This type of simulation usually has two types of objects: "agents" and "environment". Then, the characteristic attributes of all objects must be specified. To perform the simulation of the banking service supply chain factor, NetLogo Ver 5.3.1 was selected and coded, taking into account the identified factors and their relationships. Given that in agent-based simulation, agents are the "decision-making members" of the supply chain, in this study, four agents (Bank, Customers, Other organizations & FinTechs) were identified and considered as the main actors that create the most dynamism in the banking service supply chain environment that are shown in Table 3.

Table 3. How important factors and variables interact in the simulation

Variables/ how to interact with the bank agent	Agent Name	No.
<ul style="list-style-type: none"> • Resources in traditional branches • Resources in digital banking • Expenditures in traditional branches • Expenditures in digital banking • Incomes • Costs • The ratio of incomes from traditional banking to digital banking • Ratio of costs from traditional banking to digital banking • Number of traditional branches • Branch rental cost • Retained earnings 	Bank	1
<ul style="list-style-type: none"> • Number of customers • Number of traditional account opening • Number of online account opening • Number of receiving traditional facilities • Number of receiving online facilities • Number of online validation files • Number of banking service requests in online systems 	Customers	2
<ul style="list-style-type: none"> • Income of service contracts with the bank 	Other organizations	3
<ul style="list-style-type: none"> • Income of service contracts with the bank • Financial services consulting fees • The cost of implementing digital systems 	FinTechs	4

In order to explain the characteristic attributes of the agents, this attribute remains unchanged in all stages of the simulation and, like gender, maintains the general nature of the agent. In this study, there were such traits as financial indicators, which are as follows:

- Characteristic attribute of the bank: Customer attraction and profitability
- Characteristic attribute of the customers: Receiving banking facilities and services
- Characteristic attribute of the FinTechs: Profitability
- Characteristic attribute of the organizations: Profitability

Figure 3 shows the most important financial data taken from the financial statements of Resalat Qard al Hasan Bank to simulate the model.

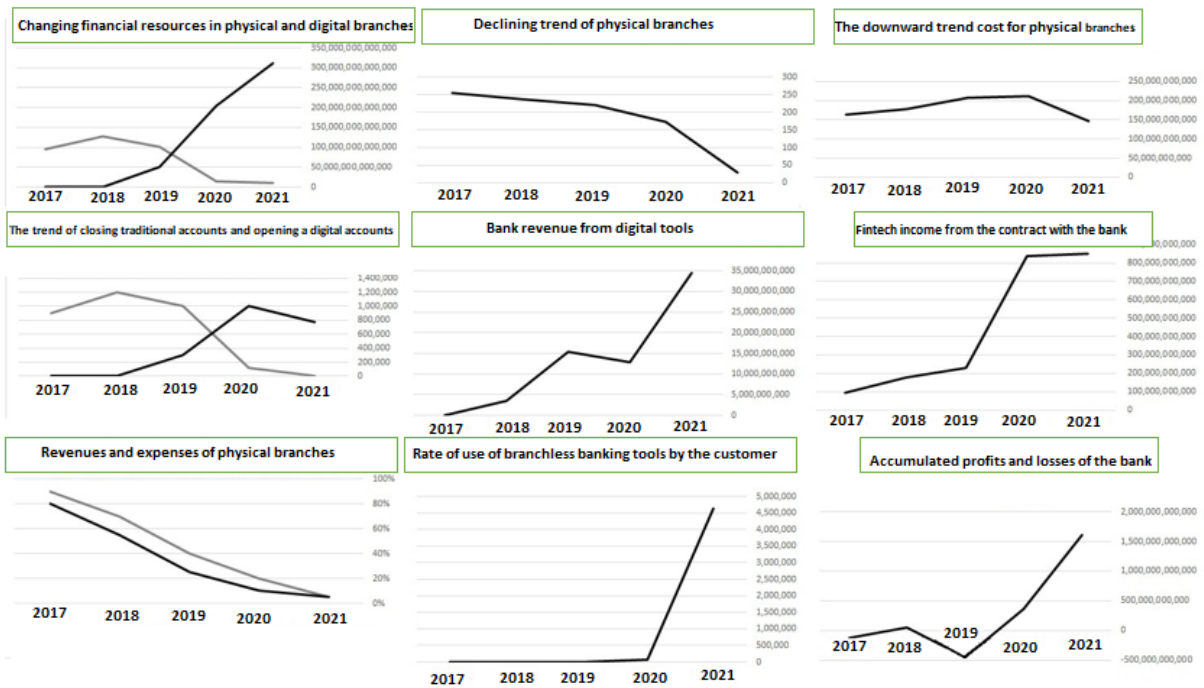


Figure 3. The most important financial data for model simulation on NetLogo

"Interaction model" is the next step. At this stage, all possible actions that may be performed by each agent, as well as the rules that it takes, are prepared. At this stage, all input and output variables in accordance with the statistical reports and financial statements of Resalat Qard al Hasan Bank and related FinTechs were explained and coded using the following logic in NetLogo.

Table 4. Interaction model among agents

No	Agents	Interaction model	Interaction codes of the respective agent
1	Customer	Customers have two options: to manage their deposit resources by going to the banks and using traditional banking services or to benefit from online services by turning to digital tools.	<pre> set digitsatisfac 0 set capital random-normal IndsAverageCapital (0.1 * IndsAverageCapital (set adigit InitialDigitalWill ask inds set dice random-float 1 set aadigit random-normal adigit adigit / 3 let r IndsAverageCapital / capital set dice (dice * r * 0.5) set diceSI random-float 1 set bankSI random-normal bankSSI bankSSI / 3 set digitrevenue sum [capital] of inds with [aadigit > dice and bankSI > diceSI] set nondigitrevenue sum [capital] of inds with [aadigit <= dice and bankSI > diceSI] set allcapital (digitrevenue + nondigitrevenue) set NCustomers count inds with [bankSI > diceSI] set bankSSI InitialBankAttraction set bankprofit 0 ask banks [set capitalgain ExtraCapitalGain * (digitrevenue + nondigitrevenue) </pre>
2	Bank	<ul style="list-style-type: none"> * By increasing the number of customer requests in digital banking systems, the bank reduces its physical branches. * As the number of bank branches decreases, personnel and branch costs decrease, and bank profits increase. 	

* With the increase in online banking services and the speed of service delivery, new customers' desire to open an account and use digital services in the bank increases.

* With increased profits from digital services, the bank invests more in FinTechs.

The bank expands its investment and network cooperation with organizations by reducing the number of branches and the need for constant availability to respond quickly to customers.

set cost (DigitalCost * digitrevenue + AncienCost * nondigitrevenue)

set Alldigitalcost DigitalCost * digitrevenue
set digitinvest max (list 0 (DigitalInvestRatio * (capitalgain)))

set bankprofit (bankprofit + capitalgain - cost - digitinvest)

set adigit min (list 0.9 (adigit * (1 + growth) ^ 2))
set bankSSI min (list 0.5 (bankSSI * (1 + growth) ^ 0.25))

3	FinTechs	* As FinTechs' revenue increases, network collaboration should increase by sharing customer information across the chain.	ask fintechs [set revenue digitinvest set cost (DigitalizationCostRatio * revenue) set growth ((revenue - cost) * 7 / (allcapital))
4	Organizations	* As FinTechs' revenue increases, network collaboration should increase through the sharing of customer information across the	ask orgs [set cost Alldigitalcost

And the last step is "**model validation**". There are two stages of validation in agent-based simulation: internal validation and external validation. There are also two processes for internal validation: first, conceptual validation and second, explanatory process. The model's validity determines whether it is suitable for its purpose. In fact, the validation process generally seeks to eliminate model bugs. In order to check the conceptual validity of the model, banking experts' opinions were received during the face-to-face interview, and after making the necessary corrections, they were approved. Then, according to the opinions of two agent-simulation experts, the model explanation process was also approved. During the external validation process, the "accuracy" of the model is tested. The model's accuracy determines the extent to which this model can reflect reality. For external validation, the values obtained from the model should be compared with those obtained by manual calculations for all parameters in each period. Deviations of up to 0.2% are acceptable (According to an interview with experts). If the deviations are more than 0.2%, coding and modeling should be reconsidered. An example of external validation results is shown in the table below, which indicates that the model is validated. Table 5

Table 5. Validation result of the simulation model

Year	Parameter	Simulated value	Measured value	deviations
2018	Accumulated profit of the bank (in million Rials)	42.270.000.000	41.386.000.000	0.02
	Number of customers	4.570.000	3.600.000	0.02
2019	Accumulated profit of the bank (in million Rials)	(457.920.000.000)	(468.708.000.000)	0.02
	Number of customers	5.790.000	5.900.000	0.01
2020	Accumulated profit of the bank (in million Rials)	362.200.000	355.925.000	0.01
	Number of customers	6.980.000	7.170.000	0.02
2021	Accumulated profit of the bank (in million Rials)	1.613.200.000.000	1.572.000.000.000	0.02
	Number of customers	7.690.000	7.500.000	0.02

The last phase in the agent-based research method is to provide a "virtual experiment" to generate relevant hypotheses or explore system dynamics for banking services. Thus, the main variables or parameters assumed to be the most appropriate variables affecting the necessary properties must be identified first. Then, the range of values of the investigated main variables should be defined as a slider.

Random numbers based on real-world data can be used to determine hypothetical variables. Then, multiple simulation times (number of replications: 5) must be performed for each set of experiments, and finally, the simulation result should be analyzed. (Figure 4)

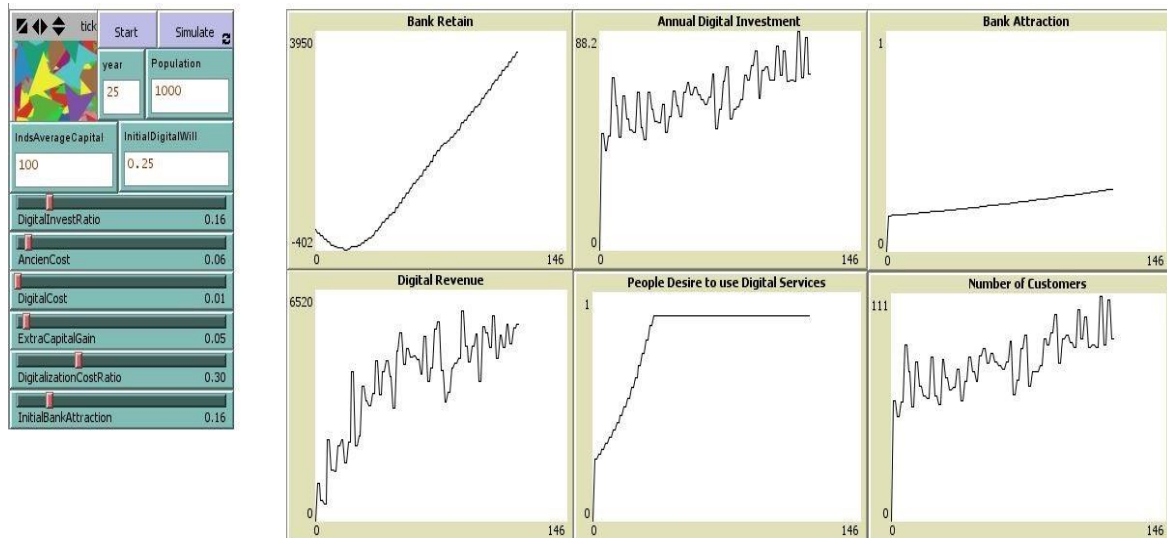


Figure 4. The virtual simulation and testing environment in NetLogo

5. Discussion and Conclusion

This study used agent-based simulation to investigate the behavior of effective factors in the supply chain of banking services in Industry 4.0. Based on the statistical reports and financial statements of Resalat Qard al Hasan Bank, the first bank in Iran without physical branches, as well as the organizations and FinTechs that cooperate with this bank as a network, the behavior of the banking service supply chain was studied. Important models such as bank retained profit, the amount of bank investment in the development of digital tools, revenues from digital banking services, the number of customers, the customers' use of digital banking tools, and the bank's ability to attract customers digitally were simulated for 2016-2021.

According to Figure 2, a regular and specific process was followed to find answers to research questions. Based on the objectives and considering the research process, the research findings can be examined in three areas: identifying the factors of digital banking services supply chain, identifying the effects of Industry 4.0, and agent-based simulation of the impact of Industry 4.0 on the banking service supply chain. According to the literature review and research, a primary list of banking service supply chain components was extracted. In the next step, the effects of Industry 4.0 on the banking service supply chain were identified. Table 3 shows the financial indicators of the research. Then, according to the bank experts and simulation, the supply chain agents of banking services were identified, and the relationships among them were drawn, as shown in Figure 2.

According to the opinions obtained from bank experts, the structural model of the banking service supply chain also includes professional service providers, service integrators, end consumers, and other members of the chain who participate in the service process. Accordingly, the bank acts as a service integrator, the customer acts as the end consumer, the FinTech acts as a financial service provider, and the organizations act as secondary service providers in the chain. Therefore, the combination of agents identified in this study was consistent with the opinions obtained from bank experts in the proposed

structural model. We contribute to the literature by attempting to evaluate the impact of Industry 4.0 on the banking supply chain by proposing an agent-based simulation. More specifically, we are the first study to generate new insights regarding the impact of Industry 4.0 on various aspects of banking operations, including the perspectives of bank revenue, bank profit, bank investment, and customers using digital banking tools. The following are the simulated model outputs for some essential items of the banking supply chain.

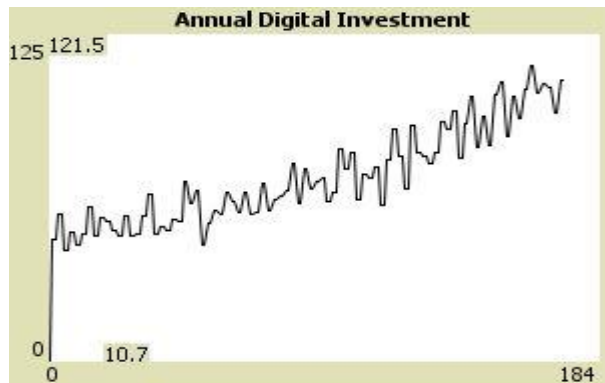


Figure 6. The effect of the advent of Industry 4.0 on the bank's investment in digital development

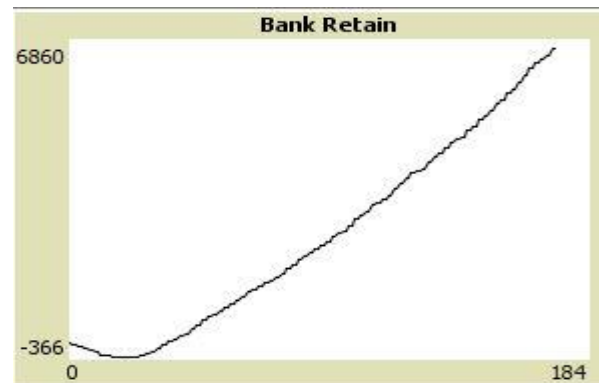


Figure 5. The effect the advent of Industry 4.0 on the retained profits of digital banking

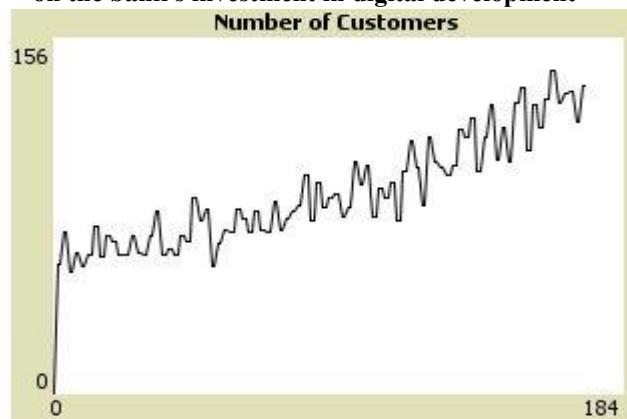


Figure 8. The effect of the advent of Industry 4.0 on the number of bank customers

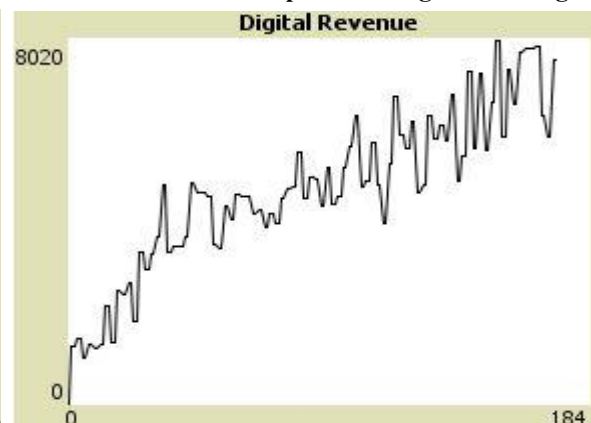


Figure 7. The effect of the advent of Industry 4.0 on revenues from digital banking services

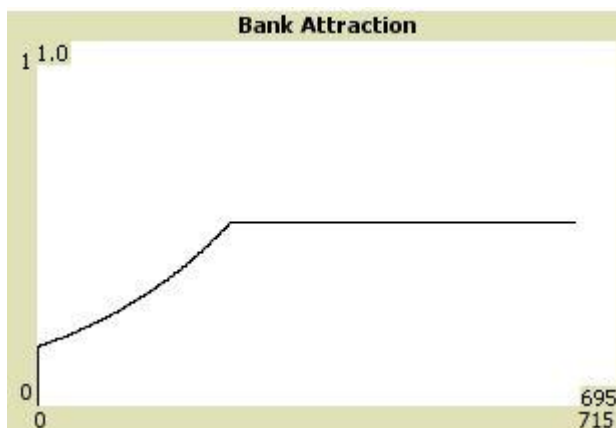


Figure 10. The effect of the advent of Industry 4.0 on the bank's ability to attract customers digitally

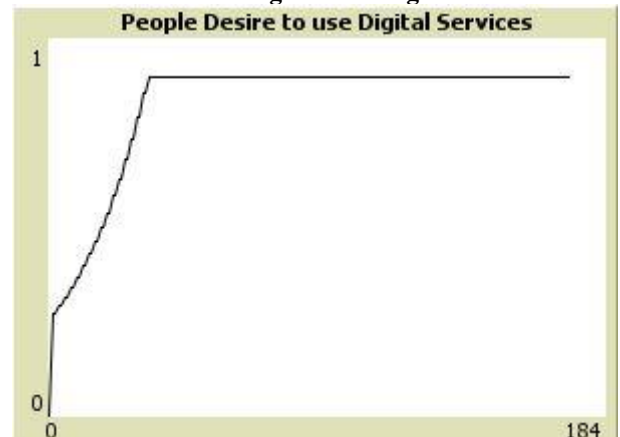


Figure 9. The effect of the advent of Industry 4.0 on customers' use of digital banking tools

According to the results presented in Figures 6 to 11, with the entry of banks into Industry 4.0 and the addition of organizations and fintechs to the supply chain of banking services, bank profitability rates, fintechs profitability, number of customers, the use of digital tools increase Findings and branch costs have dropped dramatically. More specifically, we can see from the results that there is a positive impact of Industry 4.0 on bank investment in digital development. This is not in line with our hypothesis. However, the results show that even if the banks with less amount of capital and difficulty covering the cost of digital investment, they would be able to achieve higher revenue and profit to cover the cost of investment, which induce them to engage in the investment. The positive impact of Industry 4.0 on the number of customers, retained profit, and digital revenue is in accordance with our hypotheses and arguments. We can see that there is also a positive impact of Industry 4.0 on banks' ability to attract customers digitally, as well as customers' use of digital banking tools. However, the effect is also held for a certain period of time, after which there is no significant influence. This can be explained by the fact that although Industry 4.0 incorporates the Internet of Things and other technology-based initiatives, its ability to attract customers can only be sustained by continuous technological innovation. From the customers' point of view, the use of technology in banking services and products will be increased only to a certain point. It can only be further expanded when additional technologies for financial innovations can be made, which gives banking customers more new and advanced experiences.

Extensive and comprehensive communication, close cooperation with partners and suppliers, integration of processes and information based on advanced information and communication technology, sharing information and banks and information systems of chain organizations, and as a result, complete and accurate knowledge of the components of the chain, the position and structure of each other in the fourth industrial revolution is very colorful [50]. Meanwhile, using artificial intelligence in the supply chain leads to improved response to changes in demand, reduced delivery time and reduced costs, and sustainable development. Therefore, organizations are rethinking and redefining the concept of operations management using a supply chain approach based on intelligent technologies [51]. However, in such a situation, the manager must assess the level of risk and act intelligently in all decisions. Accurate, up-to-date, and transparent information reduces the risk of making wrong decisions about digital transformation, so the need to improve digital intelligence in the organization is fully felt [52]. Therefore, digital management programs help bank managers improve their bank's operational efficiency and increase transparency in their decisions by predicting monitoring, and keeping pace with the digital transformation in the supply chain more than ever before [53].

The innovation of this research can be viewed from two aspects. One innovative aspect of this research is that the effective agents in the banking service supply chain were identified for the first time in Industry 4.0, and the interactions among them were considered in agent-based modeling. The literature study showed that, thus far, the interactions among these agents have not been identified and investigated. Despite numerous studies and modeling on the production supply chain in previous studies, no research based on digital banking supply chain simulation has been conducted. Therefore, another innovation of this research is to present a simulated model of an agent-based supply chain of banking services in Industry 4.0, which can be used in the banking system. However, the research method and modeling approach used in this research can be used in other service industries.

6. Suggestions and Limitations

The present study has weaknesses and limitations that naturally reduce the quality of results and suggestions. This includes a lack of behavior simulation of other banks and being satisfied with the financial data of Resalat Qard al Hasan Bank. Thus, it is suggested that a particular study simulates the service supply chain of several top banks in digital services. At the same time, some other influential variables and factors should be included in the proposed model. Still, due to the complexity and lack of detailed information, they were not added to the structures in the model. Therefore, in future studies, it is necessary to identify other effective variables and measure their effects on the supply chain of banking services. It is also possible to systematically analyze the important variables of the digital banking supply chain, identify the causal relationships among the variables through the system dynamics, and simulate the results by agent-based modeling.

The results showed that digital tools and cooperation with FinTechs have become the most significant lever for banks in attracting customers. Therefore, by developing such tools, banks must transform the customer experience and turn themselves into a virtual branch in the digital world. Meanwhile, in Industry 4.0, intermediaries called FinTechs have entirely transformed the supply chain of banking services, and by having customer information, they can develop business and improve services throughout the chain. In such a situation, banks should be able to distance themselves from the world of direct supply and sale of services by using Internet banking due to the cost of in-person services. At the same time, simply attracting customers virtually is not sufficient, and banks should pay special attention to developing their digital service processes to retain customers to receive future services. Banks must promptly identify customers' new demands and adopt the best appropriate solution by increasing investment in the IT sector and network cooperation with FinTechs and organizations.

More specifically, based on our main outputs derived from the innovative method, we have the following recommendations:

1. Banks should further increase the expenditure on research and development, particularly in the area of Industry 4.0; relevant innovations would not only enable them to provide goods and services to the banking customers in a more efficient way but also be very helpful to the banking operation in terms of increasing the number of customers.
2. A sustainable research environment is recommended. As can be seen from our results, customers appreciate relevant technology-incorporated banking products. At the same time, banks should continuously engage in providing innovative banking products and services in order to improve their ability to attract customers digitally and enhance the desire of customers to use digital banking tools.

Declarations

Ethics approval and consent to participate

This is an observational study. The XYZ Research Ethics Committee has confirmed that no ethical approval is required.

Permission to use the data has been obtained from the bank.

Statements

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Competing Interests

The authors have no competing interests to declare relevant to this article's content.

Author contributions

All authors contributed to the study's conception and design. All authors performed material preparation, data collection, and analysis. The first draft of the manuscript was written by [Vahid Shahabi], and all authors commented on previous versions. All authors read and approved the final manuscript.

Conflict of Interests

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria, educational grants, participation in speakers' bureaus, membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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