MARMARA UNIVERSITY
INSTITUTE FOR GRADUATE STUDIES
IN PURE AND APPLIED SCIENCES

ANALYSIS OF THE LOGISTICS 4.0 EFFECTS ON SUPPLY CHAIN RESILIENCE VIA SYSTEM DYNAMICS APPROACH

GÜLŞAH ŞAHİN

MASTER THESIS

Department of Industrial Engineering

Thesis Supervisor

Prof. Dr. Hüseyin Selçuk KILIÇ

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TEDARİK ZİNCİRİNİN DAYANIKLILIĞINA LOJİSTİK 4.0'IN ETKİLERİNİN SİSTEM DİNAMİĞİ YAKLAŞIMIYLA İNCELENMESİ

Dördüncü sanayi devrimi ya da diğer bir deyişle endüstri 4.0, hem günlük yaşamımızda hem de iş hayatının farklı alanlarında karşımıza çıkan güncel uygulamaların başında gelmektedir. Endüstri 4.0 konseptlerinden yola çıkarak ortaya çıkan lojistik 4.0 ise nakliyat, şirketler arası iletişim gibi konularda teknolojik gelişmelerden faydalanma ve dijitalleşmeyi kapsar.

Bu tezin konusu sistem dinamiği yaklaşımıyla lojistik 4.0 kapsamında ortaya konan teknolojilerin tedarik zinciri dayanıklılığına etkilerinin incelenmesidir.

Tez çalışmasının amaçlarından biri lojistik 4.0 konseptinin içerdiği teknoloji bileşenlerini belirlemek, tedarik zinciri dayanıklılığının ne olduğunu ortaya koymak ve elementlerini saptamaktır. Her bir teknolojinin tedarik zinciri dayanıklılığı üzerindeki etkilerini ayrı ayrı ortaya koymak ve bu sayede şirketlere yol gösterici olmak ise tezin bir diğer amacıdır.

Buradaki etkileşimler sistem dinamiği yaklaşımı kapsamında olan nedensel döngü diyagramıyla ortaya konmuştur ve sistemin 12 aylık davranışı referans davranış modeliyle gösterilmiştir. Buna ek olarak seçilen farklı teknolojilerin bir arada kullanımının tedarik zinciri dayanıklılığı üzerindeki etkilerini incelemek için senaryo analizleri yapılmış ve bu senaryolar sonucu sistemin göstereceği davranışlar gösterilmiştir.

ABSTRACT

ANALYSIS OF THE LOGISTICS 4.0 EFFECTS ON SUPPLY CHAIN RESILIENCE VIA SYSTEM DYNAMICS APPROACH

The fourth industrial revolution, or in other words, industry 4.0, is one of the current applications that we encounter both in our daily life and in different areas of business life. Logistics 4.0, which emerges from the concepts of Industry 4.0, covers the use of technological developments and digitalization in subjects such as transportation, communication between companies.

The subject of this thesis is to examine the effects of technologies introduced within the scope of logistics 4.0 with a system dynamics approach on supply chain resilience.

One of the aims of the thesis study is to determine the technology components included in the logistics 4.0 concept, to reveal what supply chain resilience is and to determine its elements. Another aim of the thesis is to reveal the effects of each technology on the supply chain resilience and to guide companies in this way.

The interactions are illustrated with the causal loop diagram, which is within the scope of the system dynamics approach, and the 12-month behaviour of the system is shown with the reference behaviour pattern. In addition, scenario analyzes were made to examine the effects of the combined use of different technologies selected on supply chain resilience, and the behaviour of the system as a result of these scenarios was shown.

ABBREVIATIONS

BDA : Big Data and Analytics
CLD : Causal Loop Diagram
IoT : Internet of Things
RBP : Reference Behaviour Pattern
SAR : Simulation and Augmented Reality
SCR : Supply Chain Resilience

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1. INTRODUCTION

There have been many technological developments throughout human history. Since the first industrial revolution, these technological developments have gained a great momentum and this has had various effects on many sectors. The concept of industry 4.0, which expresses the 4th industrial revolution, has been mentioned a lot in the literature in recent years. Industry 4.0, which has had a global impact, has made it possible for technologies like the internet of things, autonomous robots, and blockchain to be applied in both businesses and our daily lives.

One of the areas where Industry 4.0 is applied is the logistics sector. The concept, which is referred to as logistics 4.0 in the literature, addresses industry 4.0 technology applications in the logistics sector. In this context, the use of certain technologies within the scope of industry 4.0 in the logistics sector can be mentioned.

In today’s circumstances, any company's supply chain is defenceless to unforeseen problems. Problems that may occur in supply chains can have tremendous consequences. As a result, it is crucial for businesses to improve their supply chain resilience. Supply chain resilience has been expressed by various elements in the literature.

System dynamics is an approach in which the behaviour of the system and the interactions between various elements in the system can be observed. By using causal loops, which are included in the system dynamics approach, the relationships between the determined elements can be revealed in detail.

The aim of this thesis is to develop a model via system dynamics approach which is intended for analysing the effects of Logistics 4.0 on supply chain resilience (SCR). In order to achieve this aim, there are many objectives that has to be achieved primarily.

One of the objectives of this thesis is to reveal the concepts and components of logistics 4.0. It is one of the important milestones of the thesis to reveal the scope of the concept, which was derived from Industry 4.0 and started to be used by various companies, in detail and to determine what it contains. Industry 4.0 is frequently studied in academic researches. With this study, it is aimed to show the importance of logistics 4.0 concept, which is relatively less prominent.

Another objective of the study is related to the introduction of resilience. Determining what resilience means and what the SCR includes as a concept are important stages of the study. Along with aiming to reveal the concept of resilient supply chain, using the model to be developed, it is aimed to investigate the effects of logistics 4.0 on the resilience of the supply chain in general. With this approach, it is aimed to analyse supply chains, decide logistics 4.0 components which should be added in the model, create a SCR model via system dynamics software which includes those components and evaluate the effects of logistics 4.0 on SCR. In addition, it is aimed to be a guiding thesis for all companies operating in all sectors by demonstrating which logistics 4.0 component has more impact on the system to be developed. In this way, companies can have an idea about which activities they should create or prioritize in order to have a resilient supply chain. Thus, they may be able to respond quickly to the crises and issues that will occur, stand firm against the problems and be able to return to their former state. In addition, this study aims to raise awareness about the advantages of the use of technological developments in the supply chain management.

In this context, a general introduction is made in the first part of the study. The study's second part introduces the concept of supply chain management. The literature on SCR concepts is reviewed in the third section, and the concepts' scope is explicitly stated. The elements of SCR are expressed by looking at the literature. The concept of industry 4.0 and its development process are discussed in the study's fourth part. In the fifth part of the study, the formation, development and stages of Logistics 4.0 are mentioned. Information technologies within the scope of Logistics 4.0 are revealed. In the sixth part of the study, the system dynamics approach and working principle are mentioned. In the seventh part, a literature review is given. In this context, the literature of "SCR with Logistics 4.0 and Industry 4.0" and "Literature of SCR with System Dynamics" are searched separately in the literature. The eighth part of the study is the material and method section. In this section, the effects of each of the logistics 4.0 technologies on each of the SCR elements are revealed by conducting a detailed literature review. These interactions are demonstrated with various causal loop sub-diagrams using VENSIM software, a system dynamics tool. The main model is created by combining these sub-diagrams.

2. SUPPLY CHAIN MANAGEMENT

2.3. Supply Chain

The supply chain refers to the interconnected set of processes associated with maintaining, arranging, and monitoring the flow of materials, components, and final products from suppliers to customers (Stevens, 1989). Likewise, Christopher (1994) defined supply chain as an organizational network which connects many functions and practices that create value, via downstream and upstream links, until the time products are purchased by the final consumer.

Supply chain is a system of facilities and practices that conducts the tasks of production processes, inventory sourcing from suppliers, inventory transportation between plants, product processing, final products delivery to consumers, and after assistance for sustainability (Mabert and Venkataramanan, 1998). In other terms, it is a network of interconnected organizations that control, manage, and improve the flow of resources and information from provider to customer (Lysons and Farrington, 2006).

In another definition, supply chain in an enterprise refers to all of the elements that create value during the production of raw materials, those who deal with procurement in the transformation of raw materials and semi-finished products into finished products, and the delivery of the products to the end user via distribution channels (Yükçü and Gönen, 2008).

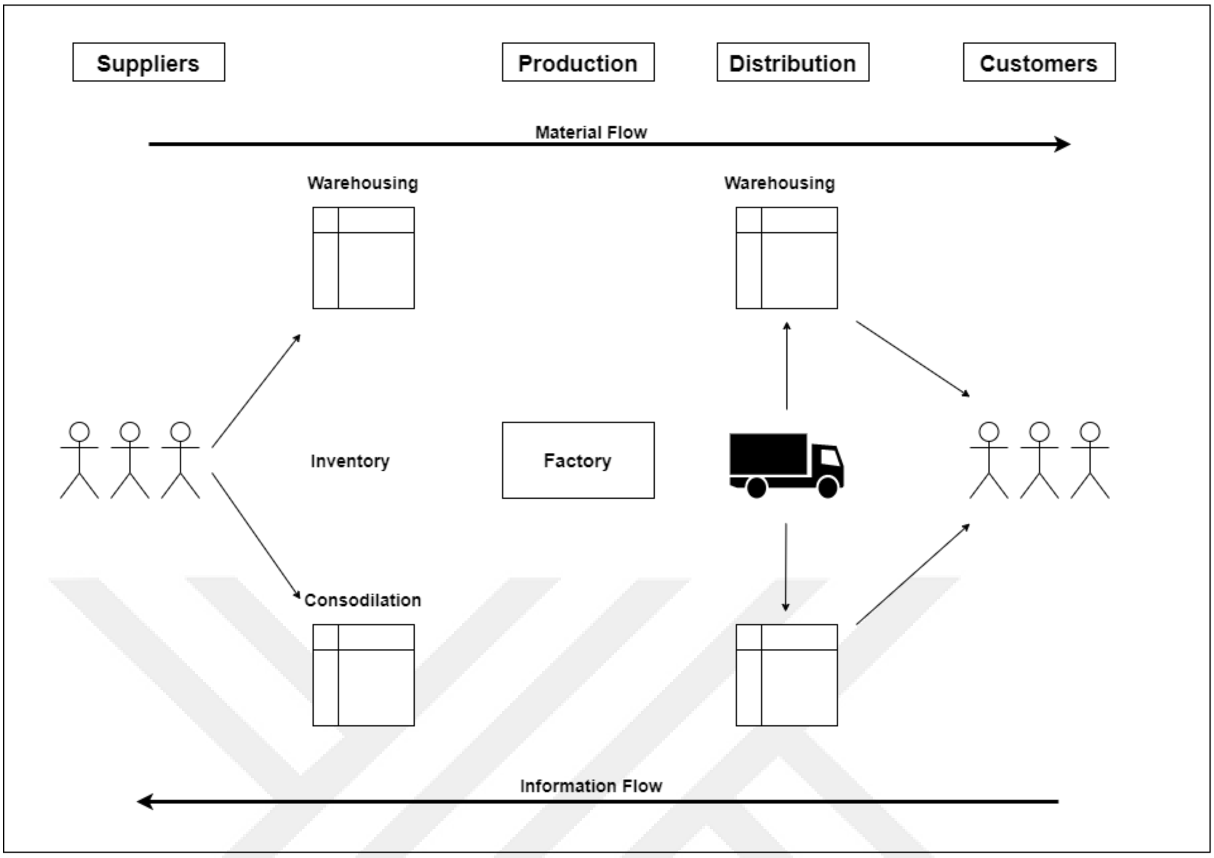

Figure 2. 1. Overview to Supply Chain

In the figure 2.1 (Stevens, 1989) it is shown that the supply chain is a linked set of actions associated with scheduling, organizing, and managing the flow of material and information between producers to consumers. Each component in the chain has its own attitude and goals, however all members should have collective supply chain aims considering their end customer needs. They should also be able to understand the natural state of their connections with each other (Mentzer et al., 2001). Therewithal, varied goods and services necessitate unique supply chain approaches that has to be compatible with customer needs (Aamer, 2017).

2.4. Supply Chain Management

At this point, the concept related to the management activities of these processes becomes important: Supply Chain Management. Business management has joined the world of internetwork rivalry and accordingly, Supply Chain Management (SCM) refers to the management of various connections throughout the supply chain (Lambert and Cooper, 2000). The coordination of data, procedures, products and funding from the initial supplier to the final customer, including waste, is related to SCM (Ellram et al. 2004).

According to the Council of Supply Chain Management Professionals' definition from 2013, supply chain management is a term that includes the planning and management of purchasing, conversion, and logistics operations. It covers all logistics management actions along with production functions, and it is responsible for enabling process and activity integration with advertising, selling, product creation, accounting, and digital systems (CSCMP, 2013).

The SCM was firstly implemented in operational tasks and then expanded to cover all entities connected at a strategic stage in order to accomplish total merger and boost efficiency (Vanichchinchai and Igel, 2009). Over time, SCM has acquired a strategic function that directly contributes to the success of the business, contrary to the traditional view that it is merely a component of operational practices (Parkhi et al., 2015).

The Global Supply Chain Forum outlined eight key processes that form the foundation of SCM (Croxton et al., 2001):

• Customer Relationship Management

• Customer Service Management

• Demand Management

• Order Fulfilment

• Manufacturing Flow Management

• Procurement

• Product Development and Commercialization

• Returns.

3. SUPPLY CHAIN RESILIENCE (SCR)

Every company's supply chain can be vulnerable to various disruptions in today's unpredictable and volatile environment (Knemeyer et al., 2009). Disruptive incidents in a supply chain can also have large and negative consequences on the financial status of concerned organizations (Craighead et al., 2007). For these reasons, the necessity of dealing with threats affecting the supply chain has become an inevitable situation for companies. At this point, we encounter a term that is frequently used in the literature: SCR.

Table 3. 1. SCR Definitions

Authors	Definitions	Year
Rice and Caniato	*"The ability to react to unexpected disruption and restore normal supply network operations"*	2003
Christopher and Peck	*"The ability of a system to return to its original state or move to a new, more desirable state after being disturbed"*	2004
Ponomarov and Holcomb	*"The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function"*	2009
Melnyk et al.	*"The ability of a supply chain to both resist disruptions and recover operational capability after disruptions occur"*	2014
Kim et al.	*"A network-level attribute to withstand disruptions that may be triggered at the node or arc level"*	2015
Tukamuhabwa et al.	*"The ability of a supply chain to prepare for and/or respond to disruptions, to make a timely and cost-effective recovery, and therefore progress to a post-disruption state of operations"*	2015
Mubarik et al.	*"The capability of a supply chain to operate in the face of massive disturbances and disruptions with or without a limited decrease in its performance"*	2021
Wieland and Durach	*"The capacity of a supply chain to persist, adapt, or transform in the face of change"*	2021

Resilience can be generally defined as a dynamic system's potential to rapidly respond to disruptions that endanger system operation, viability, or growth (Masten, 2014) and the foundations of studies on resilience have emerged during the development of social psychology theory, and it is a subject that has been studied for many years in the fields of psychology and ecology, on the other hand, in recent years it has been integrated into different topics such as risk management and supply chain (Ponomarov and Holcomb, 2009). There are various definitions of SCR in the literature. Some of these definitions are shown in table 3.1.

When the table is examined, it can be seen that most definitions focus on organizations' disruptions and reinstatement successes. Svensson (2001) defined supply chain disruption as “unplanned events that may occur in the supply chain which might affect the normal or expected flow of materials and components”. Companies should not consider SCR as unimportant in order to avoid serious damage in such events, which they may encounter, even if not frequently. Underestimating or failing to anticipate the incidence and effects of an incident can result in high-impact disruptions to SC processes, regardless of SC volume or sector, and handling SC resilience is an essential aspect for a sustainable supply chain (Ribeiro and Barbosa-Povoa, 2018).

A general literature table on SCR is given in Table 3.2. When the table is examined, it can be seen that SCR is a subject studied in the literature, a wide variety of solution methods are used and there are different application areas for this subject.

Table 3. 2. Literature Review Table of SCR

Author / Authors	Publication Year	Subject	Methods	Application Area
Geng et al.	2013	Cluster Supply Chain Resilience	Cluster Supply Chain Network Model	Hypothetical Data
Harrison et al.	2013	Supply Chain Disruptions	READI – Resiliency Enhancement Analysis via Deletion and Insertion	Hypothetical Data
Xiao and Wang	2014	Resilience Optimization of Medical Device Distribution Networks	Mixed Integer Linear Programming Model	China
Kim et al.	2015	Conceptualization of Supply Network Disruption and Resilience from the Network Structural Perspective	Graph Modeling	Hypothetical Data

Hasani and Khosrojerdi	2016	Robust Global Supply Chain Networks Design Under Uncertainty	Mixed Integer Non-Linear Programming Model	Country in the Middle East
Spiegler et al.	2016	Dynamics and Resilience of a Grocery Supply Chain	System Dynamics Approach	United Kingdom
Chen et al.	2017	Proposal of a Unified Framework for Quantifying Supply Chain Resilience and Reliability	Bayesian Network	Hypothetical Data
Das and Lashkari	2017	Production System Risk Resilience Measurement and Supply Chain Decision-Making Process Integration	Multi Objective Linear Programming	Hypothetical Data
Li et al.	2017	Definition of a new resilience measure within its maximum allowable recovery time after disruptions	Monte Carlo Simulation	China
Ivanov	2018	Supply Chain Resilience and Sustainability	Discrete Event Simulation	Hypothetical Data
Mackay et al.	2019	Supply Chain Robustness and Resilience	Empirical Research	-
Ivanov and Dolgui	2020	Introduction of a New Angle in Supply Chain Resilience and a New Scale of Viability Against Covid 19 Disruptions	Dynamic Game Theoretical Modeling	-
Gu et al.	2021	The Impact of Information Technology Usage on Supply Chain Resilience and Performance	Empirical Research	China
Novoszel and Wakolbinger	2022	Meta-analysis of Supply Chain Disruption Research	Meta-Analysis	-

3.1. Supply Chain Resilience Stages

When the literature is examined, certain reactions to various events and situations are expressed in the definitions of SCR. These reactions that need to be realized in the process and the phases they occur reveal the stages required to provide SCR. According to

Kamalahmadi and Parast (2016) to create a resilient supply chain, it is necessary to focus on 3 stages. These stages are shown in figure 3.1 and explained in detail in this section

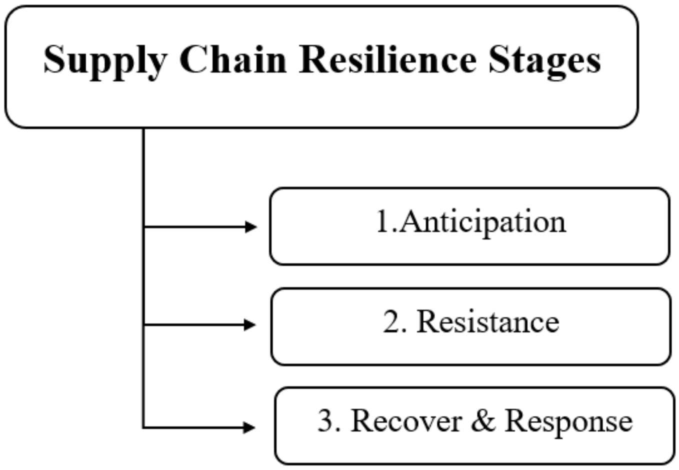

Figure 3. 1. SCR Stages

3.1.1. Anticipation

The first stage of SCR, anticipation is about being prepared for potential disruptions. Therefore, proactive strategies should be applied at this stage. Proactive strategies refer to abilities required in the pre-disruption period; important elements in the definitions are plan, anticipate, warn, and make preparations (Ali et al., 2017). The consequences of disruptions should be properly acknowledged, the probability of their emergence should be reduced and, for crises, contingency preparations should be developed (Kamalahmadi and Parast, 2016).

3.1.2. Resistance

Resistance is related to the capacity to respond rapidly in the case of a disruption in order to deal with it in the during-disruption stage (Ali et al., 2017). The capability of a mechanism to reduce the damage of a disruption by avoiding it totally or by shortening the period between the beginning of the disruption and the beginning of recovery from that disruption is referred as resistance ability (Melnyk et al., 2014). To avoid SC and market breakdowns and assure the availability of products and services, SC resistance to disruptions must be assessed on a spectrum of viability (Ivanov and Dolgui, 2020).

3.1.3. Recover and Response

Recovery refers to a system's capacity to recover operating conditions after a disruption (Melnyk et al., 2014). After disruptions, companies may notice new risks or opportunities and may need to rebuild, modify, or reorganize their risk management systems to decrease threats and capitalize on possibilities (Ambulkar et al., 2015). This stage basically covers the following consideration: companies should be able to give the appropriate and necessary reaction to the incidents that occur and then be able to return to the preferred state (Brandon-Jones et al., 2014; Tan et al., 2020).

3.2. SCR Elements

When the literature is examined, it can be seen that many SCR elements are mentioned. Flexibility and redundancy can be seen as two of the most cited key elements in the literature (Sheffi and Rice Jr, 2005; Tomlin, 2006; Carvalho and Cruz-Machado, 2011; Pal et al. 2014). In addition to these two, Azadeh et al. (2014) specified visibility and velocity as SCR elements. On the other hand, Shekarian and Mellat Parast (2021) added agility and collaboration to these two elements. Jüttner and Maklan (2011) expressed the important elements affecting SCR as flexibility, visibility, collaboration and velocity. In this study, SCR elements are considered as flexibility, redundancy, velocity, visibility, collaboration and efficiency and the aforementioned elements are explained in this section and shown in figure 3.2.

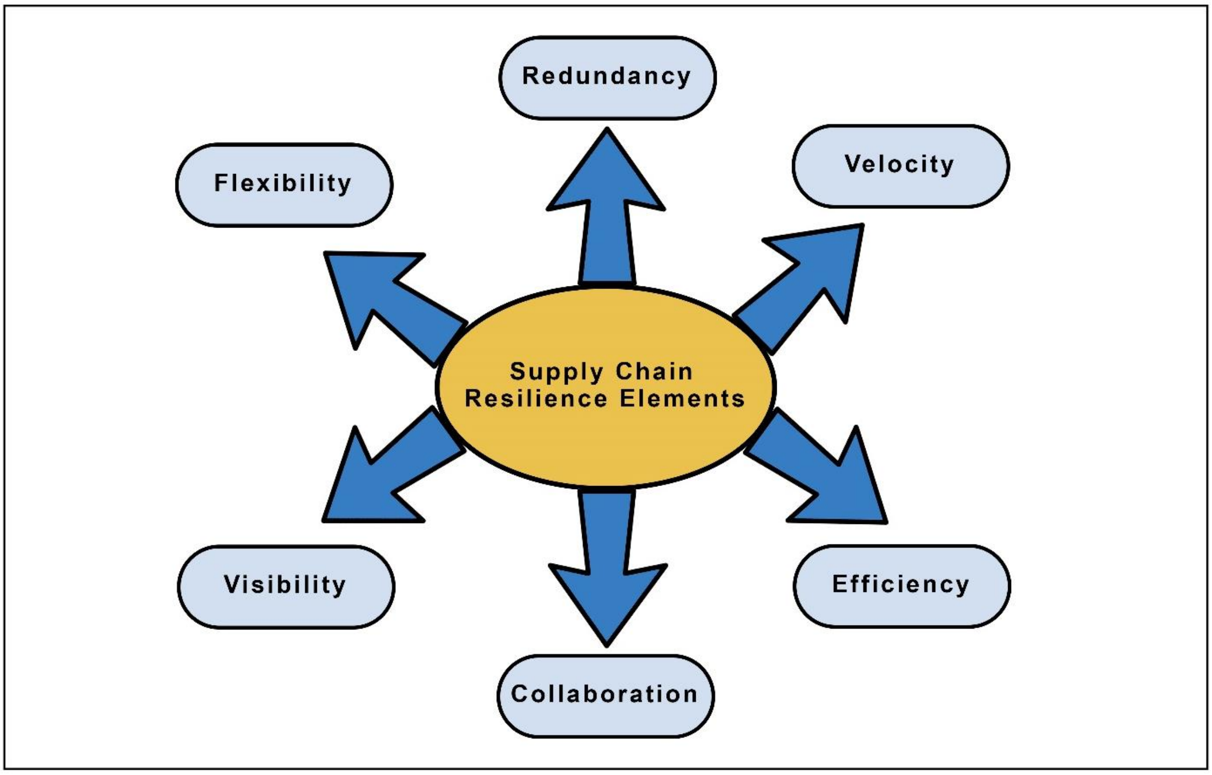

Figure 3. 2. SCR Elements

3.2.1. Flexibility

Flexibility is stated as the capacity to adapt/change in general (De Toni and Tonchia, 1998). According to Upton (1994) flexibility can be expressed with three components:

(1) Range: It refers to a skill to affect or adapt a wide range of a change.
(2) Mobility: It is the simplicity of changing some factors such as time and money in certain changes.
(3) Uniformity: It represents the stability factor in the range while the system is running.

The supply chain's flexibility is critical in constructing emergency action plans for disruptions (Kamalahmadi and Parast, 2016) and also it may provide strategic advantages in daily operations (Sheffi and Rice Jr, 2005). Flexibility in the supply chain is a crucial aspect in developing efficient supply chain network (Tummala et al., 2006).

3.2.2. Redundancy

One of the ways to create a resilient supply chain is to create a redundancy (Sheffi and Rice Jr., 2005). The term ‘redundancy’ refers to some resource reserves prepared in advance of potential interruptions and the efficiency of it is determined by the size and extent of the design at the proactive phase, as well as its actual use during disaster and post-disaster recovery process (Pavlov et al., 2019). In the scope of redundancy, capital and capacity investments can be considered to assure the continuation of the ability to respond to interruptions in the supply chain (Kalkan et al., 2021).

3.2.3. Velocity

The term velocity is defined as "speed of motion, action or operation, rapidly and swiftness" (Jüttner and Maklan, 2011). In terms of supply chain, it can be associated with how quickly it can respond to demands and changes in those demands (Mandal et al., 2016). There are three core cornerstones of enhanced supply chain velocity: simplified procedures, decreased lead-times, and lowered nonvalue-added time (Christopher and Peck, 2004). Thus, velocity assists adaptive ability over all three stages of a risk occurrence: pre, during, and post disruptions (Jüttner and Maklan, 2011).

3.2.4. Visibility

Supply chain visibility is the ability to easily access supply chain elements and various disruptions that may arise in this process, and to take action against these disruptions (McCrea, 2005; Francis, 2008). Visibility is a significant skill that enables a company to reduce weak points in their supply chain in order to protect corporate success (Brandon-Jones et al., 2014). As the issue of visibility gained importance and companies became aware of this issue, they focused on identifying and correcting their deficiencies in order to increase their productivity and efficiency (Lee and Rim, 2016). The overall expense of distributing, reduced storage level, holding and overall cost, better transportation, business and market success, flexibility and performance are some of the advantages of strong visibility (Pidun and Felden, 2012). Increased resilience can be obtained by improving visibility throughout the supply chain (Silva et al., 2017).

3.2.5. Collaboration

Collaboration was defined as the capacity to successfully cooperate with other individuals for common advantage (Pettit et al., 2010). This term also refers to the necessity to broaden employee's view of the system in order to increase profits (Simatupang and Sridharan, 2008). Supply chain collaboration demands a considerable degree of confidence, dedication, and sharing of knowledge among supply chain members which have a mutual vision (Spekman et al., 1998). According to this vision, efficient collaboration among supply chain members is fundamental to achieving company goals (Kampstra et al., 2006).

3.2.6. Efficiency

Efficiency was identified as the ability to generate outcomes with the reduced resource needs and it is related with waste minimization, worker performance, equipment usage, and output variation (Pettit et al., 2010). These related situations may be understood as holding less inventory throughout the supply chain for some companies, and when dealing with a potential disruption, it should be recognized that it might negatively impact SCR, therefore the risks associated with these situations should be considered (Ivanov, 2018). The majority of enterprises had a desirable influence on overall expense, expenses of raw materials, labour expenses, and quality as a result of efficiency (Gunasekaran, 2015).

4. INDUSTRY 4.0 – FOURTH INDUSTRIAL REVOLUTION

Since the first industrial revolution, substantial changes in production have occurred, affecting all processes, beginning with steam machines and proceeding through digitalization in production (Qin et al., 2016). The term industry 4.0, which expresses the fourth industrial revolution, has been mentioned frequently in the literature in recent years. Kamble et al. (2018) defined industry 4.0 as a production revolution that provides a completely new vision on how production may combine with new technologies to achieve the highest output with the lowest raw material use. According to Pfohl et al. (2015) "Industry 4.0 is the sum of all disruptive innovations derived and implemented in a value chain to address the trends of digitalization, autonomization, transparency, mobility, modularization, network-collaboration and socializing of products and processes.". In this section, the history of industrial revolutions is explained and an overview of the concept of industry 4.0 is given.

4.1. History of Industrial Revolutions

Various technological and social developments over the centuries have led to industrial revolutions. The first industrial revolution (Industry 1.0) began with the invention of the steam engine by James Watt in the 18th century and caused a massive change in the way of production: machines working with water and steam power began to be used (Koc and Teker, 2019). These changes have led to the replacement of manual labor, which has been going on for centuries, by machines and the need for various equipment (Popkova et al., 2019). Steam transportation vehicles built during this period resulted in significant developments because of its ability to carry people across longer distances in shorter times and with the increase in productivity, small shops began to evolve into large companies (Sharma and Singh, 2020). Another notable accomplishment during this period was the production of the first mechanical loom (Yıldız, 2018). Generally, the first industrial revolution is associated with mechanization (Qin et al., 2016).

The second industrial revolution (Industry 2.0) occurred in the late nineteenth and early twentieth centuries as a result of accumulating technological developments in manufacturing (Popkova et al., 2019). During this period, electrical energy was used in production and is referred to as the period when mass production was started (Yıldız, 2018). This time period is related to greater rationalization and separation of labor in industrial firms (Torres et al., 2022). Innovations such as the telephone, gas turbine and inorganic fertilizers took place during this period, as well as the development of electricity grids and new transport systems (Thomas and Nicholas, 2018).

The Third Industrial Revolution (Industry 3.0), that occurred shortly after World War II, resulted in fundamental transitions in informational theory and the power of data and it played an important role in constructing an environment that needed new structures after the war (Thomas and Nicholas, 2018). There were innovations in telecommunication, electronics, automation, and robotics technology throughout this time period (Colombo, 2021). Production systems have ceased to be analogue and digital systems have been integrated into the manufacturing departments of companies (Yıldız, 2018). During this time, the necessity of human labor declined, but the velocity of manufacturing continued to rise owing to computer technology (Koc and Teker, 2019).

These three industrial revolutions provided increased productivity and various solutions to the needs of the age. However, issues such as changing consumer demands over time, various developments in technology, more complex production processes arising from product diversity, and the need to adapt quickly to changes made it necessary to form the fourth industrial revolution. The Fourth Industrial Revolution, also known as Industry 4.0, is one of the terms we have heard frequently in recent years. When the literature is examined, it can be seen that concepts such as "smart factories", "intelligent manufacturing", "industry+" and "industrial internet" are used in various parts of the world as equivalent to the concept of Industry 4.0 that emerged in Germany. Industry 4.0 was initially used as a term in 2011 during the Hannover Fair, and the concept has gained popularity year after year (Vogel-Heuser and Hess, 2016). Article from Kagermann et al. (2011) created a theoretical perspective for Industry 4.0 (Alçin, 2016). The biggest difference of Industry 4.0 from the other three industrial revolutions is that it is based on the Cyber Physical System and in this way, it strives to reach the smart factory (Cheng et al., 2016).

4.2. The Concept of Industry 4.0

Industry 4.0 refers to the combination of various technologies and paradigms in different fields and aims to create smart factories by using cyber physical systems (Thames and Schaefer, 2016). The core of the industry 4.0 idea is the implementation of network-connected smart solutions that enable self-regulating manufacturing which resulted in people, machinery, equipment, and items interaction (Gubán and Kovács, 2017). It is one of the main goals of Industry 4.0 to facilitate communication and information sharing among people, among people and items, and among the items themselves (Ślusarczyk, 2018). With Industry 4.0 applications, information flow can be improved, which can increase the traceability of processes and materials, thus improving the quality control and competitiveness of companies. (Bakhtari et al., 2020).

Products in smart factories are also considered 'smart,' with integrated sensorics that gather actual information for localization, monitoring production stage, and environmental factors over a wireless connection (Rojko, 2017). Smart, linked items provide exponentially growing prospects for new functionality, substantially improved dependability, significantly higher product usage, and features that exceed traditional product limits (Porter and Heppelmann, 2014).

Industry 4.0 comprises horizontal information flow interconnection among partners, vendors, and clients, and also vertical information flow incorporation within enterprises and it combines the digital and actual environments (Hozdić, 2015). Also, all workers and managers can actively join in the operation of production via the internet, which is the form of social manufacturing (Wan et al., 2015).

5. LOGISTICS 4.0

5.1. Logistics

The term 'logistics,' which is at the core of contemporary transportation networks, implies a level of order and supervision over freight transfers which only new technology could have created (Rodrigue et al., 2001). Logistics is the management of material movements and storage in order to deliver the final products to the client at the highest possible quality and at the reasonable cost (Strandhagen, 2017). According to the Council of Supply Chain Management Professionals' definition from 2013, logistics is the practice of planning, executing, and managing processes for the efficient and productive delivery and warehousing of items, including services, and relevant knowledge, from the beginning level to the consuming level in order to meet the needs of clients (CSCMP, 2013). With the widespread use of the supply chain approach, the logistics sector is seen as an important link that provides forward and backward product flow between the production processes and the customer and includes planning, implementation and control (Burmaoglu, 2012).

Logistics sector operations are very important since they can help to both provide minimum cost and numerous advantages to organizations compared to other companies (Uvet, 2020). They were initially limited to transportation and storage, have expanded considerably as a result of increasing globalization activities and technological developments (Sürmen and Aygün, 2006). These logistics operations include purchasing, distribution, inventory control, order management and processing, packaging, items and service assistance, production planning, returns, sales forecasting, waste recovery and disposal, and customer service (Gümüş, 2009).

5.2. History of Logistics

Although the history of logistics dates back to ancient times, significant developments have been witnessed in the last few centuries. The railway was invented in the early nineteenth century, and the plane in 1903; the marine container, which is vital in marine shipping, was invented in 1956 (Speranza, 2018). When these developments are examined, a relationship can be established with industrial revolutions.

Industrial revolutions caused by new technologies and developments in the world have had significant and lasting effects in various fields of companies. In the history of global trade, logistics operations such as shipping, storing, and distributing have undergone numerous changes because of these effects (Yavas and Ozkan-Ozen, 2020). In the figure 5.1, these changes are shown as evolution of logistics. In the figure, attention is drawn to the historical process of the developments, and some of the technological improvements in these processes are expressed. The degree of complexity of each process is also shown in the figure 5.1 (Radivojević and Milosavljević, 2019). These processes are detailed in this section.

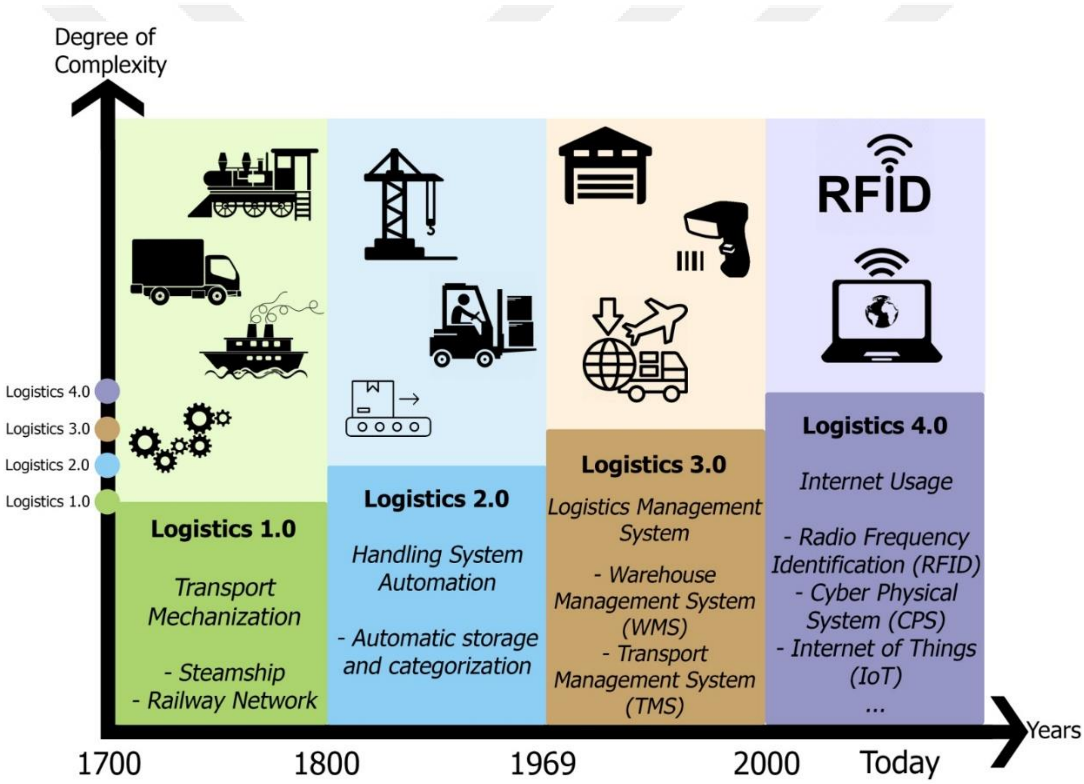

Figure 5. 1. Evolution of Logistics

5.2.1. Logistics 1.0

Logistics 1.0 refers to the effects of developments such as mechanization in the industry on logistics and their causes to technological developments related to logistics. The keyword expressing this period can be determined as ‘transport mechanization’ (Amr et al., 2019). The effects of the use of water and steam power, which are among the most important developments in first industrial revolution period, were significantly seen in logistics. Ships and trains powered by steam engines were utilized as primary forms of travel rather than people and animals for carrying significant amounts of commodities and containers across distant locations (Wang, 2016). In this period, the perspective of warehouses was as departments reserved for storing raw materials and finished products, and products entering or leaving the warehouse were handled and transported manually by manpower (Şekkeli and Bakan, 2018). All of the activities such as the collection and preparation of the products as the order came, were carried out with human power, and this caused the processes to run very slowly and to create a lot of costs due to the need for too many employees (Görçün, 2018).

5.2.2. Logistics 2.0

The finding of electricity and mass production in industry resulted in logistics 2.0 and its keyword can be expressed as 'handling system automation' (Wang, 2016). In this period, electricity and petroleum started to be used as a power source (Domingo Galindo, 2016). With the presence of electricity in the period, electrical logistics equipment started to be used in warehouses, and by this means, products could be placed on the shelves or removed from the shelf automatically (Şekkeli and Bakan, 2018). Synchronised fleet vehicles transported final products and raw materials, and the distribution phase of commodities was handled in accordance with demand forecasts set before to manufacturing (Domingo Galindo, 2016). Along with motorized handling and transportation vehicles in companies, container ships were also used frequently in this period (Wang, 2016; Şekkeli and Bakan, 2018).

5.2.3. Logistics 3.0

Logistics 3.0 refers to a period in which the effects of developments in computer and electronic systems on logistics are seen significantly, and the keyword of this period can be expressed as 'Logistics Management System' (Thomas and Nicholas, 2018; Radivojević and Milosavljević, 2019). The usage of Warehouse Management System (WMS) and Transport Management System (TMS) in the administration of logistics operations was one of the most significant developments of the period (Domingo Galindo, 2016). With these developments as a result of the use of information technologies, the automation and effectiveness of stocking and shipment have been considerably developed

(Wang, 2016). The shipping was carried out by fleet vehicles that had a pre-plans and optimized routes estimated by appropriate software (Domingo Galindo, 2016).

5.2.4. Logistics 4.0

Industry 4.0 has expanded throughout the world and is having a big impact on variety of industries. The concept of Logistics 4.0, which is formed by the application of innovations, software, technologies and applications covered by Industry 4.0 to the logistics sector, has taken its place in the literature as a subfield of Industry 4.0. When the literature is examined, it can be seen that the term ‘smart logistics’ is used synonymously with Logistics 4.0. Smart logistics or Logistics 4.0, emerged with the goal of meeting growing consumer demands and offering sustainable logistics services, its emergence dates back to 2011 (Bag et al., 2020). Smart logistics was defined by Kauf (2019) as the execution of logistic operations, development of smart innovations, considered as outfitted in advanced computer support mechanisms, that allows for full automation of activities. According to Barreto et al. (2017) it is a logistics system that may increase flexibility, adaptability to economic fluctuations, and getting the firm closer to the demands of its customers. One of the most important aspects of Logistic 4.0 is its usage of Cyber-Physical systems, which track and regulate dynamic systems in order to determine, sense, and find the object, and then transfer the input to a computer, which may gather and analyze the necessary information (Domingo Galindo, 2016).

According to Feng and Ye (2021) logistics 4.0 has four characteristics: intelligence, self-organization, flexibility and integration of logistics.

1)Intelligence: Technologies such as artificial intelligence, automation technologies, information and communication technologies are expressed as intelligent technologies and have significant impact on managing logistics management challenges and reducing the demand for labor in operations (Feng and Ye, 2021).

2) Self-Organization: Self-organization refers to a system's ability to function without the need for considerable input from directors, engineers, or technological management (Pan et al., 2016). The self-organization concept allows processes to be autonomous and spontaneous in the absence of an outside influence (Zhang et al., 2017).

3) Flexibility: Because Logistics 4.0 provides flexibility in managing fluctuating and unbalanced customers' needs, organizations can be more receptive to advances that may be made in their manufacturing processes, and that can lead to increased customer satisfaction (Amr et al., 2019).

4) Integration of Logistics: Logistics operations can be controlled from a single point using various technologies that enable data exchange, and connections between various logistics operations can be improved (Feng and Ye, 2021).

Logistics 4.0, owing to various technologies, may provide numerous benefits to businesses. One of them is that it can decrease storage costs by ensuring that customer and supplier orders are completed simultaneously (Wang, 2016). It is known that logistics is one of the most important factors that cause environmental pollution. Logistics 4.0 can find the optimal amount of energy use and thus minimize environmental pollution and provide economic benefits (Kauf, 2019). Another advantage of logistics 4.0 is the reduction of human labor and the standardization of connecting logistic operations to data components (Szymańska et al., 2017). The fleet cars can have a guided software that uses an online portal to collect the essential data, in this way, the traceability of the vehicles can be ensured. (Wang, 2016). One of the main goals of Logistics 4.0 is to enable the long-term fulfilment of customer requirements while reducing service expenses by the use of developing technologies that simplify the control of Cyber Physical Systems (von Stietencron et al., 2021). Logistics 4.0 enables people to evaluate and make forecasts based on real-world data, and it improves the capacity to coordinate activities and interactions (Wang, 2016).

5.3. Information Technologies in Logistics 4.0

There are some key information technologies within the scope of Industry 4.0. In the literature, it can be seen that the concept of logistics 4.0 has developed with the effects of some of these technologies on the logistics sector. In this section, the characteristics of these technologies and their use and benefits in the context of logistics 4.0 are mentioned.

5.3.1. Internet of Things (IoT)

Madakam et al. (2015) defined Internet of Things (IoT) as “An open and comprehensive network of intelligent objects that have the capacity to auto-organize, share information, data and resources, reacting and acting in face of situations and changes in the environment". The IoT connects smart things with embedded software, hardware, and other components with broad Internet technologies, allowing them to integrate and communicate, ensuring data gathering and, eventually, creating a worldwide network (Miorandi et al., 2012). The adoption of IoT allows for the improvement of a simulation world of virtual reality in which enterprise frameworks will be able to control tasks and procedures based on knowledge about the present condition of objects (Radivojević and Milosavljević, 2019). It enables each and every thing to have a distinct identity and to transfer information with one another and with central systems without the need for human interaction. Iot enables users and "things" to be linked 24/7 in every place, preferably without any channel and any service, resulting in a connection between the real and digital universes (Lampropoulos, 2019).

Vehicle tracking systems, determining the location of finished products in large areas such as ports or warehouses, ensuring the performance of transportation conditions by monitoring the openings of containers and cold storage for insurance purposes, and detecting storage incompatibilities in flammable goods stored close to substances in explosive containers are the most common IoT applications used in logistics (Gökrem and Bozuklu, 2016). Real-time monitoring is possible because to the data acquired by sensors in smart devices. IoT, which provides considerable benefits for swiftly recognizing and solving problems that may arise in logistical operations, also helps management activities. In addition to providing in-vehicle information such as temperature and humidity in various transportation areas, it also supports the wayfinding processes of vehicles (Manoj Kumar and Dash, 2017).

Radio-Frequency Identification (RFID)

Despite the widespread usage of barcodes, Radio-Frequency Identification (RFID) technology is gradually replacing them and it has the primary benefit of being distinct of line-of-sight issues and capable of detecting items from a range (Ahuja and Potti, 2010). RFID is made up of three fundamental elements: a reader, a tag, and an antenna: (Maraşlı and Çıbuk, 2015)

- Readers are elements that use radio signals to obtain messages about an item in the format of a numerical code, owing to tags placed on the items.

- Tags are elements that hold data.
- Connection between the tag and the reader is accomplished by the use of antenna.

After obtaining the signal, the reader produces electrical signals through an antenna, and the tag releases identifying data from local memory. The reader then receives and recognizes the data returned by the tag through an antenna. Finally, the reader transmits the information of the identification to the host (Xu et al., 2017). The general working principle of an RFID system is shown in figure 5.2 (Xu et al., 2017).

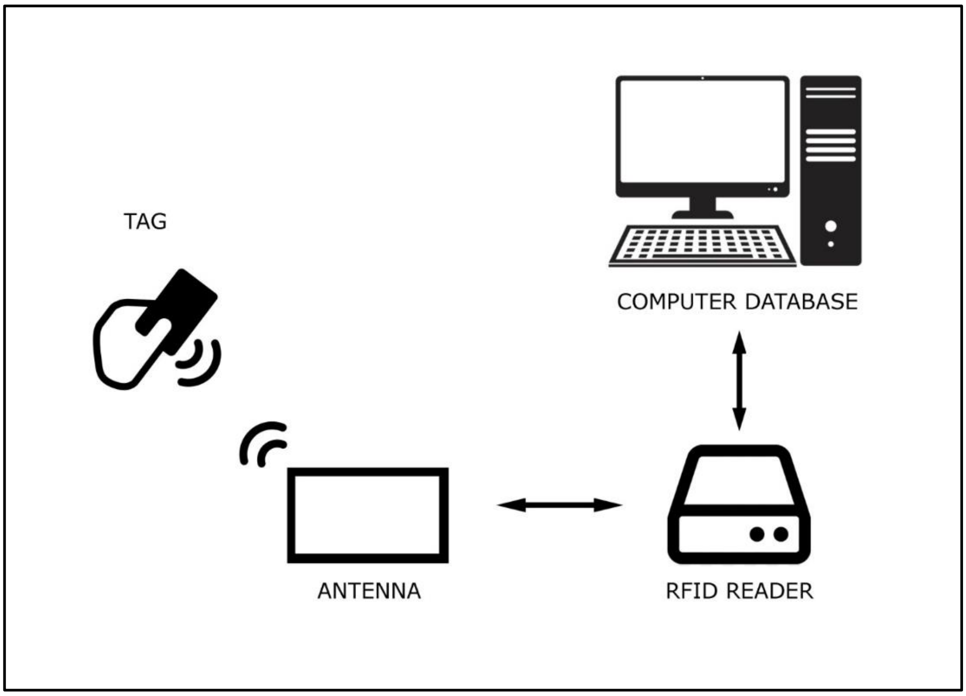

Figure 5. 2. Working Principle of RFID

The information acquired during logistics procedures can be tracked over an internet-based system using RFID, sensors, and global positioning systems (GPS), making logistics activities quicker, more flexible, and transparent (Tadejko, 2015). RFID technology allows for the simultaneous tracking of stock and logistical resources for customers, as well as the visualization of all service operations and thus, systems that respond quickly can be created by increasing visibility in logistics processes (Chow et al., 2007). Some of the advantages of RFID are that it can overcome problems related to stock management, it can reduce inventory and logistics costs, and it can increase overall efficiency, while its disadvantage is that it is a more costly technology than barcode system (Sangani, 2004).

5.3.2. Autonomous Robots

Companies have often used robotics to handle complicated tasks in many sectors, and with the expansion of the usage area of robots, autonomous robots are emerging; and to execute complicated activities in complex situations, these autonomous robots must determine the proper time for preparation and reaction, the proper method for identification and recovery from failures, and dealing with competing objectives (Rüßmann et al., 2015; Simmons 1994). They are being more autonomous, agile and cooperative and, as a result, they can connect with each other and; learn from humans and also securely operate with them. Such robots may expense lower and also have a larger range of functionality than those used in production currently (Rüßmann et al., 2015). Owing to the advent and success of Industry 4.0, robotic technology that provided an extremely valuable impact in industrial manufacturing has recently experienced a significant growth (Dalenogare et al., 2018; Gao et al., 2020; Zezulka et al. 2018).

Robots are commonly practiced in warehouse operations. Non-autonomous robots can perform basic warehouse tasks. However, customers' demands for customised products and specialized activities have raised the need for autonomous robots. The combination of relevant sensors into a robotic device opens up new possibilities for improvements such as recognition of numerous items and barriers, secure routing in human workplaces, and accurate placement with given uncertainties (Wahrmann, 2019).

Companies that execute storing and unloading activities with forklifts depending on human control have slower operating processes which are more difficult to regulate (Demiral, 2021). Autonomous robots enable these operations to be quicker, less expensive, and more controllable. Apart from these, reasons such as ensuring safety and increasing sensitivity are important reasons for the preference of autonomous robots. Autonomous robots, owing to sensors and components such as artificial intelligence, can recognize the areas they are in and perform their movements without the need for mapping or defining specific starting points beforehand, and they can also reach narrower areas (Fragapane, 2020).

5.3.3. Big Data and Analytics (BDA)

The meaning of big data refers to massive, varied and dynamic data sets that have an effect on the company's internal decision-making on its strategic plan. Larger data volumes and enhanced technical skills thus boost the competitive benefit of companies by adding value, productivity and innovation (Erboz, 2017). The storage of data day by day has brought it to massive proportions and revealed the concept of big data (Eker, 2022). The method of Big Data Analytics is to evaluate massive databases to have insight on consumer habits, algorithms for patterns, trends and other details, and it can be used in various fields (Ji and Wang, 2017). The compilation and systematic evaluation of data from a large variety of sources and customer service processes should become a standard to assist decision-making tasks (Rüßmann et al., 2015).

In the literature, 4 characteristics that define big data are given as Volume, Variety, Veracity, and Velocity (Guo et al., 2014). The term "Volume" refers to the ability of big data systems to manage massive amounts of data (Koseleva and Ropaite, 2017). The term "Variety" points to the fact that data can be of many types and sources (Shu, 2016). The “Veracity” of data refers to how much information may be accepted considering the reliability of its provider (Parwez et al., 2017). “Velocity” relates to the rapid generation and processing of data (Shu, 2016).

Big data analytics helps firms increase business productivity and profitability, and its significance is growing as big data expands swiftly (Jin and Kim, 2018). Tools used in logistics to handle big data enable effective and easy management and analysis of massive amounts of data generated by sensors on paths and cars, client apps, GPS systems and webpages (Ayed et al., 2015). In addition, real-time data analysis and interpretation may help businesses make better, quicker decisions to meet client demands and it can also assist organizations in improving the development and maintenance of their supply chains by lowering costs and eliminating risks (Govindan et al., 2018).

5.3.4. Simulation and Augmented Reality (SAR)

Simulation modelling is an approach by which models of a real or imaginary system are used to help fully understand or forecast the actions of the designed system and comprehensively demonstrate it. Simulation helps minimize expenditures, cuts production times, increases product efficiency and significantly improves information systems (Rodič, 2017). Classical simulation techniques focus essentially on design and manufacturing processes, while multidisciplinary modelling in future factories may also play an increasingly crucial role in short-term decisions and in the stages of ramp-up and actual manufacturing (Weyer et al., 2016). Such modelling can use real-time data to replicate the actual conditions in a computer environment that can involve devices, elements and people (Rüßmann et al., 2015).

The expression Augmented Reality was identified which "supplements the real world with computer-generated objects that appear to coexist in the same space as the real world" (Azuma et al., 2001). Augmented-reality-based technologies provide a range of services, such as the selection of parts in the storage facility and submission of repairing information through smart phones. With Industry 4.0, organizations may allow a much greater use of augmented reality to provide staff with real-time knowledge to enhance decision-making and tasks (Rüßmann et al., 2015).

SAR technologies can be used in most parts of logistics processes. The advantages of integrating AR to production design and planning tasks include the optimization in the construction phase, the minimization of both time and expenses required for product advancement, and the prevention of any mistakes that may emerge in later phases (Rejeb, 2019). AR can enhance logistics components implementation and reduce product collection duration in human-powered warehouses (Cirulis and Ginters, 2013). AR can have an important part in keeping carriers' everyday activities easier, and it can give practical answers to order selecting difficulties, allow for interactive operation with minimal mistakes and also, help the process when unexpected problems arise throughout the picker's path (Plakas et al., 2020).

5.3.5. Additive Manufacturing - 3D Printing

In Industry 4.0, additive manufacturing techniques are commonly used to manufacture small amounts of personalized products that provides some benefits, such as complicated design. High-performance, integrated additive manufacturing processes can minimize shipping distances and the inventories (Rüßmann et al., 2015). Operations can be easier and cheaper via additive manufacturing techniques such as fused deposition method (FDM), selective laser melting (SLM) and selective laser sintering (SLS) (Landherr et al., 2016). The most basic production method that companies use to create and produce special and personalized components is 3D printers, and even these words are used interchangeably in the literature. 3D printing is an additive manufacturing because it acts as adding up substances in layers with a computer-aided structure; every layer is printed until a 3D object is produced (Manners-Bell and Lyon, 2012). Because of the sample products produced in 3D printers, errors in production can be noticed and minimized or eliminated, which ensures cost minimization (Wieczorek, 2017).

Stock levels and storage needs can be reduced as a result of mass customization through additive manufacturing. Mass manufacturing's long production cycles can be replaced by mass customization's short manufacturing runs and items created to order. Less work-in-progress and completed items in storage and in transportation can lower the total expenses logistics (Attaran, 2017).

5.3.6. Blockchain

The presence and improvement of blockchain technology has made cryptocurrency a total option to conventional ones in recent years (Lo et al., 2017). A blockchain is a technology that allows you to build a reliable, open and secure distributed ledger (Davidson et al., 2016). It creates a different economic system by pioneering how people interact online (Lee, 2019). Applying timestamps on transactions and messages, blockchain offers universally verifiable proof of a transaction's existence or lack in a distributed system (Faber et al., 2019).

Blockchain is a technology that, with the assistance of the networks, verifies and records all transactions between system users. As a result, it is described as a database made up of blocks that are entirely trustworthy and the dubious transactions that make them up (Ünal and Uluyol, 2020).

Blockchain is utilized frequently in the Bitcoin crypto currency (Ahram et al., 2017). Satoshi Nakamoto published the first paper on Bitcoin in October 2008 outlining its properties as a decentralized payment system (Nakamoto, 2008). Bitcoin is a matter of blockchain being successfully applied, that is the first decentralized global cryptocurrency. With the advancement of blockchain technology, blockchain is predicted to widen its destructive ability for tokening and decentralizing not only currency but also other business assets (Lee, 2019).

Blockchain is a significant technology for the logistics sector since it delivers solutions to supply chain concerns by providing aspects such as traceability, sustainability, and security (Ghimire et al., 2022). The development of blockchain technology allows for continuous product tracing across the supply chain. Blockchain has the potential to reduce the number of mediators in the supply chain, hence disintermediating it. As a result, time and trading losses can be eliminated, and the product can be available at the lowest possible price (Kihel, 2022).

6. SYSTEM DYNAMICS

A system is defined as a collection of various elements that interact with one another (Lin et al., 2020). System thinking is the study of cognitive modeling and logical structuring that has evolved to cope with difficulties in complex systems and make sense of relationships and interconnections between these systems' components, thus, its practical application is known as system dynamics (Haraldsson, 2000).

System Dynamics is a method that focuses on the connection of multiple parts of a system in period and incorporates the dynamic nature by including terms like as stocks, flows, feedback, and delays, and so gives awareness into the dynamic behaviour of a system over time in complicated engineering challenges (Tang and Vijay, 2001). Jay Forrester of MIT pioneered the System Dynamics approach in the 1950s for simulation software analysis of complicated behaviours in social and physical systems (Forrester, 1958).

System dynamics is a disciplined collaborative approach that can accelerate learning by combining a multifaceted perspective that provides understandability on complex environments (Richmond, 2010). In system dynamics, the aim is not optimization, but to examine the behaviour of the system in the face of certain changes and to help determine the strategies, and to examine the behaviour of the system at the macro level in the long term (Şenaras, 2017). The basic principle is to analyze the system's behaviour in response to particular changes and make decisions by defining the strategies to control this response rather than anticipating the system's values (Hjorth and Bagheri, 2006).

6.1. Causal Loop Diagram

Causal Loop Diagram (CLD) is a valuable technique in the field of systems thinking for managing with complicated problems because it may discover the fundamental feedback patterns and leverage spots in a system (Sahin et al., 2020). It was introduced by Maruyama in 1963 as a simple approach to represent the interacting components in feedback systems (Galanakis, 2006).

CLDs provide several advantages (Sterman, 2000):

1- Rapidly acquiring hypotheses concerning the origins of dynamics;
2- Identifying and capturing solo or group cognitive structures;
3- Interacting critical feedbacks considered of being the source of an issue.

Many aspects of the construction of the system and fundamental connections can be visually represented with CLDs. Identifying the variables connected with a system is the first step in making a CLD. The second step is to determine which of these identified variables is causally connected to other variables in the system, and finally, it should be decided whether the influence of one variable on the other is positive or negative (Toole, 2005).

A CLD is made up of variables linked by arrows that represent the causal effects between those variables (Kiani et al., 2009). A positive (+) arrow connecting one variable to another indicates that a change in the first variable creates a change in the second variable in the same way, so if the first variable increases, so does the second; A negative (-) arrow indicates that a change in the first variable has the opposite impact on the second variable, which implies that if the first variable increases, the second variable decreases (Sarriot et al., 2015).

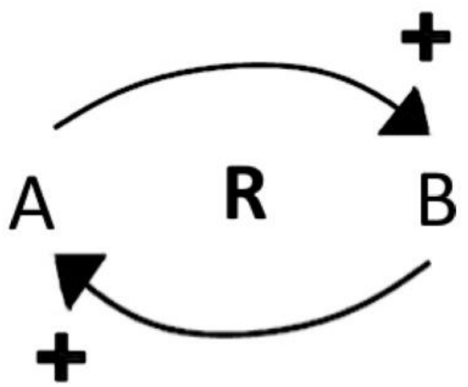

Figure 6. 1. Reinforcing Loop

Reinforcing loops (positive feedback loops) are created when the sign of continuous improvement in the feedback loop is positive and these loops are shown with "R" or "+" symbol. The "R" symbol indicates a positive association between the two components. It either generates systematic development or reduction (Sterman, 2000). It is shown in figure 6.1.

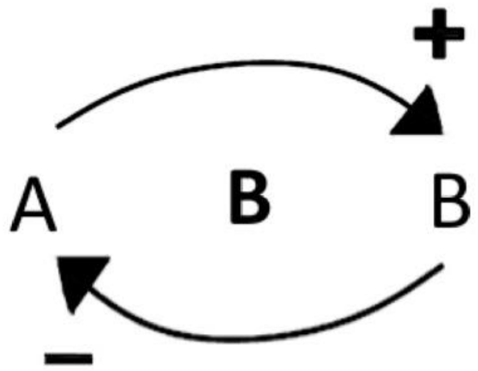

Figure 6. 2. Balancing Loop

Balancing loops (negative feedback loops) are loops with a "B" or "-" in the middle, and they indicate a negative relationship between components. In this sense, we can deduce that an increase in one variable will result in a decrease in the other variable, or vice versa (Sterman, 2000). It is shown in figure 6.2.

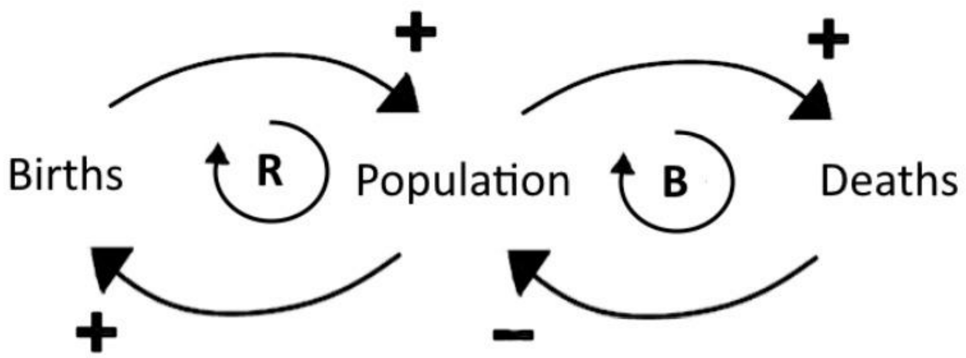

Figure 6. 3. Causal Loop Example

A CLD example is given in figure 6.3. This diagram shows the causal relationship between births, deaths and population. According to this:

• Population is positively affected if births increase.

• Increasing population positively affects births.

• If population growth positively affects deaths, deaths increase and the population is negatively affected.

In this diagram, the birth-population cycle creates a reinforcing loop, and the population-death cycle creates a balancing loop (Bala et al., 2017).

6.2. Reference Behaviour Pattern (RBP)

The Reference Behaviour Pattern (RBP) is a graphical illustration of the behaviour of one or more parameters over time in the loops that are being analyzed. These visuals are used to understand the system and observe the effects of the parameters on the loops. It is not created with numerical data; it expresses a general understanding. (Haraldsson, 2004).

RBP basically includes exponential growth, goal seeking and oscillation. While the reinforcement loop displays an exponential growth behaviour, the balancing loop exhibits a goal seeking behaviour. The existence of delayed restorative elements in balancing loops causes oscillation, leading the system to repeatedly swing around its objective. S-shaped growth, oscillating overshoot, and overshoot and collapse are examples of frequently encountered dynamic behaviour (Mirchi et al., 2012).

7. LITERATURE REVIEW

7.3. Literature of SCR with Logistics 4.0 and Industry 4.0

Logistics 4.0 and SCR are two topics that are studied separately in the literature. In this study, the publications that include the concepts of logistics 4.0 and SCR, as well as the studies that include industry 4.0, which is the main topic of logistics 4.0, and SCR are examined. Scopus database was used for this review process. In the literature, articles in which the terms of "logistics 4.0" and "supply chain resilience" are mentioned together in the article title, abstract or keywords have been searched, but zero results have been reached. When the articles in which the terms of "industry 4.0" and "supply chain resilience" were mentioned together in the article title, abstract or keywords, 31 results were obtained. When the results are examined, it is seen that all of the studies were published in the last 5 years. The distribution of studies by years is shown in figure 7.1.

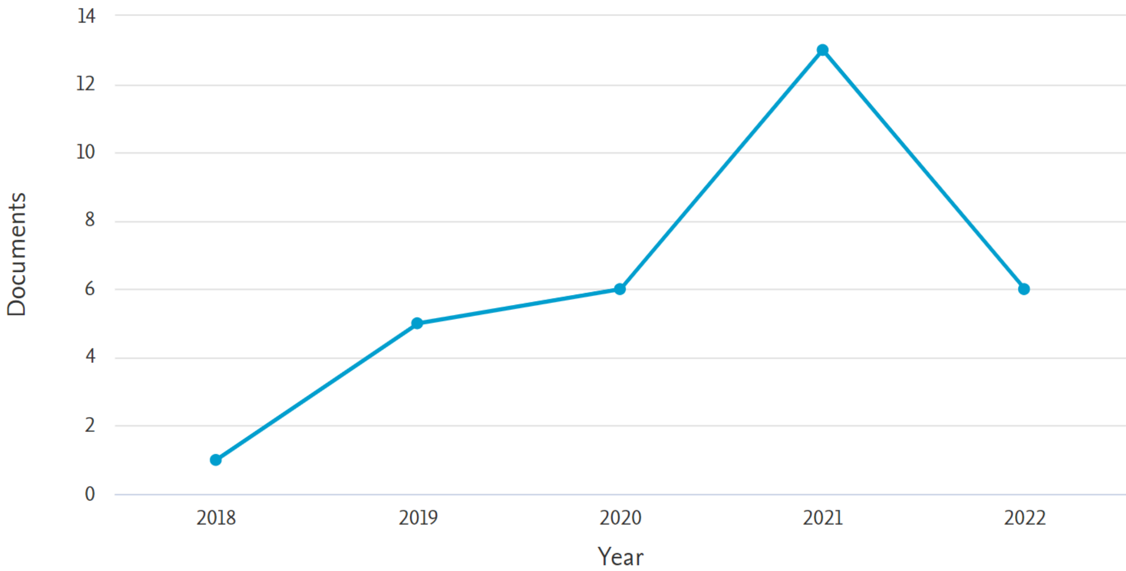

Figure 7. 1. Publication Years of Documents

When examining the type of documents of these studies, it is seen that the most studies are articles with 51.6%, conference papers come second with 19.4%, and there are reviews with 12.9%, book chapters with 9.7% and conference review with 6.5%. The document types distribution is shown in figure 7.2.

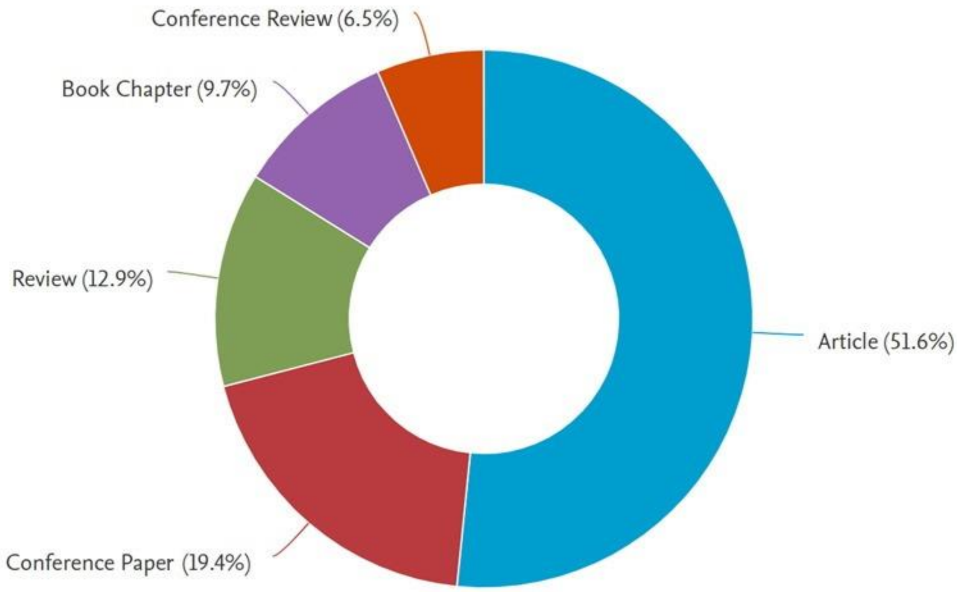

Figure 7. 2. Types of Documents

The subject areas of these studies are also an important point. When the literature is examined, it is concluded that 26.2% of the studies are in the field of Business, Management and Accounting, 17.9% are in the field of Decision Science and again 17.9% are in the field of Engineering. The distribution graph of the documents according to the subject areas is given in figure 7.3.

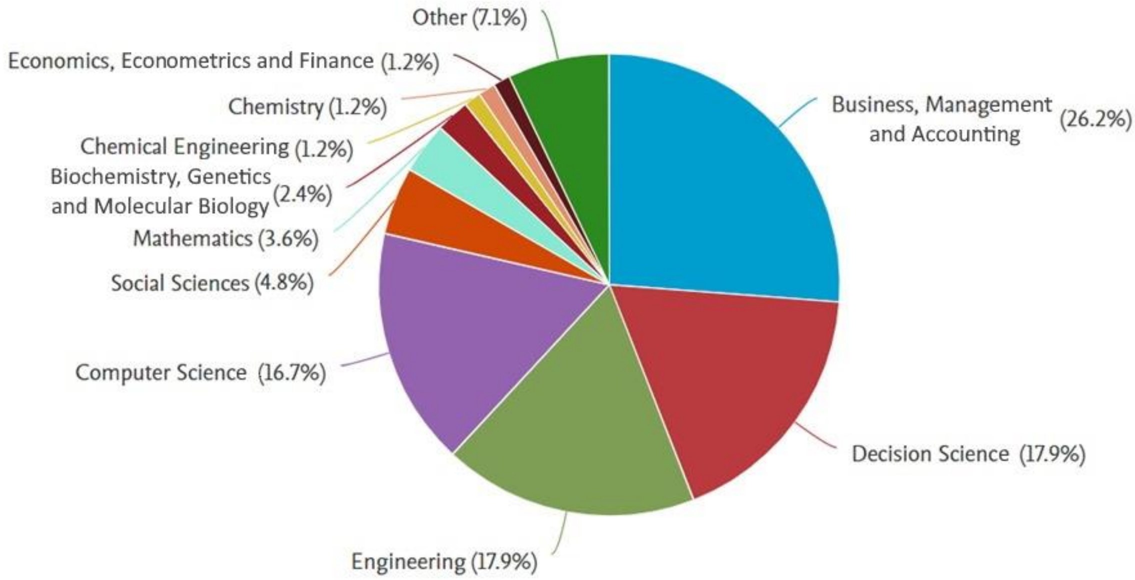

Figure 7. 3. Subject Areas of Documents

Some of the publications reached as a result of this literature review are explained in detail in this section.

The study of Agarwal et al. (2022) revealed the obstacles to resilience by using the example of a manufacturing organization that utilizes industry 4.0 information technologies. 5 types of obstacles, 23 sub-obstacles and 6 skills was determined. A hybrid AHP fuzzy TOPSIS technique was used to rank determined skills. In this way, the information that businesses need to know in order to generate flexibility and resilience was provided.

In the study by Tortorella et al. (2021) the impact of integrating information and communication technologies of industry 4.0 into supply chains on SCR was examined. The importance of industry 4.0 technologies to SCR was empirically revealed, the influence of processing technologies in improving restorative ability was examined and multichannel technique was integrated with mentioned technologies as a way of resilience creation and development.

In the article by ur Rehman and Ali (2021) the threats that are most likely, severe, and involve longer healing times were determined using a hybrid multi criteria decision making approach (AHP-TOPSIS). These insights were then utilized to identify resilience methods using a quality function deployment approach. According to the results, it has been revealed that it is one of the most important resilience measures of industry 4.0. Other measures are expressed as alternative sourcing, agility, threat identification, and global diversity of suppliers, marketplaces, and processes.

In addition to evaluating the effect of supply chain mapping on SCR, Mubarik et al. (2021) intended to examine the function of supply chain visibility in the link between supply chain mapping and supply chain flexibility. It was stated that supply chain mapping is fundamental in organizing a firm with industry 4.0 demands. The outcomes revealed that by using Industry 4.0 philosophies and principles, organizations may become more resilient, sustainable, and morally aware.

The impacts of COVID-19 on the supply chain in the aviation and automotive industries were analyzed in the study of Belhadi et al. (2021), and the reaction methods formed in the supply chains were highlighted. It has been stated that the obstacles of the COVID-19 process can be overcome by generating local supply chain resources for the automotive sector, applying industry 4.0 technologies, and defining all flight activities in the aviation sector. Moreover, it was noted that for two sectors, big data analytics can be a valuable source of information in overcoming the effects of the pandemic in supply chains.

The goal of the study from Ralston and Blackhurst (2020) was to acquire an understanding of industry 4.0 technologies, and an answer was reached to the question of whether these technologies will negatively impact human talent loss and SCR. The study revealed that smart systems positively influence firm performance and taking use of industry 4.0 processes gives a competitive supply chain advantage, however, it does not cause in any loss of human talent. It was stated that smart systems may enhance SCR through capability growth and new talent advancement.

In this article by Ivanov et al. (2019), literature and case studies are examined in order to progress the debate with the assistance of a conceptual framework for studying the associations between digitalisation and supply chain disruption risks. This is the first study that helps combine business, data, engineering, and analytics philosophies on digitalisation and SC risks. The connections of supply chain disruption risks and industry 4.0 technologies are examined, the role of digitalisation in ripple effect management is stated, and which technology extensions can improve supply chain risk analytics are expressed.

7.4. Literature of SCR with System Dynamics

A search in the Scopus database for "system dynamics" finds 40,303 results. Since there are various techniques belonging to different disciplines with the same name, it is more appropriate to specify the search process. 1,570 results can be obtained for "causal loop diagram" OR "causal loop" OR "causal loops". If "supply chain resilience" AND "causal loop diagram" OR "causal loop" OR "causal loops" is searched, 14 publications can be obtained. By examining these, the publications found in the results due to the similarity of names and containing methods belonging to different disciplines were excluded from the results. As a result, 8 publications remained. When the outcomes are analyzed, it can be seen that there is no document from more than 6 years ago. The distribution of publications by years is shown in figure 7.4.

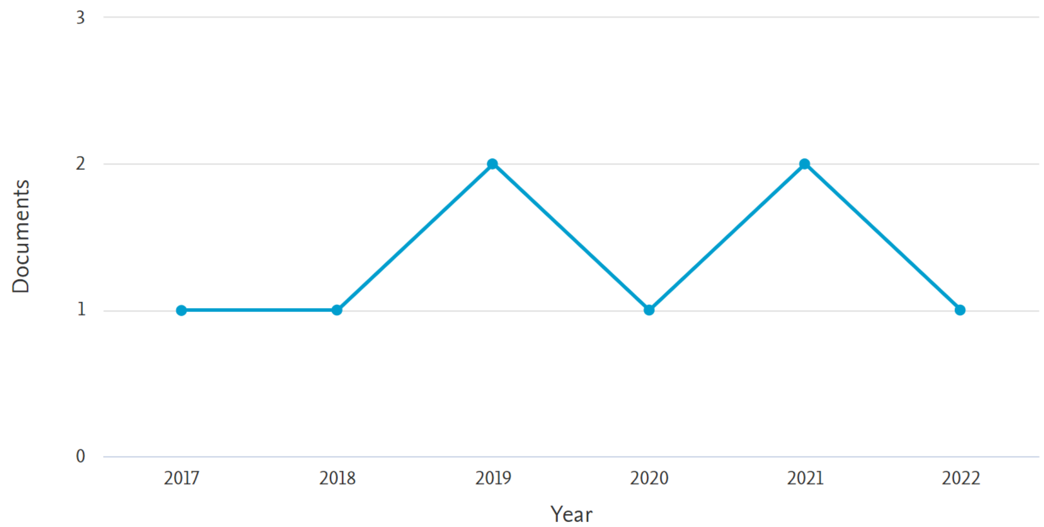

Figure 7. 4. Publication Years of Documents

When the types of documents of these studies are analyzed, it is found out that majority of them are articles (62.5 %), and it is followed by conference papers (25.0 %) and book chapters (12.5 %). The distribution of publication types is shown in figure 7.5.

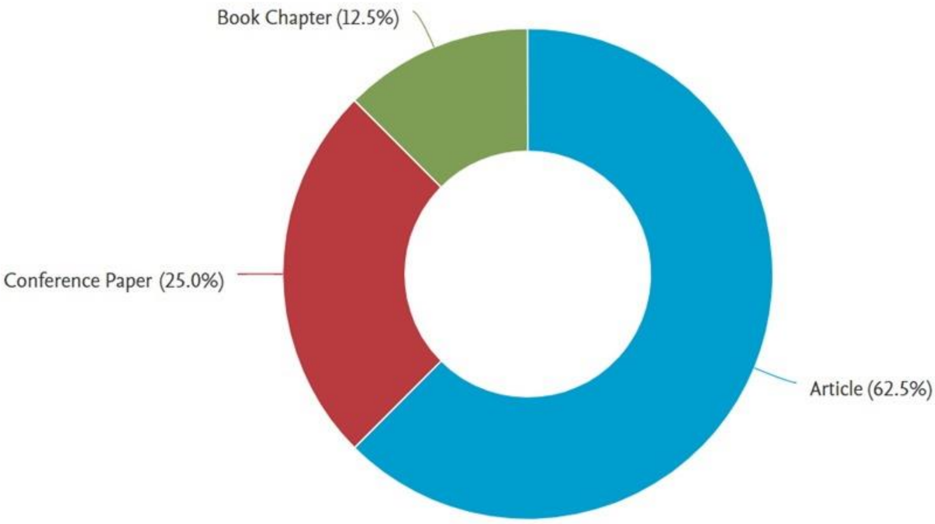

Figure 7. 5. Types of Documents

When the literature is analyzed, it is determined that 33.3% of the studies are in the subject of Business, Management, and Accounting, 22.2% are in Engineering, and 16.7% are in Decision Science. Figure 7.6 demonstrates the distribution of documents according to subject areas.

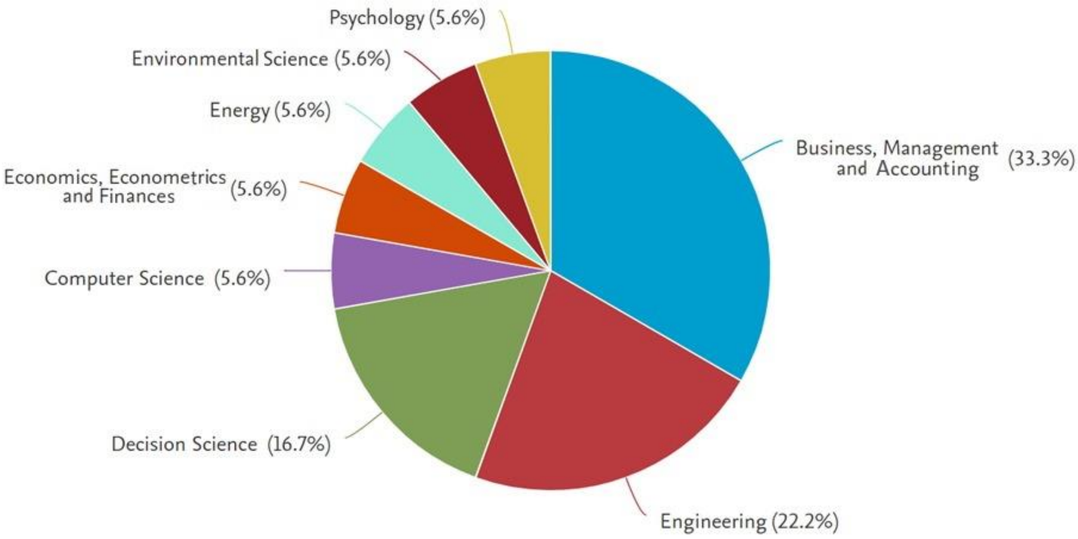

Figure 7. 6. Subject Areas of Documents

Some of the publications reached as a result of this literature review are explained in detail in this section.

In the paper of Ekinci et al. (2022) the actions of countries against COVID-19 were noted for an amount of time using the System Dynamics approach, and then the growth in uncertainty was examined with entropy measurement to evaluate whether the systems are resilient or not. Also, the variations in reporting between the first and second waves of the pandemic were indicated in the constructed model, and it was observed that, with the exception of Turkey, second wave reporting variations were fewer than first wave reporting variations. As a result of learning situations, it was concluded that the amount of exposure to the second wave was less than the first wave, so it can be said that countries were more resilient to the second wave. The study is very useful in terms of both firms and governments.

In the article by Shao and Jin (2020), the system dynamic approach was performed to examine supply-chain resilience, and the pricing, supply, and requirement systems were constructed to be the three resilient methods of the lithium supply chain. The need for new energy vehicles, resource supply interruption, recycling ratio, reserve, and replacement were set as model sceneries. It was concluded that the flexibility of lithium supply chains decreases under the influence of new energy vehicles and also, flexibility is badly affected in case of long-term supply interruption.

The components impacting the resilience of the supply chain for the health sector, as well as the dynamic relationships between them, are investigated in the study by Jafarnejad et al. (2019). For this purpose, the Delphi method was used as well as the system dynamics method. For the first time in the literature, system dynamic analysis was used in this study to determine the important parameters impacting the resilience of the medical equipment supply chain.

The role of data transfer in a three-tiered supply chain was analyzed in the article by Li et al. (2017). The supply chain model was constructed using system dynamics program, and three decision-making procedures were designed based on varying levels of data transfer. The three ordering systems' effectiveness with shock were evaluated. The findings of the tests demonstrated the importance of data transfer in the supply chain when there is disruption or shock.

8. MATERIAL AND METHOD

8.3. Methodology

Ensuring SCR is of paramount importance to companies in today's competitive environment. Knowing how Logistics 4.0 technologies affect which SCR elements will provide important advantages to companies in this sense. In this section, CLD model formation is explained to determine the effect of logistics 4.0 on SCR. An iterative approach was followed in the formation of this diagram. First of all, the subject has been divided by considering logistics 4.0 information technologies. Afterwards, the literature was examined in detail and it was determined how each of these technologies was related to the SCR elements, with which intermediate components, if any, and their interactions were ensured. The formation of sub-diagrams step by step is shown by expressing the relations between the components. In this manner, a CLD was created using the literature.

8.4. Model Building

The causalities between the components were determined in this section by thoroughly reviewing the literature. To create the CLD, sub-diagrams were developed after these causalities were determined. In this context, each logistics 4.0 information technology was discussed separately in this section.

8.4.1. Causal relations of IoT

When the IoT, one of the most basic information technologies of Logistics 4.0, is examined in the literature, it has been seen that it has a relationship with visibility, one of the SCR elements. According to Al-Talib et al. (2020), the IoT increases transparency within the supply chain. The diagram showing these relationships is given in figure 8.1.

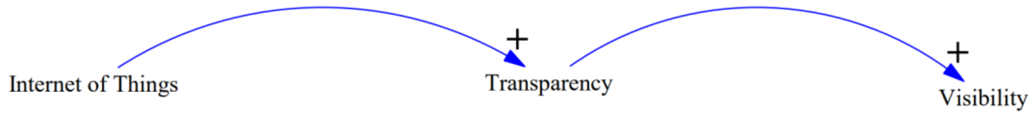

Figure 8. 1. Causal relations of IoT on visibility

When the causal relation between IoT and collaboration is analyzed, it is stated in the publication of Al-Talib et al. (2020) that IoT provides effective information flow in the supply chain. As a result, it is mentioned that collaboration is increased. Hereby, it can be concluded that the IoT affects collaboration positively. The causal relationships mentioned are given in figure 8.2.

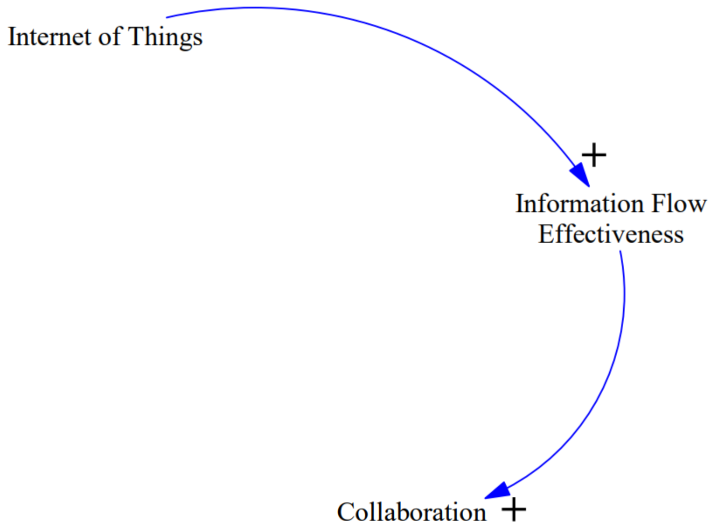

Figure 8. 2. Causal relations of IoT on collaboration

According to Robinson (2015), with integrating the IoT into supply chains, companies are able to react more swiftly to changes in customer requirements and supplier availability. As a result, it can be stated that IoT increases velocity, which is one of the SCR elements. This relationship is shown in figure 8.3.

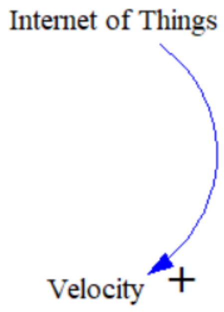

Figure 8. 3. Causal relations of IoT on velocity

In the study of Al-Talib et al. (2020), it was stated that IoT can increase constancy and the capacity to tolerate accidents in the supply chain, and consequently enhance flexibility. Based on this information, a diagram showing the causal relationships of the given components was created and shown in figure 8.4.

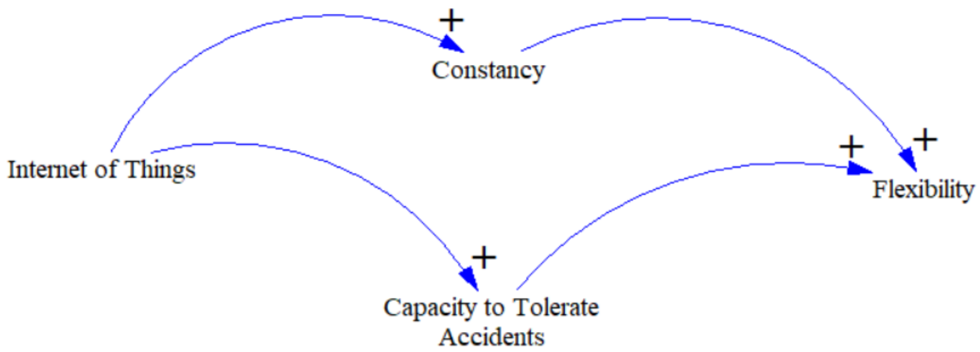

Figure 8. 4. Causal relations of IoT on flexibility

8.4.2. Causal relations of additive manufacturing

In order to show the causal relationships of additive manufacturing with efficiency, two different sub-diagrams were created as a result of the literature review. According to research from Naghshineh and Carvalho (2020), additive manufacturing allows for the reduction of supply chain stages. It was stated that this reduces supply chain complexity, which results in less packaging, storage and transportation, and therefore increased supply chain efficiency. These relations are demonstrated with a sub-diagram in figure 8.5.

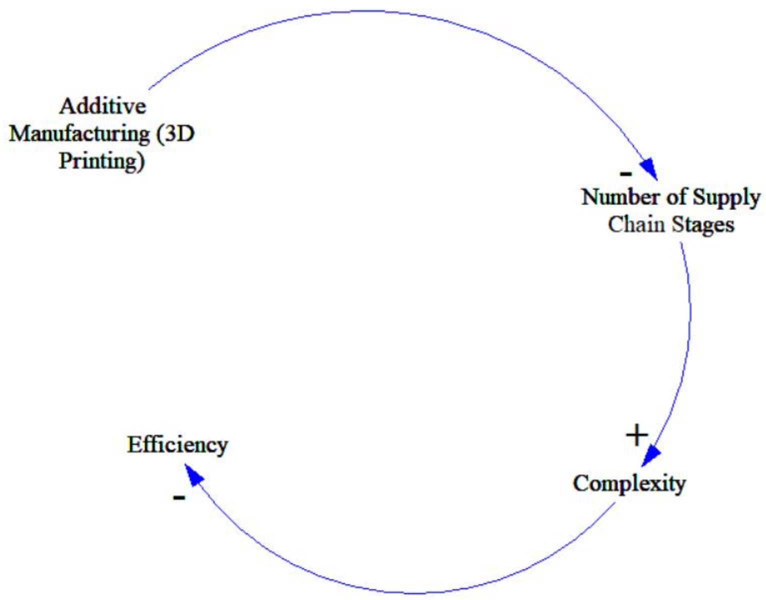

Figure 8. 5. Causal relations of additive manufacturing on efficiency first sub-diagram

The second sub-diagram was created by combining information from two different publications. According to Mohr and Khan (2015), 3D printing could significantly reduce overproduction. Overproduction increases excess inventory (Chan et al., 2021). Additive manufacturing improves "resource productivity", which means producing more product from the same amount of a given resource, by minimizing excess inventory (Campbell et al., 2011). The second sub-diagram showing the causal relationship between additive manufacturing and efficiency according to these publications is given in figure 8.6.

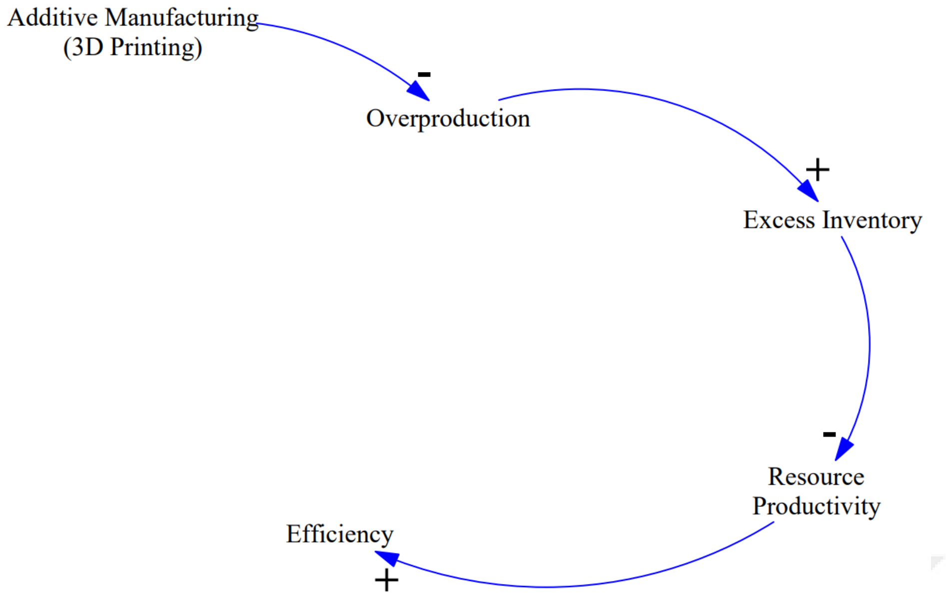

Figure 8. 6. Causal relations of additive manufacturing on efficiency second sub-diagram

According to Wu et al. (2016), the production of customized products can be increased thanks to this technology, as printing a complex structure in 3d printers and printing a simple structure do not require very different processes. That is, additive manufacturing technology has a positive effect on customization. Customization is the capacity of the supply chain to alter its services and goods to satisfy the needs of the client in a very short amount of time and with a broad range of customized features (Zidi et al., 2022). In the study of Pandey et al. (2021), it was stated that an increase in the customization level would make accurate demand forecasting difficult. In other words, customization has a negative effect on accurate demand forecasting. When the study of Kot et al. (2011) is examined, it can be revealed that accurate demand forecasting has a positive effect on efficiency. The third sub-diagram showing the causal relationship between additive manufacturing and efficiency according to these publications is given in figure 8.7.

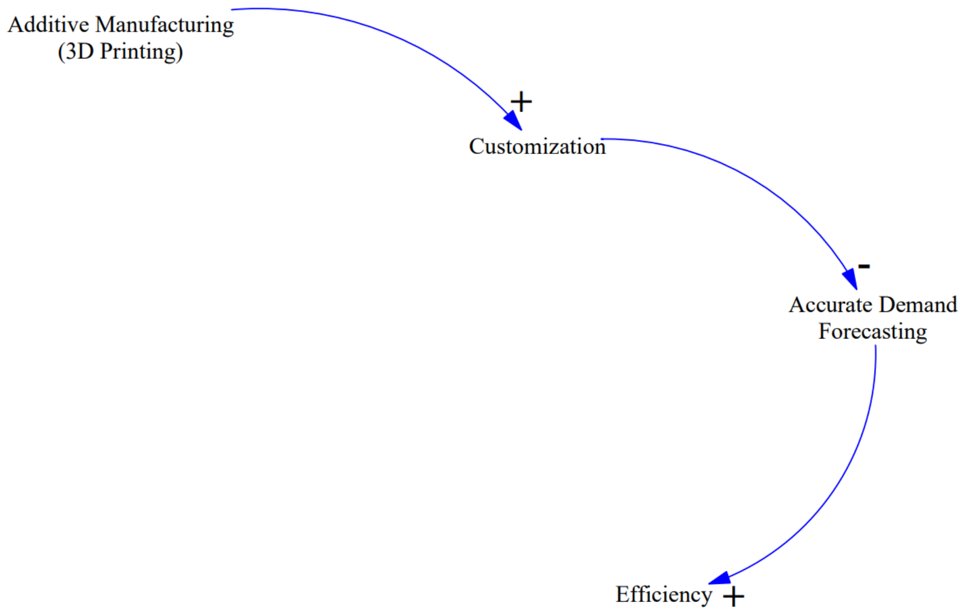

Figure 8. 7. Causal relations of additive manufacturing on efficiency third sub-diagram

Since additive manufacturing allows for integrated production, it can reduce assembly time, product design time, and production time, especially in more complex items. Products can be obtained more rapidly this way (Verboeket and Krikke, 2019). As a result, it can be stated that additive manufacturing increases the velocity. The sub-diagram showing causal relationships is given in figure 8.8.

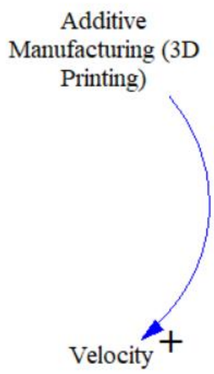

Figure 8. 8. Causal relations of additive manufacturing on velocity

8.4.3. Causal relations of BDA

BDA, as noted in the study of Brandon-Jones et al. (2014), increase information sharing, and this increase in information sharing enhances visibility. The sub-diagram created with these causal relationships is given in figure 8.9.

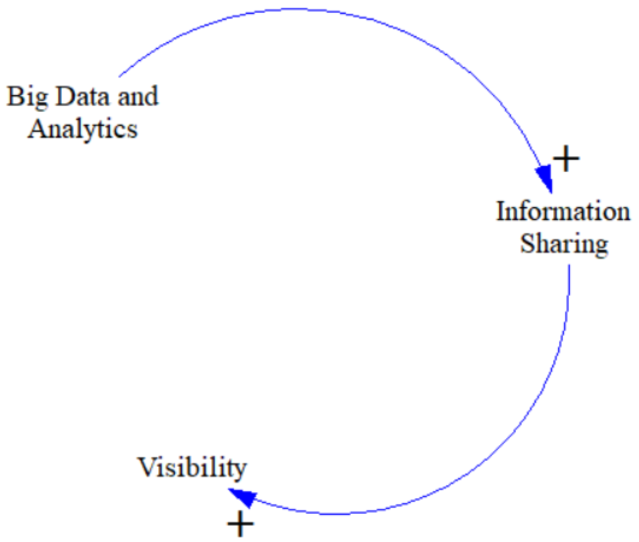

Figure 8. 9. Causal relations of BDA on visibility

Meyerson et al. (1996) introduced the term "swift trust" to characterize the emergence and growth of trust links in short-term virtual groups where there are no pre-existing working links. Study of Dubey et al. (2018) indicated that BDA increase swift trust. It was stated that the increase in swift trust increases visibility and collaboration. The sub-diagram in figure 8.10 illustrates the aforementioned causal relations.

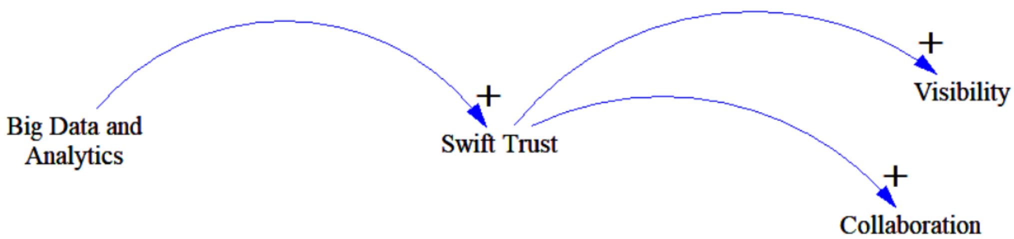

Figure 8. 10. Causal relations of BDA on visibility and collaboration

With BDA technology, data can be examined in detail and companies can make more accurate demand forecasts. As a result, sourcing costs are reduced as the necessary source purchases are better planned (Ali and Govindan, 2021). An increase in sourcing cost has a negative effect on efficiency. As a result, enhancement in the BDA technology increases efficiency (Iftikhar et al., 2022). The sub-diagram of these causal relationships is given in figure 8.11.

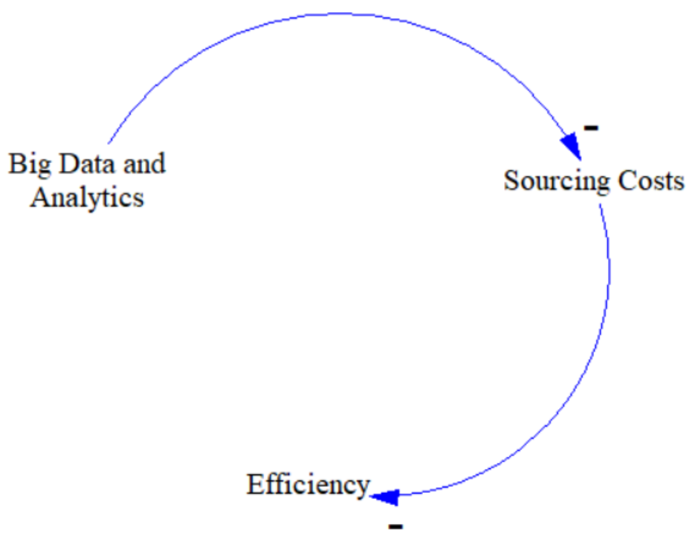

Figure 8. 11. Causal relations of BDA on efficiency

8.4.4. Causal relations of SAR

According to research of Stoltz et al. (2017), augmented reality devices can provide eye-free and hands-free solutions, information can be presented in multiple locations at the same time, and it eliminates the necessity of going to the location where it is situated when an operator is distracted. For these reasons, it was stated that augmented reality increase flexibility. The sub-diagram of these causal relationships is given in figure 8.12.

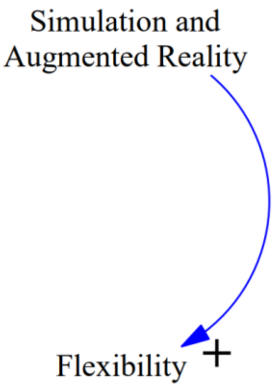

Figure 8. 12. Causal relations of augmented reality on flexibility sub-diagram

The logistics industry has benefited from the use of SAR technology since labor costs are lower, errors are decreased and as an overall result, efficiency is increased (Wang et al, 2020; Rejeb et al., 2021). The sub-diagram of this causal relationship is given in figure 8.13.

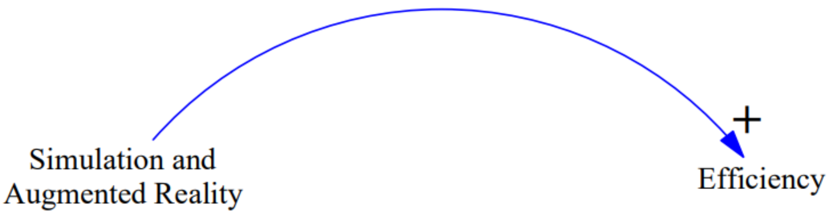

Figure 8. 13. Causal relations of SAR on efficiency

8.4.5. Causal relations of autonomous robots

Providing information with the artificial intelligence capabilities of autonomous robots and their applications can increase the efficiency in supply chain processes. At the same time, efficiency increases as the use of autonomous robots reduces waste and technical training costs (Bugmann et al., 2011). These relations are shown in figure 8.14.

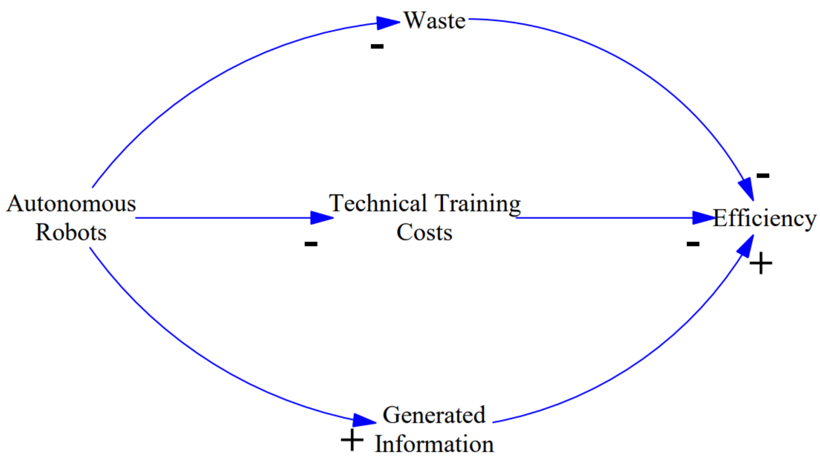

Figure 8. 14. Causal relations of autonomous robots on efficiency first sub-diagram

According to Smids et al. (2020), one's work life is more meaningful by the work they accomplish. As they attain personal success and make a positive impact on the company, they thereby achieve psychological job satisfaction. It's important for them to recognize their talents. In a work environment where autonomous robots do important work and workers maintain only general control, employee self-esteem may deteriorate. Consequently, it can be indicated that autonomous robots have a negative effect on self-esteem. Pierce and Gardner (2004) revealed the positive effect of self-esteem on work motivation. According to the study of Kuznetsova et al (2017), work motivation positively affects efficiency. The relations are shown in figure 8.15.

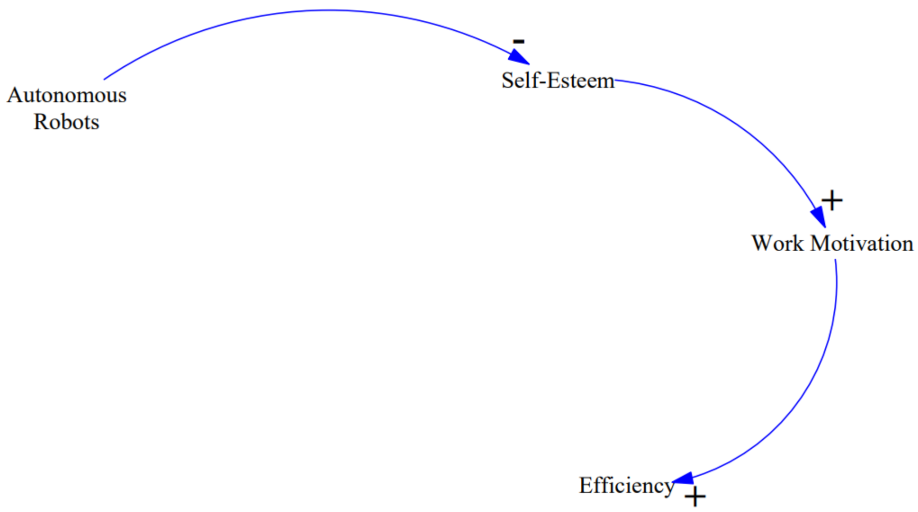

Figure 8. 15. Causal relations of autonomous robots on efficiency second sub-diagram

8.4.6. Causal relations of blockchain

According to Min (2019), the higher visibility along the supply chain that comes from increased transparency acquired through publicly accessible open ledgers is one of the managerial advantages that blockchain may bring to typical business procedures. The sub-diagram of these causal relationships is given in figure 8.16.

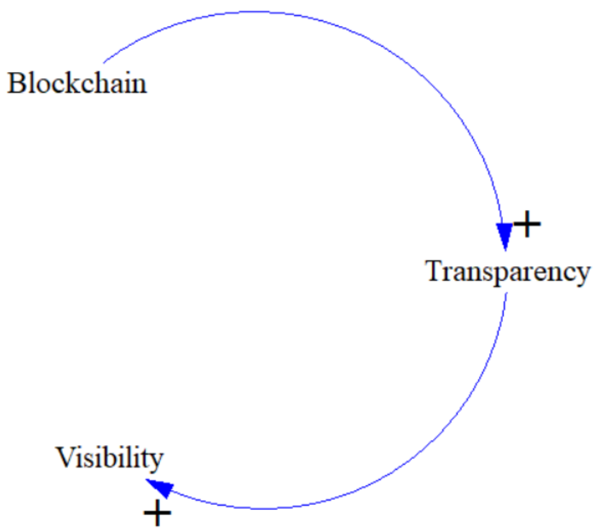

Figure 8. 16. Causal relations of blockchain on visibility

With the use of blockchain technology, information can be transferred between supply chains that enable production planning and inventory management more reliably and transparently, and flexibility across supply chains is consequently enhanced (Nandi et al., 2021). The sub-diagram of these causal relationships is given in figure 8.17.

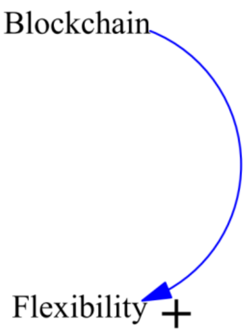

Figure 8. 17. Causal relations of blockchain on flexibility

In the study of Sharma et al. (2021) it was stated that the blockchain technology can enable the company to increase the velocity for more effective supply chains and the relationship is shown in figure 8.18 with a sub-diagram.

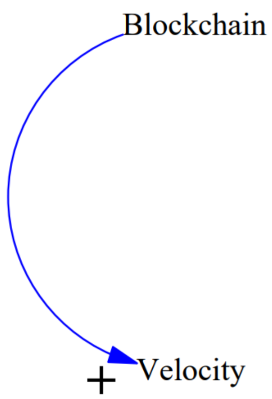

Figure 8. 18. Causal relations of blockchain on velocity

8.4.7. Causal Relations Starts from SCR

According to the study by Abeysekara et al. (2019) SCR and some of its practises have a positive influence on competitive advantage of companies. From the study from Čater and Čater (2009), it can be said that competitive advantage affecting company performance positively. Bernhardt et al. (2000) revealed that the increase in company performance causes an increase in customer satisfaction. Williams and Naumann (2011) emphasises that customer satisfaction positively affects revenue. When the studies of Li et al (2022) and Ng et al (2013) are examined, it can be stated that the increase in the revenue of the companies positively affects the firm size. According to Olushola (2019), the IoT is significantly and positively impacted by the firm size. The relationship between SCR and IoT shown in figure 8.19.

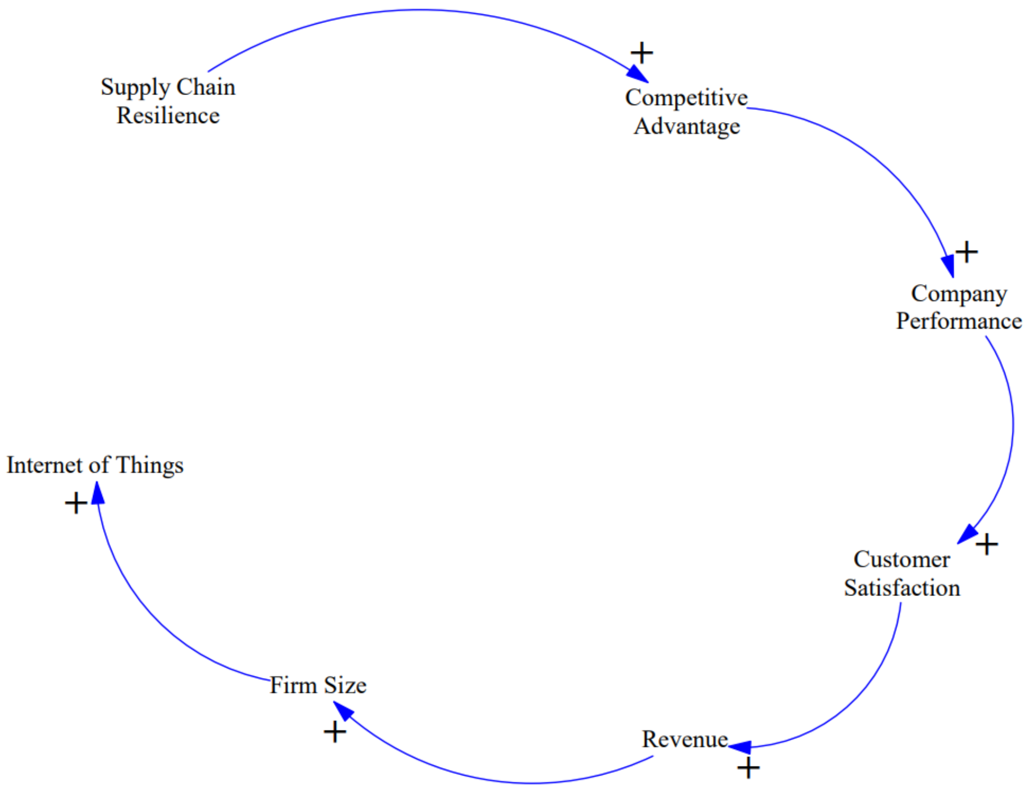

Figure 8. 19. Causal relations from SCR to IoT

When all the relationships between IoT and SCR are examined, the causal loop sub diagram in figure 8.20 emerges.

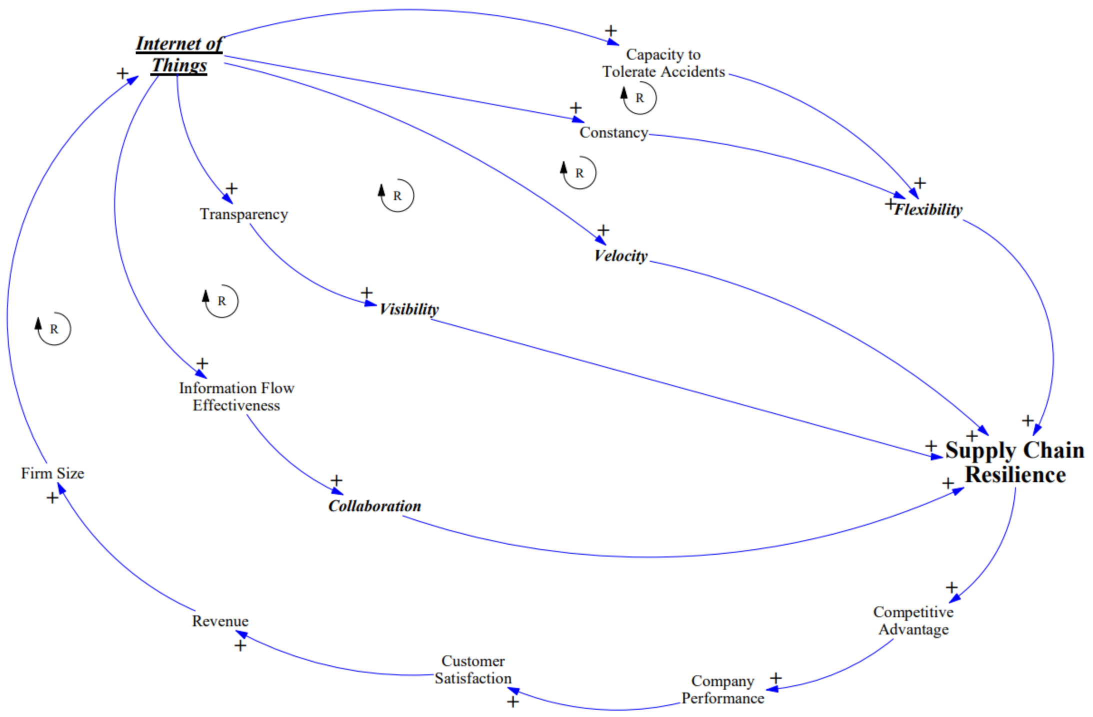

Figure 8. 20. Loops between IoT and SCR

In addition to stated relationships regarding SCR, according to Olawumi et al., (2020), revenue positively affects technological infrastructure investments in companies. The same study states that, the increase in these technological infrastructure investments has a positive effect on blockchain technology. The relationship between SCR and blockchain is shown in figure 8.21.

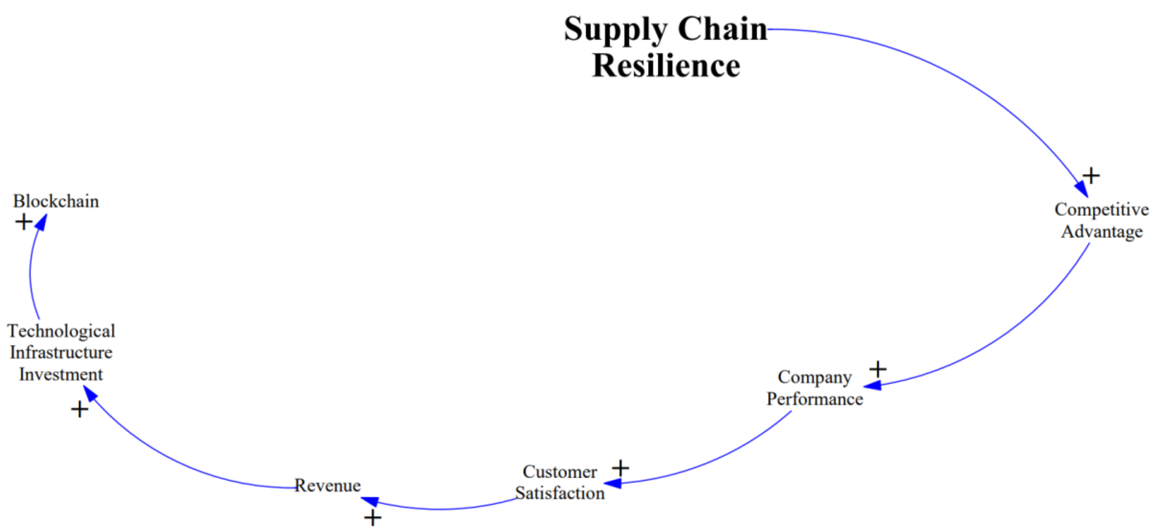

Figure 8. 21. Causal relationship from SCR to blockchain

When all the relationships between IoT and SCR are examined, the causal loop sub diagram in figure 8.22 emerges.

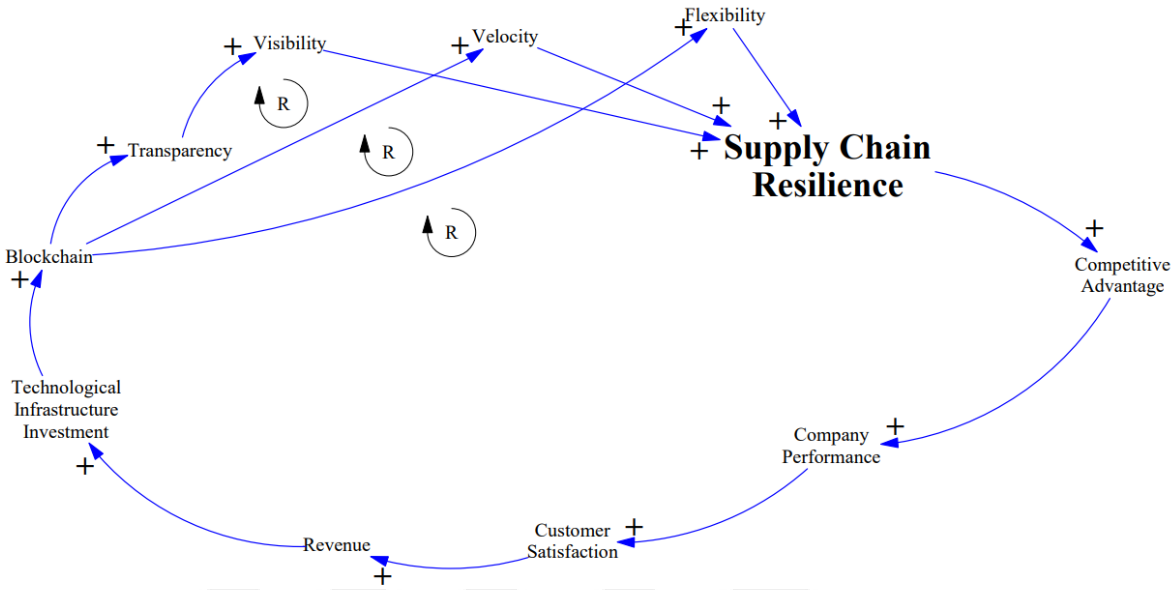

Figure 8. 22. Loops between Blockchain and SCR

When the studies of Ponomarov and Holcomb (2009) and Namada (2018) are examined, the reinforcement loop between competitive advantage and organizational learning can be expressed. The positive effect of organizational learning on top support management can also be demonstrated. When the studies of Shamout et al (2022) and Pizam et al (2022) are examined, it can be mentioned that Top Management Support has a positive effect on Autonomous Robots. The relationship between SCR and autonomous robots is given in figure 8.23.

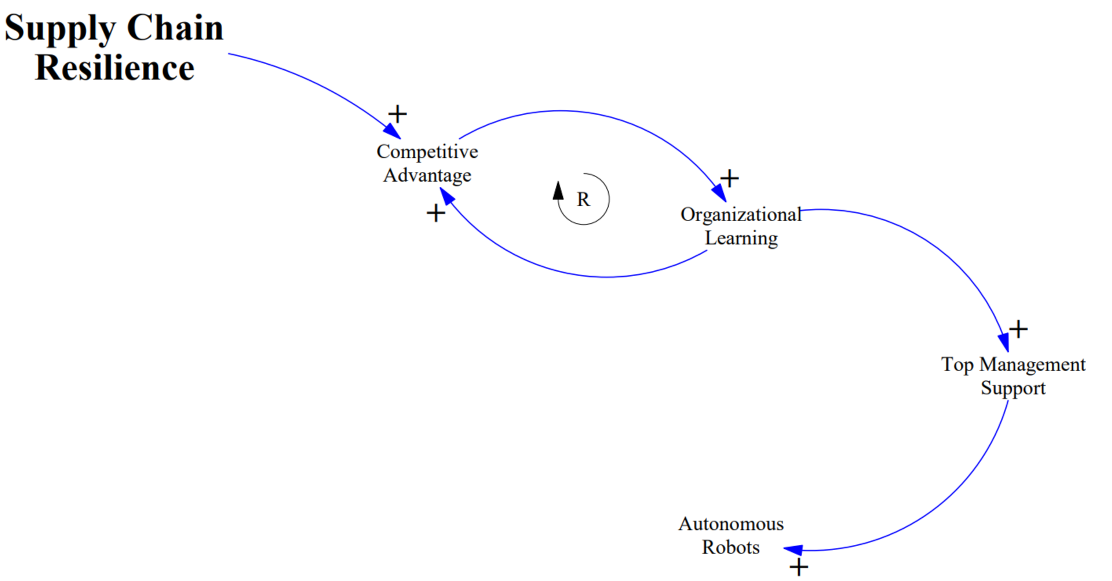

Figure 8. 23. Causal relationship from SCR to autonomous robots

Chandra and Kumar (2018) revealed in their study that Top Management Support has a positive and significant effect on SAR technology. Considering the previous relationships, the causal diagram in figure 8.24 can be drawn iteratively.

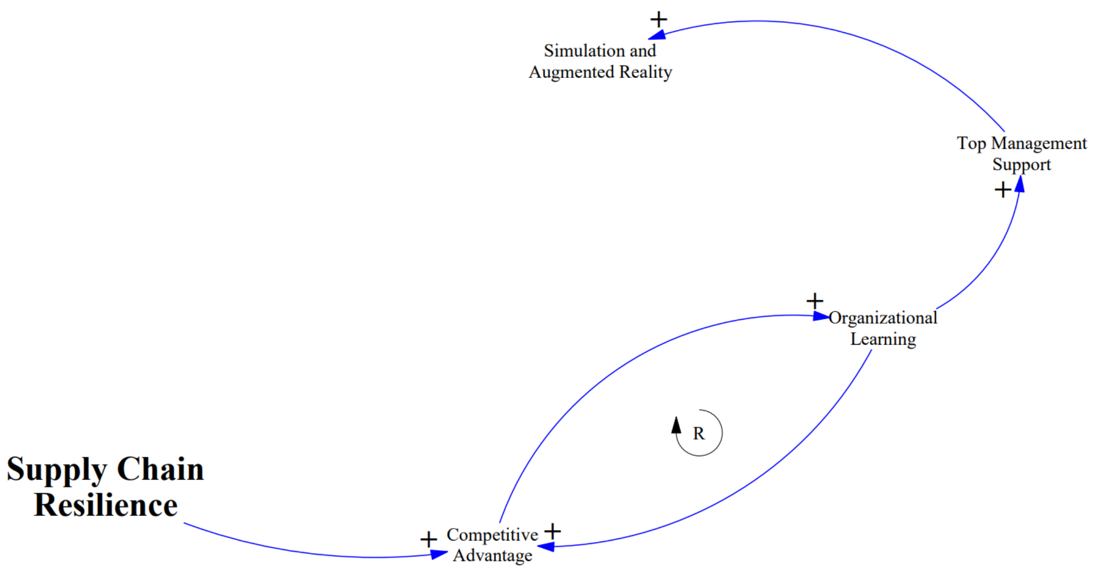

Figure 8. 24. Causal relationship from SCR to SAR

According to Naghshineh and Carvalho (2021), technological infrastructure investments positively affect additive manufacturing. When the previous relations are also examined, the sub-diagram given in figure 8.25 can be created.

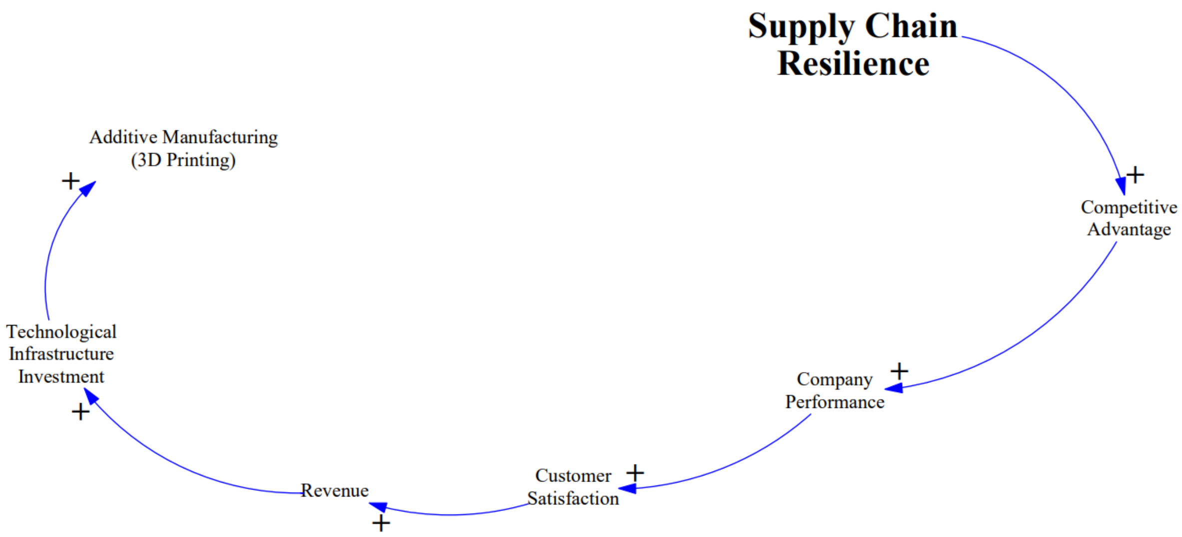

Figure 8. 25. Causal relationship from SCR to additive manufacturing

The development of BDA technology is enabled by the growth and development of tools such as sensors used in IoT technology, in accordance with a study by Vassakis et al. (2018). In other words, the development of the IoT causes the development of BDA. In the study of Khakifirooz et al. (2018), it was revealed that BDA technology has a positive effect on IoT technology. As a result of these relations, the reinforcement loop in figure 8.26 was created. This relationship is shown in the figure. As a result of this relationship, the indirect causal relationship of SCR with BDA technology can be mentioned.

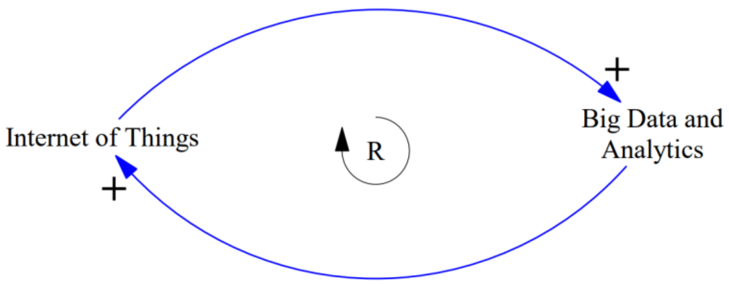

Figure 8. 26. Causal relationship between IoT and BDA

8.5. Proposed Model

By combining the sub-diagrams given in Section 8.2, the CLD containing all the mentioned elements was created from the VENSIM software. The model is shown in figure 8.27.

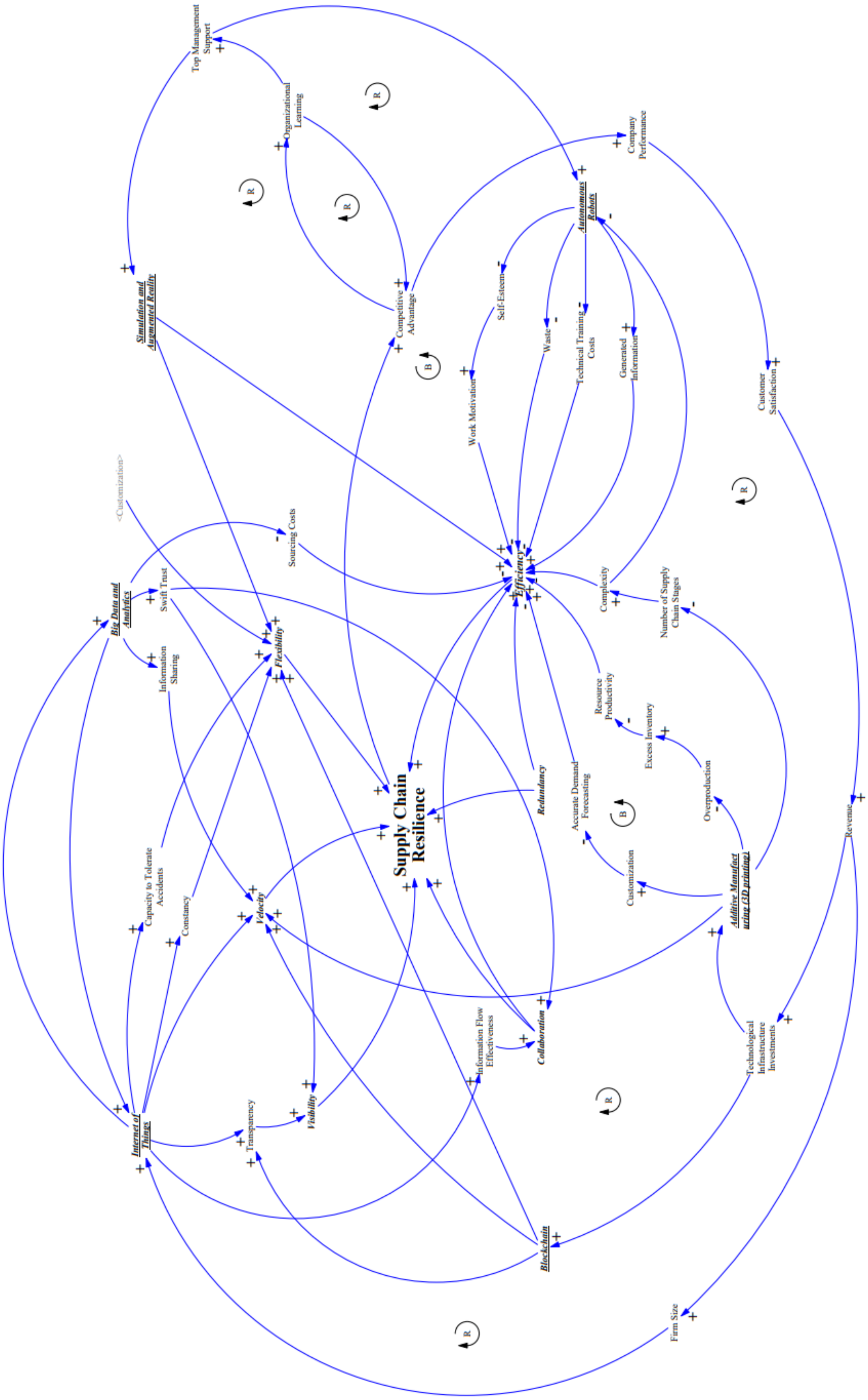

Figure 8. 27. CLD of SCR and Logistics 4.0

9. RESULTS AND DISCUSSION

In this study, a wide literature review was made and sub-diagrams were constructed showing the effects of logistics 4.0 technologies on SCR elements. Then, these sub-diagrams were combined to create a CLD. By examining the CLDs, the effects of logistics 4.0 technologies on SCR elements can be examined, if there are intermediate components that cause the effects on these elements, it can be seen and the effect of each of the SCR elements on SCR can be identified. In this area, the diagram has been examined in terms of the effects on the SCR elements.

Visibility:

- IoT has a positive effect on data quality, reliability, productivity. The increase of these intermediate elements increases the visibility. IoT has a negative impact on time spent by labors. Increasing time spent by labors also reduces visibility. At this point, it can be concluded that there is a positive relationship between IoT and visibility.
- With the use of blockchain technology, transparency increases, as a result of which visibility increases. Thus, it can be concluded that there is a positive relationship between blockchain and visibility.
- BDA have a positive effect on swift trust, there is also a positive relationship between swift trust and visibility. In this sense, it can be said that there is a positive relationship between BDA. In other words, visibility increases as the use of BDA increases.
- No study has been found that expresses the effect of other information technologies discussed in this study on visibility.

Velocity:

- When the diagram is examined, it can be seen that the IoT has a positive effect on the velocity.
- The increase in BDA provides an increase in information sharing. The increase in information sharing increases the velocity. In this way, it can be stated that there is a positive relationship between BDA and velocity.

- It can be observed from the diagram that there is a positive relationship between blockchain technology and velocity.
- When the diagram is examined, it can be concluded that the increase in additive manufacturing causes an increase in velocity.
- No study has been encountered that expresses the relationship between SAR, autonomous robots and cyber-physical systems and velocity.

Flexibility:

- The IoT has a positive effect on constancy and capacity to tolerate accidents. It can be seen from the diagram that these two intermediate elements have a positive effect on flexibility. As a result, it can be concluded that the IoT increases flexibility.
- There is a positive relationship between SAR and flexibility. That is, SAR increase flexibility.
- When the diagram is examined, it can be deduced that there is a same-way relationship between blockchain and flexibility.
- No study has been encountered that expresses the relationship between flexibility and other logistics 4.0 technologies discussed in the study.

Efficiency:

- The increase in the use of BDA reduces the sourcing cost. It can be stated that the increase in the sourcing cost decreases the efficiency. In other words, there is a negative relationship between sourcing cost and efficiency. In this context, it can be concluded that there is a positive relationship between BDA technology and the efficiency element.
- When the diagram is examined, it can be observed that there is a positive relationship between SAR and efficiency.
- The use of autonomous robots as a logistics 4.0 technology reduces waste and technical training costs. The increase of these two intermediate elements decreases the efficiency, that is, there is a negative relationship between them. Also, autonomous robots increase generated information, which results in increased efficiency. In this context, when the relations are examined, it can be stated that there is a positive relationship between autonomous robots and

efficiency, and efficiency can be increased with the increase in the use of autonomous robots.

- Increased use of additive manufacturing reduces excess inventory and overproduction. Increasing exit inventory and overproduction also reduces resource productivity. There is a positive relationship between resource productivity and efficiency element. Apart from that, additive manufacturing reduces the number of supply chain stages. Increasing the number of supply chain stages increases complexity and decreases efficiency. When all these relationships are examined, it can be concluded that there is a positive relationship between additive manufacturing and efficiency.

Redundancy:

- No studies have been encountered that express the relationship between the logistics 4.0 technologies covered in this study and the redundancy SCR element. According to this result, it can be concluded that the concept of redundancy does not have much place terminologically in studies involving logistics 4.0 technologies.

Collaboration:

- It can be seen from the diagram that the IoT reduces unexpected outcomes. The decrease in unexpected outcomes causes an increase in collaboration because there is a negative relationship between them. Increases IoT information flow effectiveness, which in turn increases collaboration. When these relationships are examined, it can be stated that the increase in IoT increases collaboration, that is, there is a positive relationship between them.
- BDA swift increases trust and increase of swift trust causes an increase in collaboration. As a result, there is a positive relationship between BDA and collaboration.

Each of the SCR elements, whose relations with logistics 4.0 technologies are examined one by one, also has a positive relationship with SCR. In other words, owing to these technologies, a potential improvement in any of the elements of SCR improves institutions' SCR.

When CLD is analyzed with VENSIM software, it is seen that there are 31 loops in total in the diagram. 29 of them are loops containing the SCR element. Although technologies often create reinforcement loops, it can be concluded that the CLD also includes some balancing loops. In order to examine the 12-month behaviour of the system, the reference behaviour pattern was created and shown in figure 9.1. When the system is examined, it can be said that SCR will show an exponential increase at first thanks to the reinforcement loops, but as time progresses, it will stabilize with the effect of balancing loops. This situation is visualized by the created S-shaped graph. According to the literature, systems under similar situations display similar behaviours.

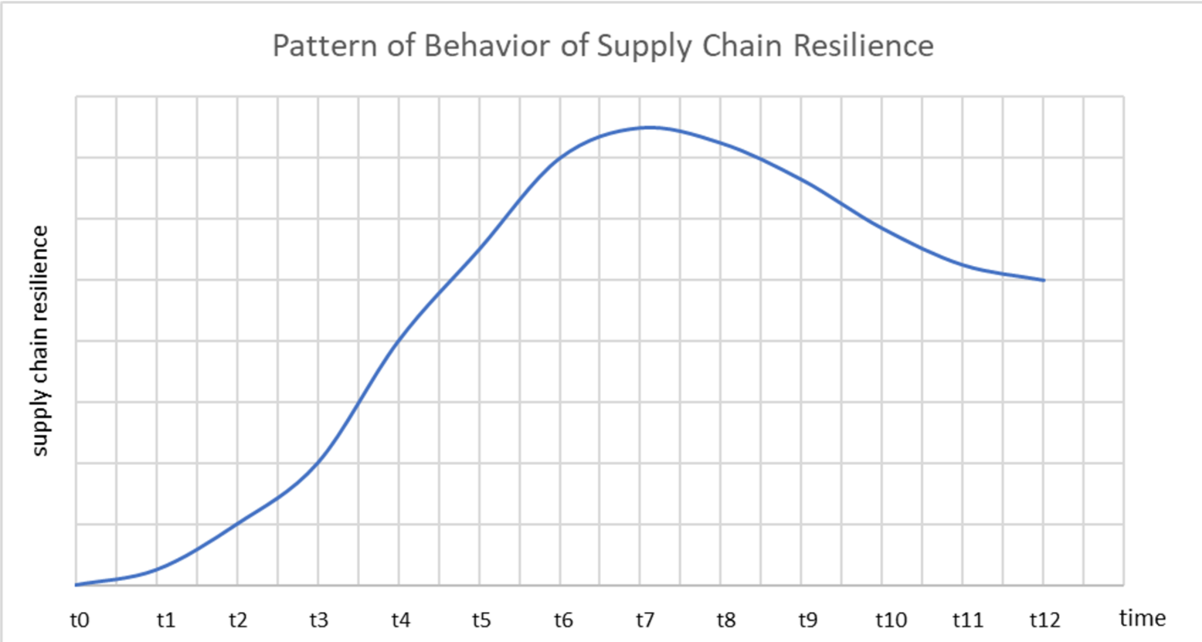

Figure 9. 1. RBP of Created CLD

Thanks to the causal loop diagram created, the effects of logistics 4.0 technologies on supply chain resilience and the factors that cause these effects can be examined in detail. In this sense, it can be a guide for companies considering the application of logistics 4.0 technologies. But companies may not implement all of these technologies at the same time. In this context, various scenarios have been produced in order to analyze what kind of results the use of several of these technologies in different combinations will create in companies.

When the causal loop created is examined, it can be stated that there is more than one loop showing the effect of the determined logistics 4.0 technologies on the SCR. For this reason, only one of the loops in which the technologies are included was chosen with expert opinions to examine the effects on SCR in the scenarios. The loop chosen to display the effects of Internet of Things on the SCR includes Internet of Things - Transparency - Visibility - SCR - Competitive Advantage - Company Performance - Customer Satisfaction - Revenue - Firm Size elements and is shown in figure 9.2. Since it is a reinforcement loop, it is given R1 notation and named as Internet of Things effects on SCR.

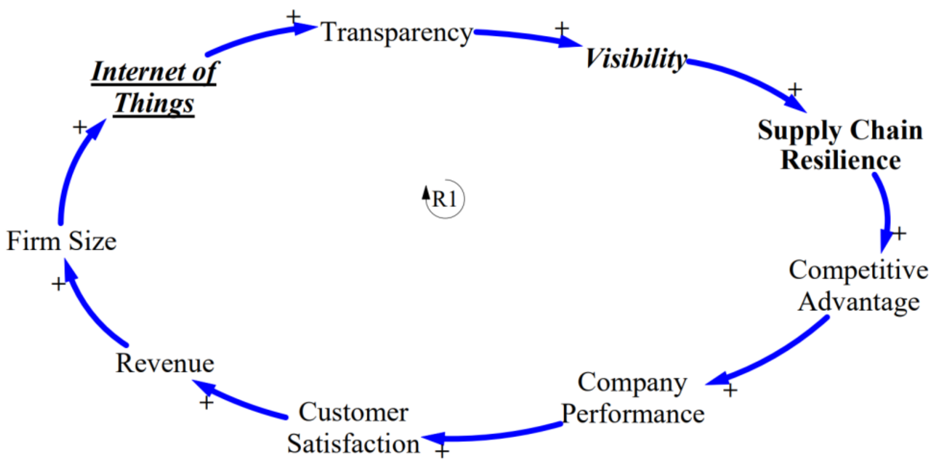

Figure 9. 2. Loop R1: Internet of Things Effects on SCR

The loop selected for Additive Manufacturing (3D Printing) consists of Additive Manufacturing (3D Printing) - Customization - Accurate Demand Forecasting - Efficiency - SCR - Competitive Advantage - Company Performance - Customer Satisfaction - Revenue - Technological Infrastructure Investments elements. The balancing loop is denoted with B1 notation and is named Additive Manufacturing (3D Printing) Effects on SCR. The loop is given in figure 9.3.

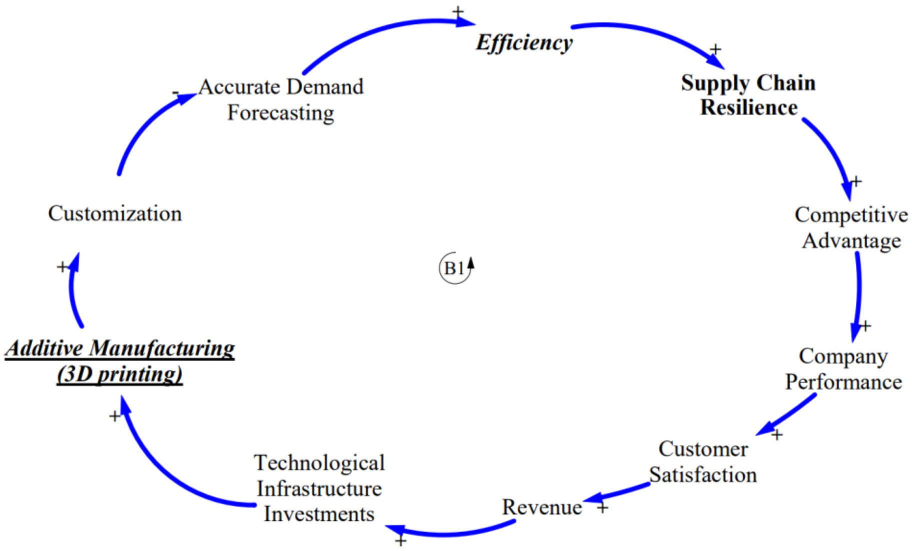

Figure 9. 3. Loop B1: Additive Manufacturing (3D Printing) Effects on SCR

The loop selected for Autonomous Robots technology includes Autonomous Robots - Technical Training Costs - Efficiency - SCR - Competitive Advantage - Organizational Learning - Top Management Support elements. The reinforcement loop expressed with the notation R2 and the name Autonomous Robots Effects on SCR is given in figure 9.4.

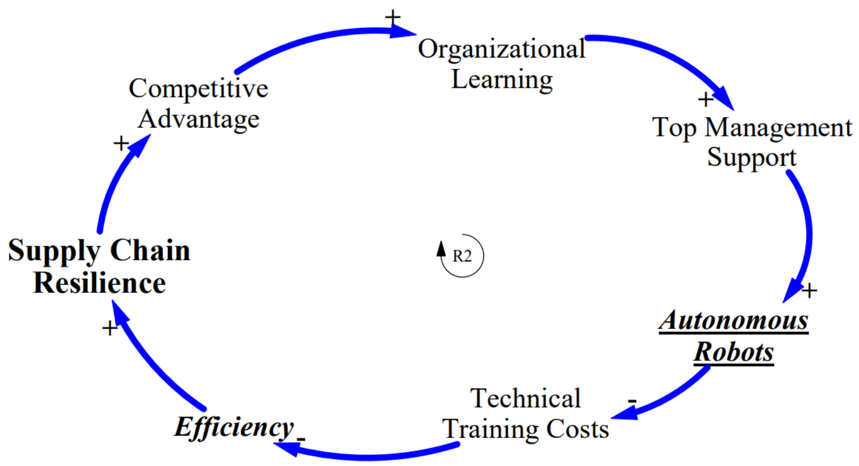

Figure 9. 4. Loop R2: Autonomous Robots Effects on SCR

The representative loop selected for SAR consists of SAR - Flexibility - SCR - Competitive Advantage - Organizational Learning - Top Management Support elements. The Reinforcement loop is represented by the R3 notation and is named SAR effects on SCR. The loop is shown in figure 9.5.

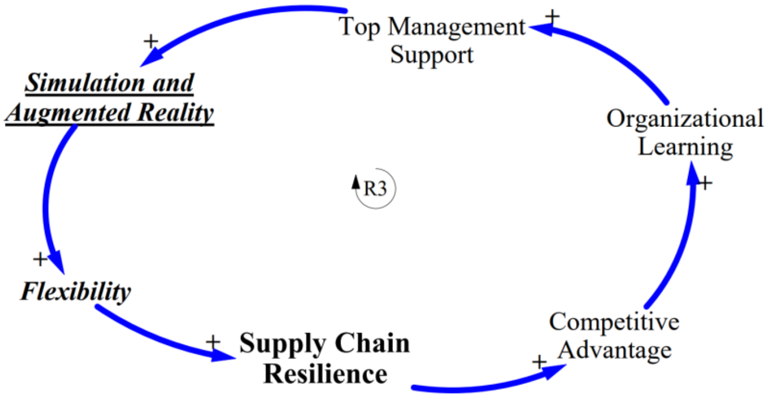

Figure 9. 5. Loop R3: SAR Effects on SCR

Elements of the loop chosen to demonstrate the impact of blockchain technology on SCR are Blockchain - Transparency - Visibility - SCR - Competitive Advantage - Company Performance - Customer Satisfaction - Revenue - Technological Infrastructure Investments. The reinforcement loop with R4 notation and named as Blockchain effects on SCR is given in figure 9.6.

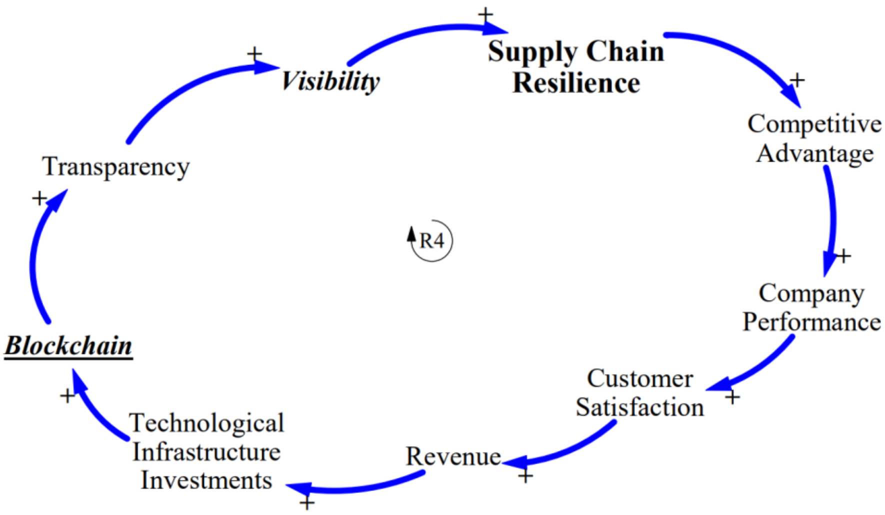

Figure 9. 6. Loop R4: Blockchain Effects on SCR

Reinforcement loop, expressed as loop R5 notation and Big Data and Analytics effects on SCR, chosen to express the effects of Big Data and Analytics technology on SCR, includes Big Data and Analytics - Sourcing Costs - Efficiency - SCR - Competitive Advantage - Company Performance - Customer Satisfaction - Contains Revenue - Firm Size - Internet of Things elements. The loop is given in figure 9.7.

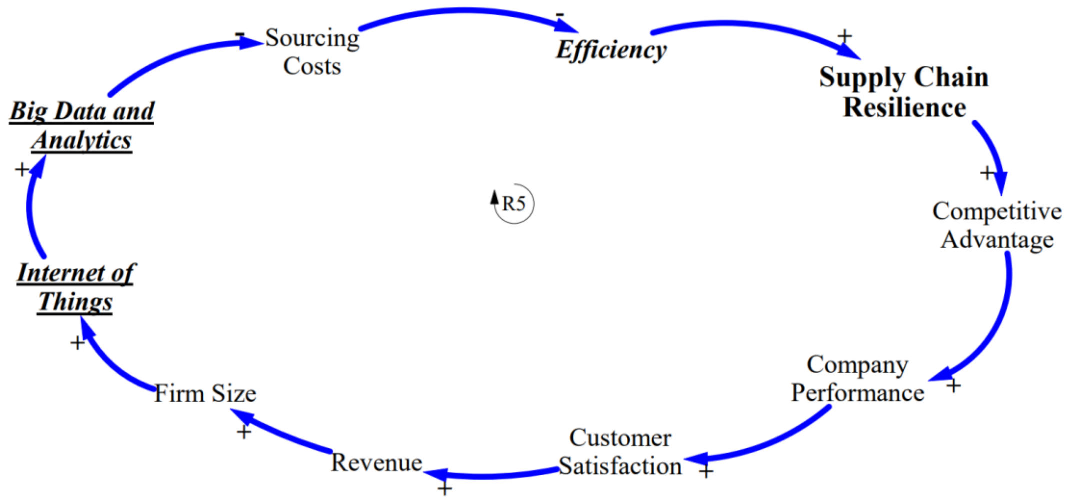

Figure 9. 7. Loop R5: Big Data and Analytics Effects on SCR

After the representative loops are selected, various scenarios were generated and causal loop diagrams were created for each scenario. In order to evaluate the results of these scenarios RBP was used. Acceptable orders for implementing the technologies mentioned in scenarios in companies are established in order to examine the RBP and these orders are determined using the literature.

Scenario 1. A company's application of Internet of Things, Autonomous Robots and Additive Manufacturing (3D Printing) technologies

In this scenario, a company's application of only these three logistics 4.0 technologies is examined: Internet of Things, Autonomous Robots and Additive Manufacturing (3D Printing). In order to provide sensor-based monitoring for autonomous robots, IoT technology is needed, according to Routray et al. (2020). The Internet of Things should be implemented to companies before autonomous robots for this reason. IoT technology is initially required for the proper application of additive manufacturing (3D printing) in companies. 3D printers can now be directly connected to the cloud and simply monitored and remotely operated thanks to IoT technology. For this reason, it would be appropriate for companies to adopt IoT technology before Additive Manufacturing (3D Printing) technology (Wang et al., 2019; Routray et al., 2020). Autonomous robots' components can be printed by 3D printers, as these printers can produce a wide variety of products at low cost. For this reason, the implementation of 3D printer technology before the implementation autonomous robots technology is an order that may be preferred by companies (Mohammed, 2016; Patterson et al., 2022). In this case, the proper implementation order of mentioned logistics 4.0 technologies in companies was determined as: IoT, Additive Manufacturing, Autonomous Robots. RBP was created according to this order.

The initial phase and selected representative loops for the scenario are given in the figure 9.8. IoT will be implemented first in the scenario. Since the representative loop of IoT technology is a reinforcement loop, it will cause an exponential growth on the SCR. This first phase is shown in the figure 9.9. Additive manufacturing will be applied in the second place in the scenario. Since the representative loop of Additive manufacturing is a balancing loop, if it was applied alone, it would cause an exponential decrease. However, since there is both IoT technology and additive manufacturing technology in the system, it will tend to show a decrease as in the figure 9.10 expressing phase 2. The representative loop of autonomous robots technology, which is the third technology in the scenario, is also a reinforcement loop, which by itself provides an exponential increase in the system. The effect that will occur as a result of the presence of these three technologies in the system at the same time is given in the figure 9.11 showing phase 3. Phase 4, on the other hand, is the situation that occurs as a result of applying all the technologies in this system for a while. As can be seen in figure 9.12, the system will be balanced with the effect of reinforcement and balancing loops.

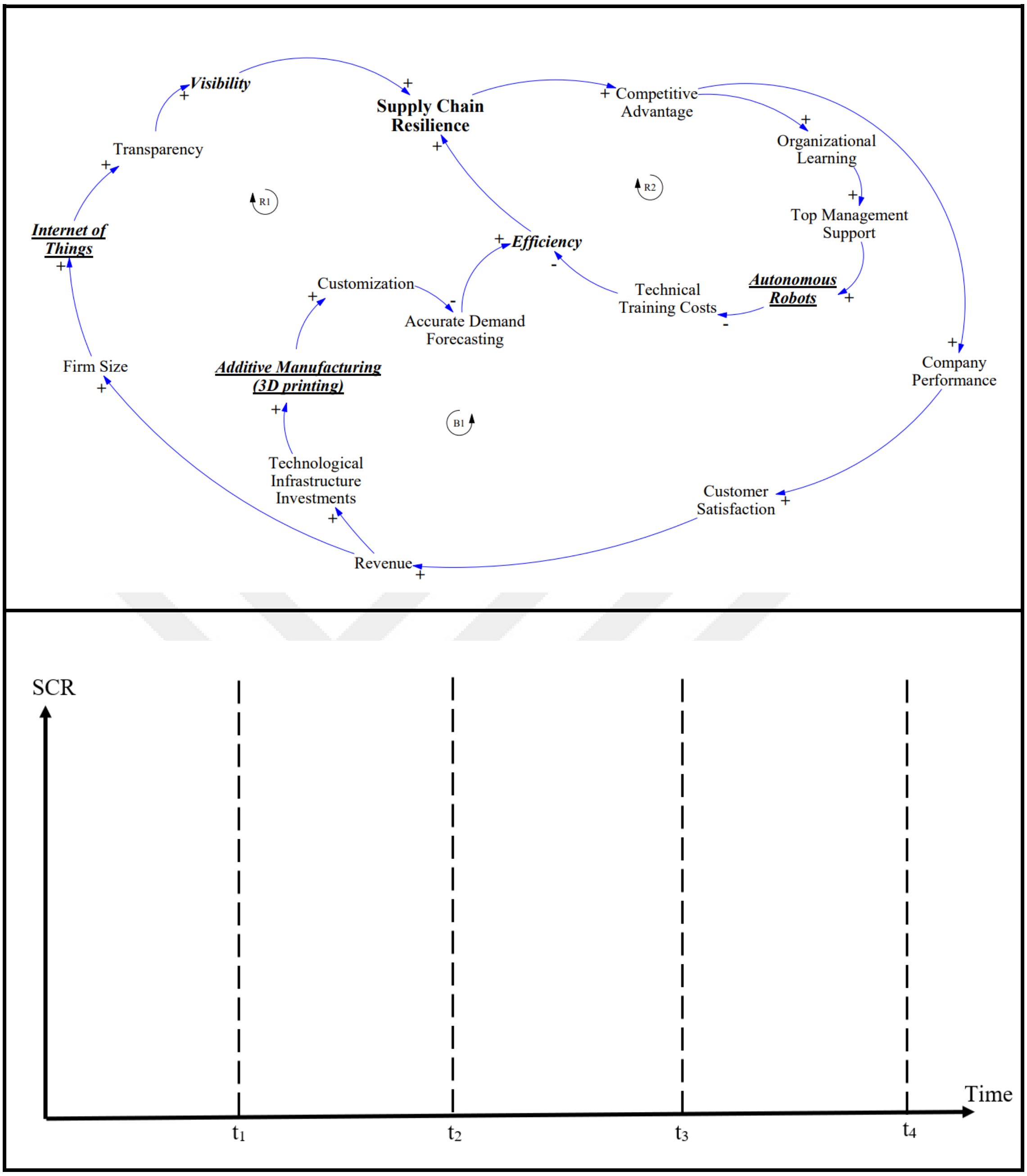

Figure 9. 8. Initial Phase of the Scenario 1

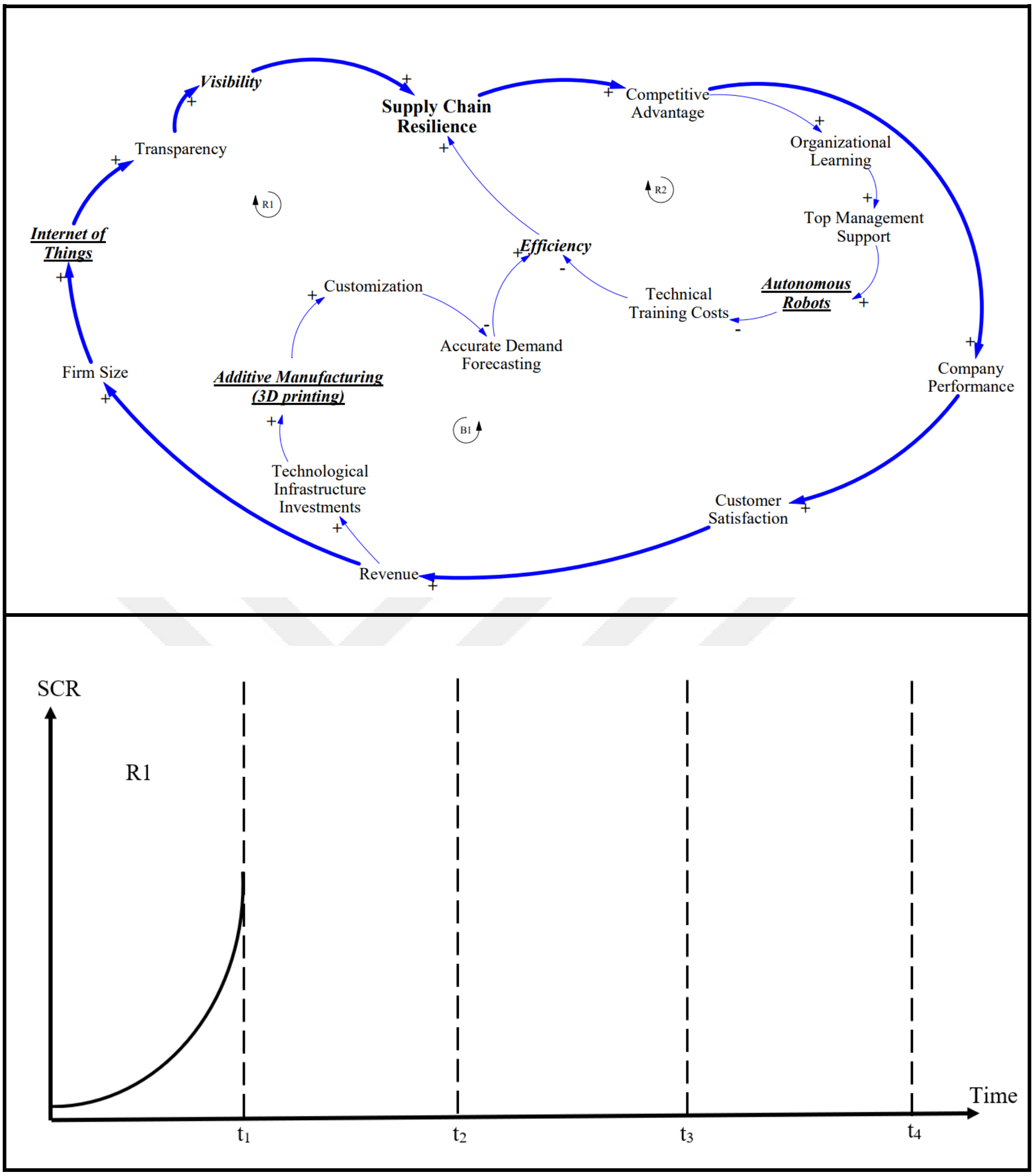

Figure 9. 9. RBP for IoT Implementation Phase of the Scenario 1

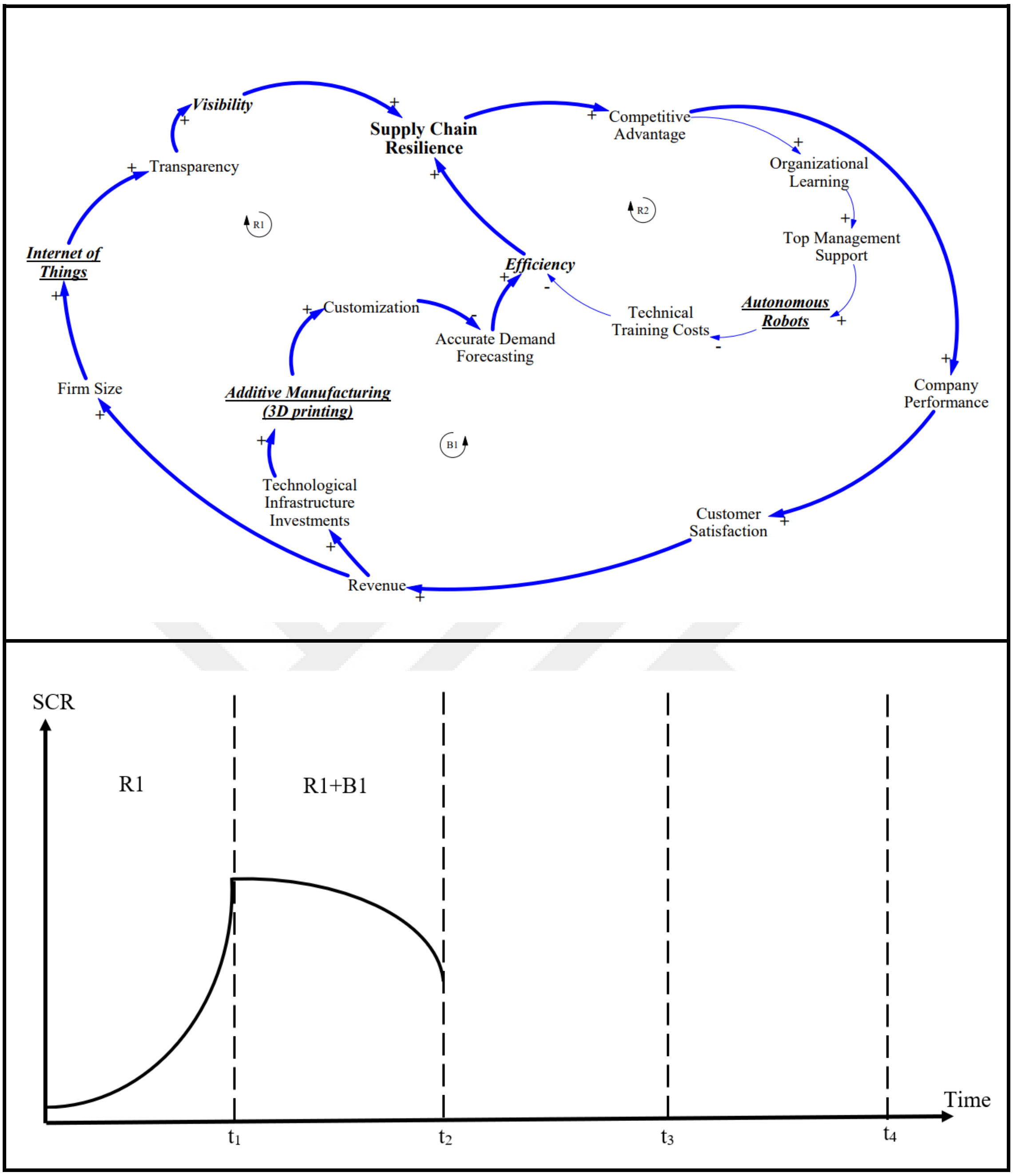

Figure 9. 10. RBP for IoT and Additive Manufacturing (3D Printing) Implementation Phase of the Scenario 1

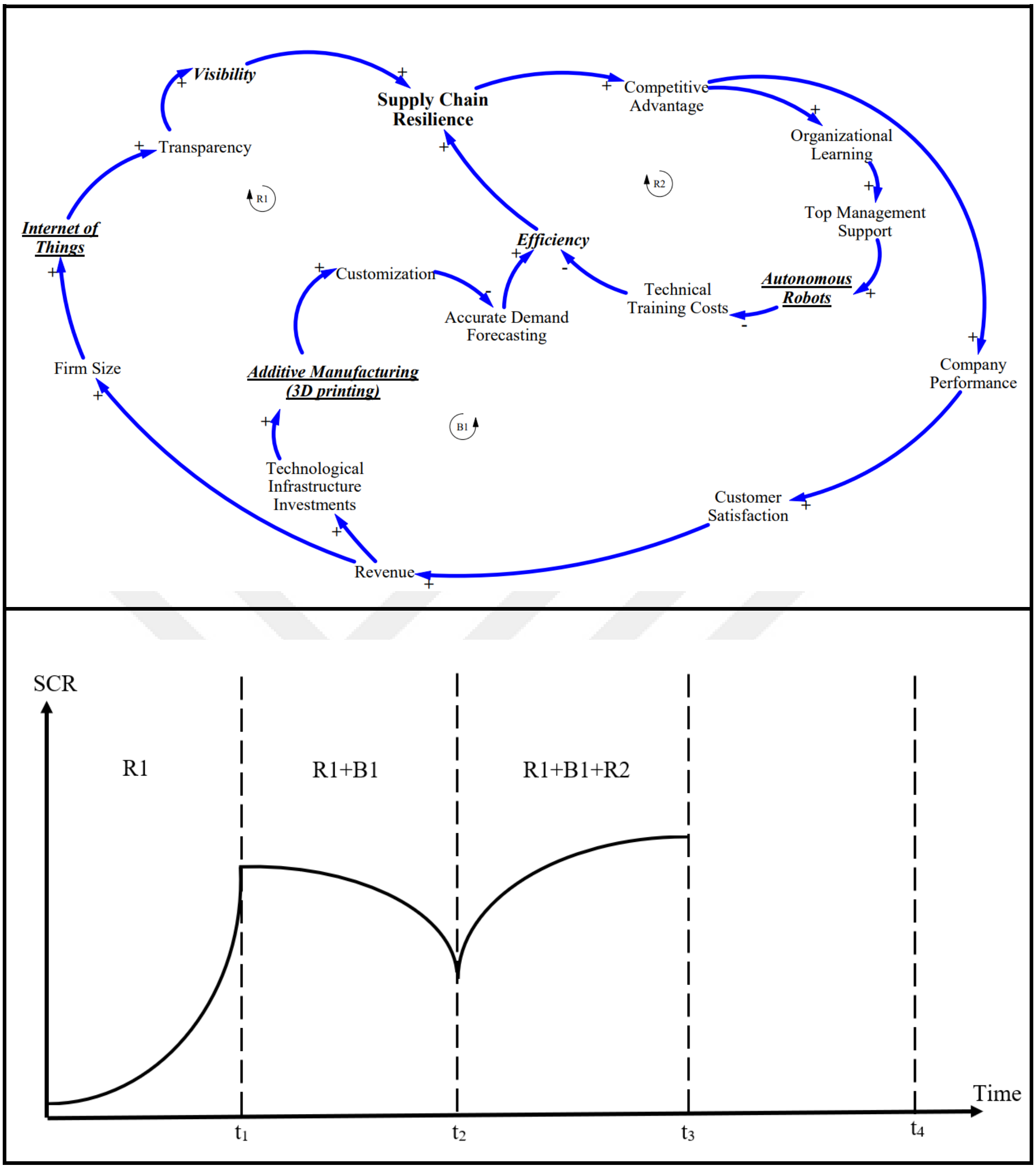

Figure 9. 11. RBP for IoT, Additive Manufacturing (3D Printing) and Autonomous Robots Implementation Phase of the Scenario 1

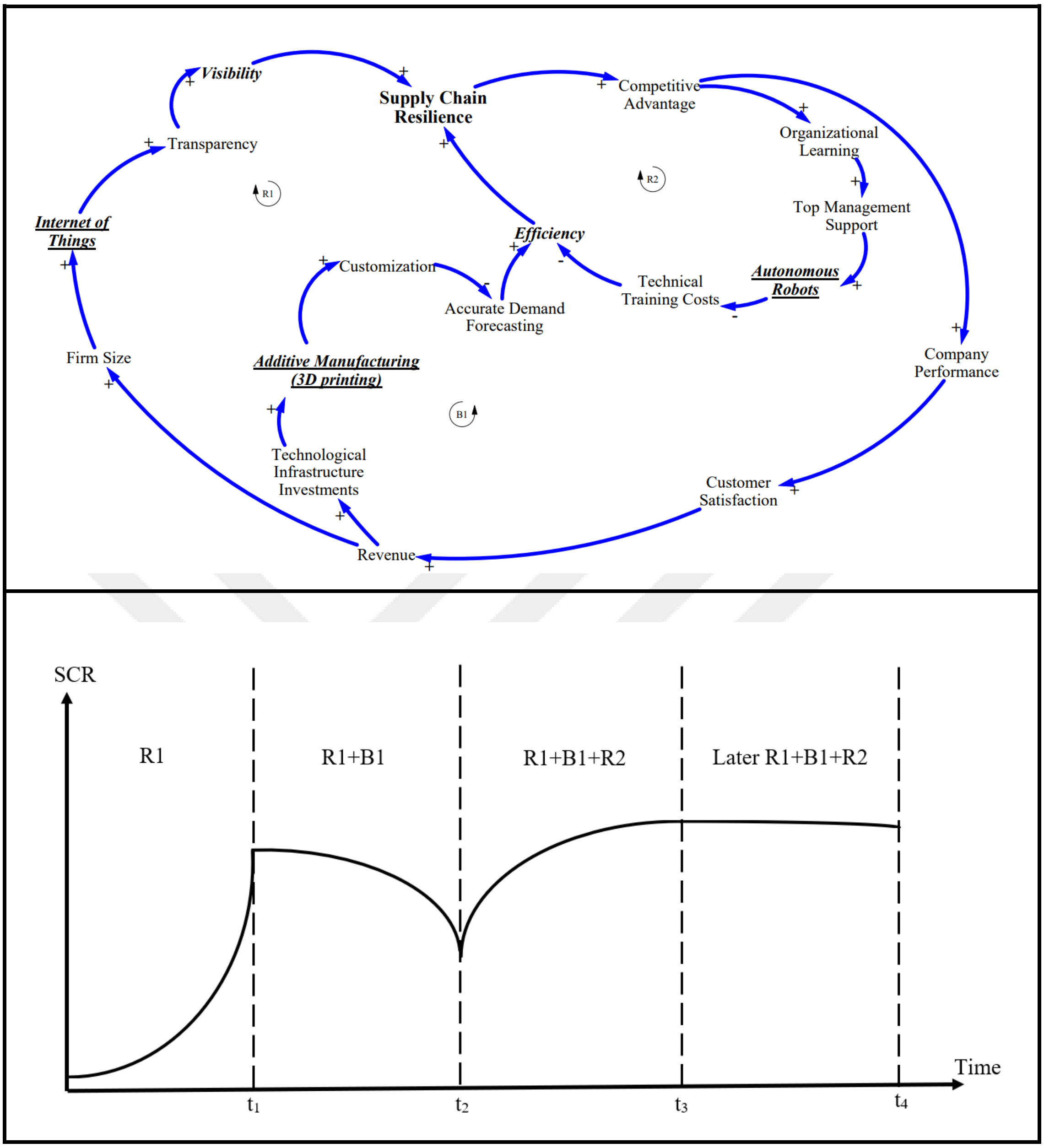

Figure 9. 12. RBP for Balancing Phase of the Scenario 1

Scenario 2. A company's application of SAR and Blockchain Technologies

Augmented reality allows planned developments to be visualized before they are implemented in the logistics stages, enabling needs to be determined. Ensuring that these needs are met securely without the need for intermediation can be achieved with blockchain technology. As a result, companies can adopt SAR technology first and then blockchain technology for use in logistics operations (Cannavo and Lamberti, 2020; Rejeb, 2019; Kihel, 2022). In this context, it is desired to find the behavioural pattern of the application of these two technologies. The initial phase is shown in figure 9.13. The effect of the R3 loop is seen in the first 2 periods of the 4-term modelling and it is shown in figure 9.14. The effect of R3+R4 in the last 2 periods and it is shown in figure 9.15. Due to the fact that R3 is a reinforcement loop, it increases SCR exponentially. Since R4 is also a reinforcement loop, it further increases the effect of R3 on the SCR, and as can be observed in the last 2 periods, there is a faster growth compared to the first 2 periods. There are 2 phases in this pattern. As the two reinforcement loops are examined, there will be a continuous increase in SCR, no balance phase will occur.

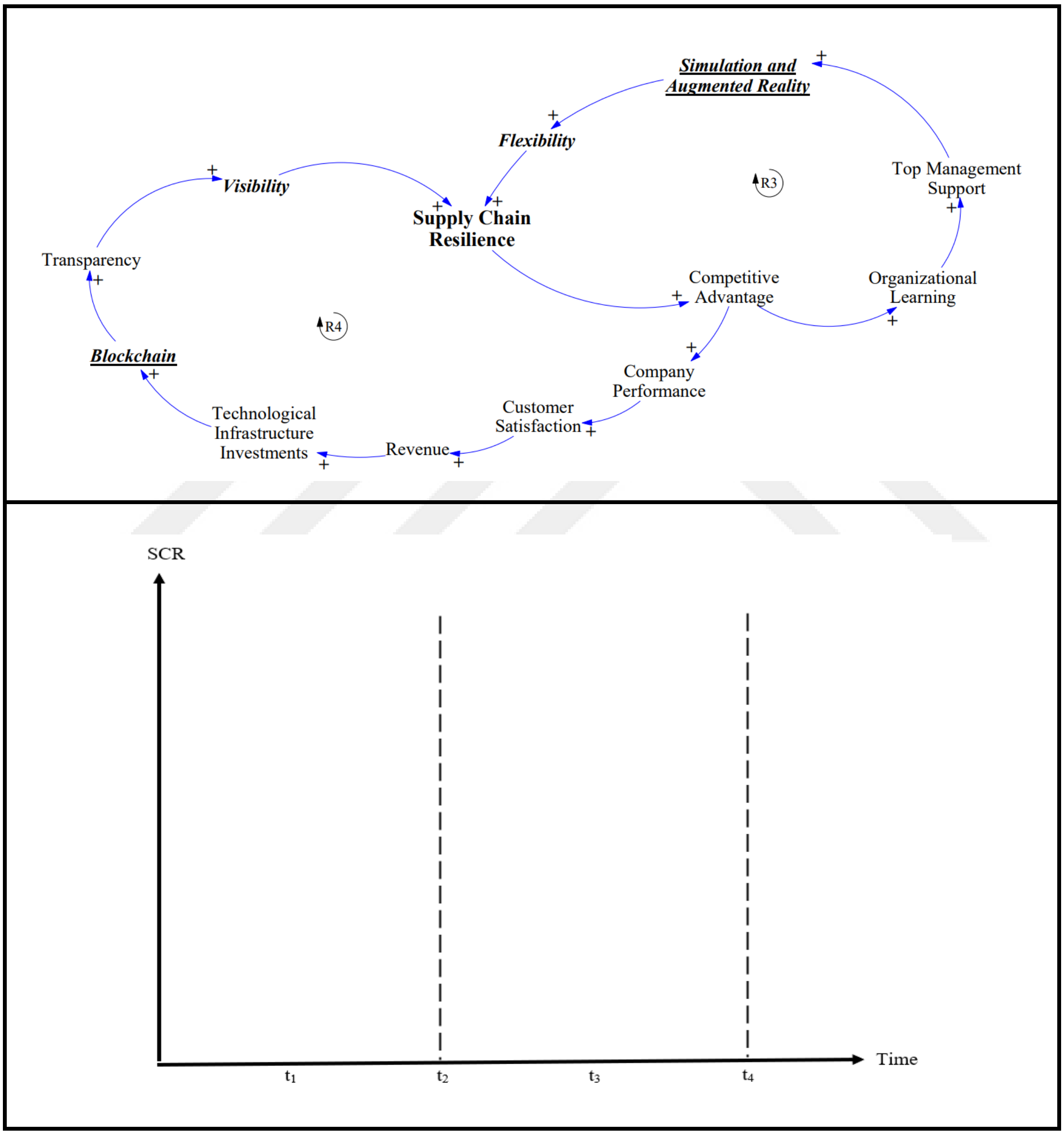

Figure 9. 13. Initial Phase of the Scenario 2

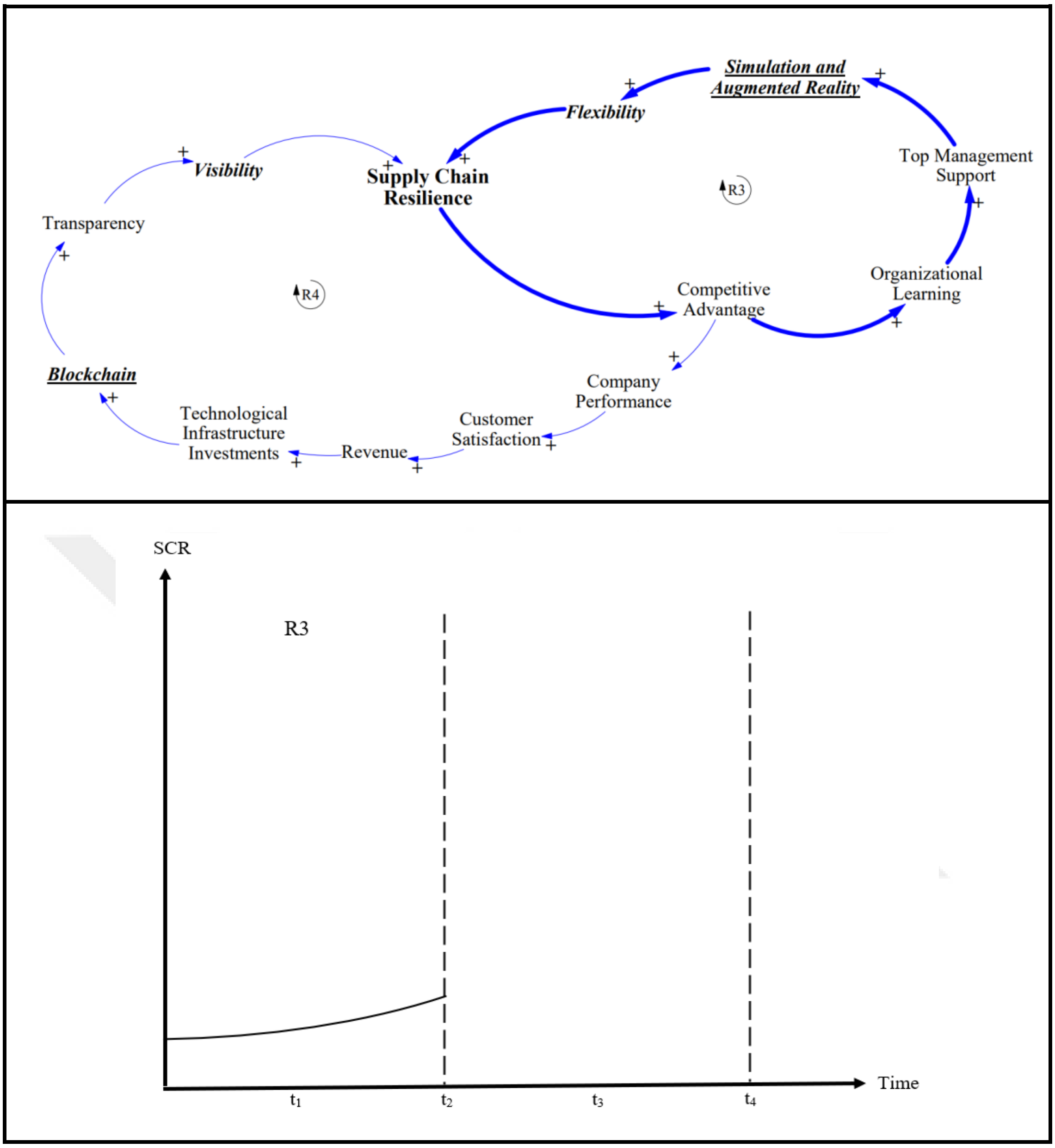

Figure 9. 14. RBP for SAR Implementation Phase of the Scenario 2

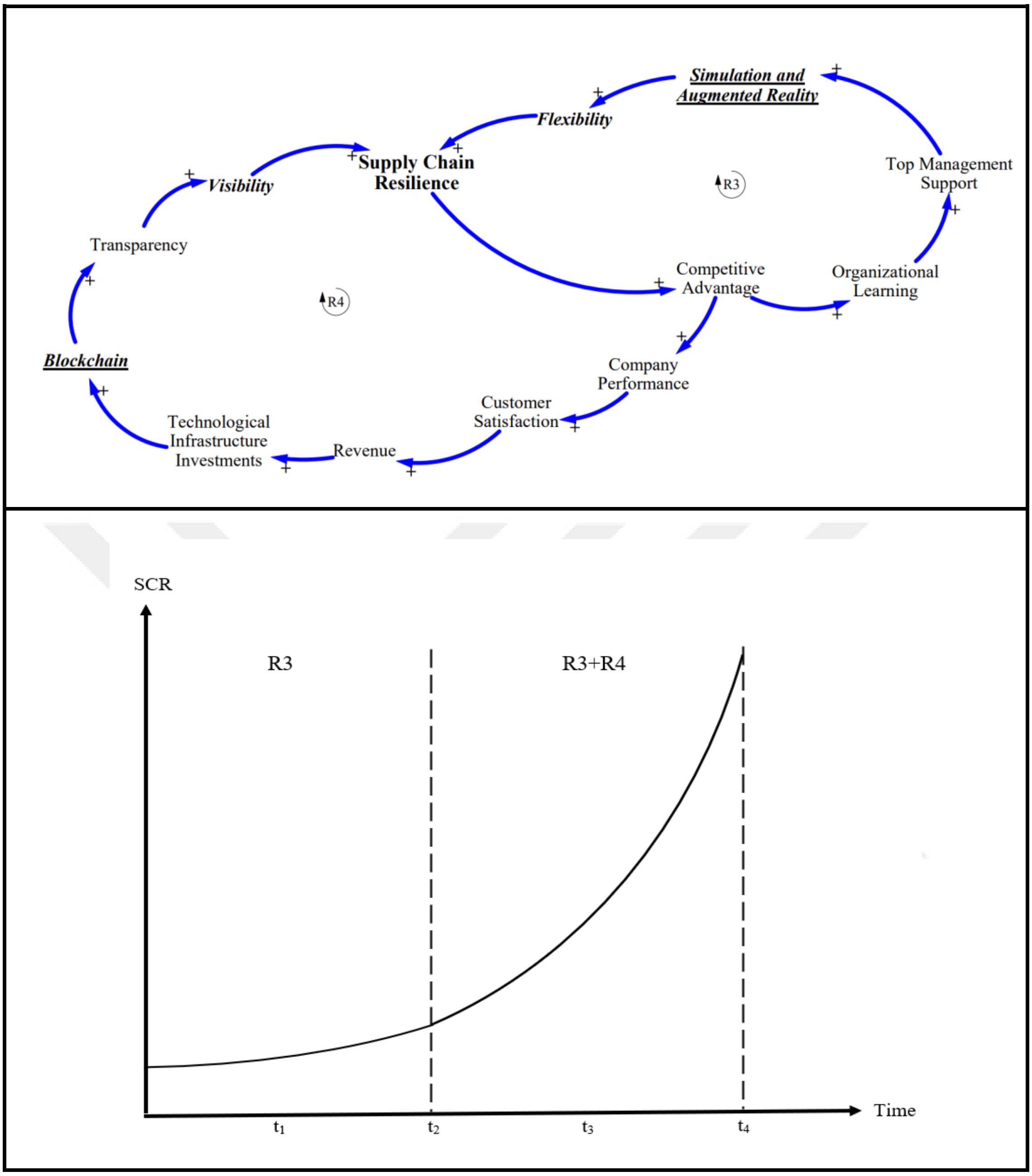

Figure 9. 15. RBP for SAR and Blockchain Implementation Phase of the Scenario 2

Scenario 3. A company's application of IoT, Big Data and Analytics, Additive Manufacturing (3D Printing) and Blockchain Technologies

Because IoT collects data through numerous sensors and is a significant resource of big data, it is generally a good idea to use IoT technology before big data and analytics (Ahmed et al., 2017). With Big Data and Analytics technology, data is translated into meaningful results. Being able to visualize these meaningful results is an important point in understanding the results obtained with big data (Bermejo et al., 2017). Since additive manufacturing is a technology that has the potential to display data, big data and analytics can be practiced before additive manufacturing (Weber and Gadepally, 2014). While additive manufacturing allows for rapid and less wasteful production, blockchain allows these products to have an electronic presence and build a secure payment system. Given this context, additive manufacturing may be implemented by companies prior to blockchain (Ghimire et al., 2022). Considering all these relationships, the application sequence can be determined as IoT, Big Data and Analytics, Additive Manufacturing (3D Printing), Blockchain.

The initial phase of scenario 3 is given in figure 9.16. Since it is a reinforcement loop expressing IoT technology, an increase in the effect of R1 is observed until time t1. It is shown in figure 9.17. Since the loop that Big Data and Analytics is in is a reinforcement loop, there is an exponential increase with the effect of R1+R5 between time t1 and time t2, increasing more drastically than at time t1. The increase can be seen in figure 9.18. While there is a decrease with the effect of B1 balancing loop in addition to R1 and R5 loops between t2 and t3 times and it is shown in figure 9.19, the effects of R1+R5+B1+R4 loops are seen between t3 and t4 times and an increasing graph emerges. It is displayed in figure 9.20 It can be seen that the effects of all loops reach a state of equilibrium over time between time t4 and t5 and the balancing phase can be seen in figure 9.21.

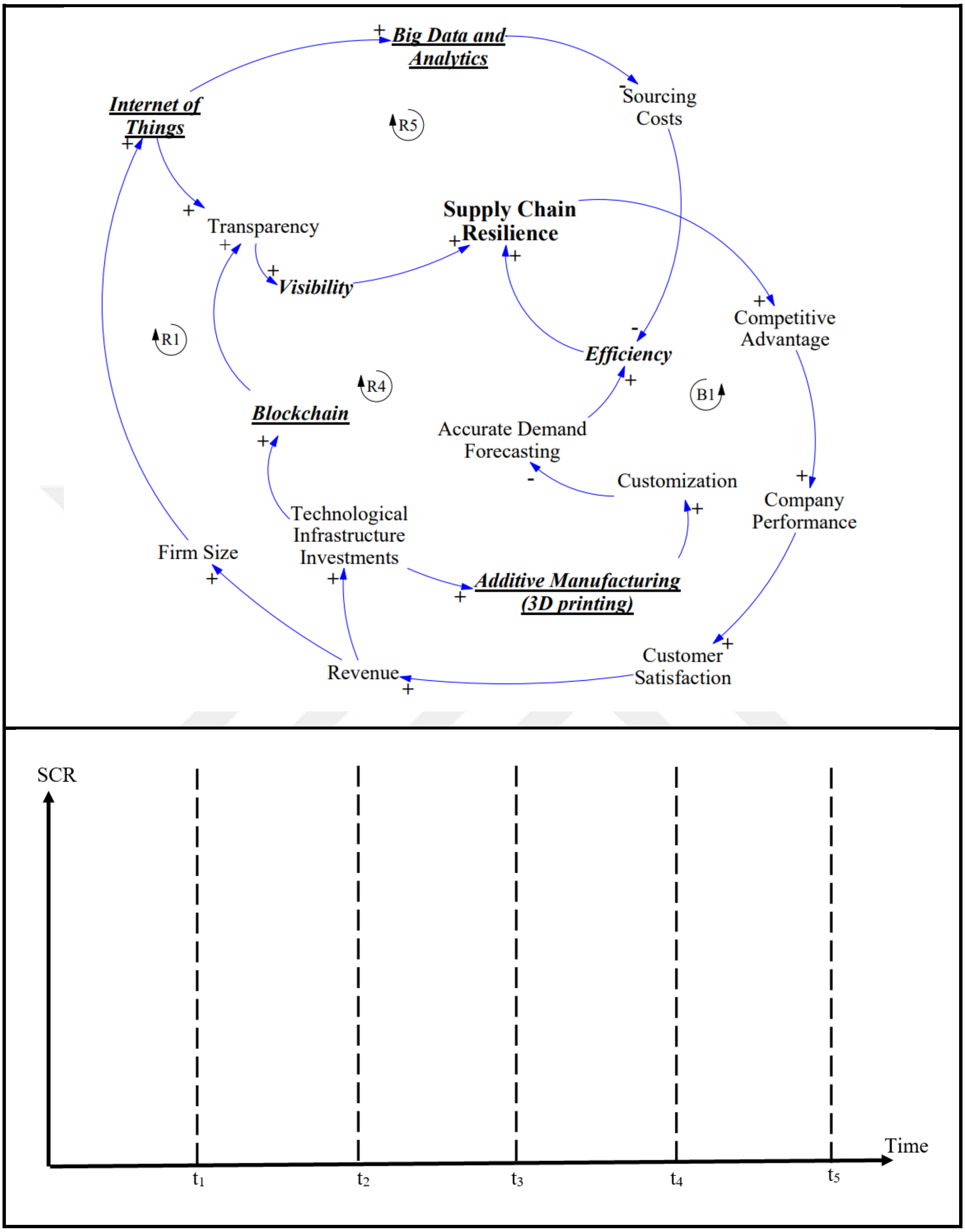

Figure 9. 16. The Initial Phase of the Scenario 3

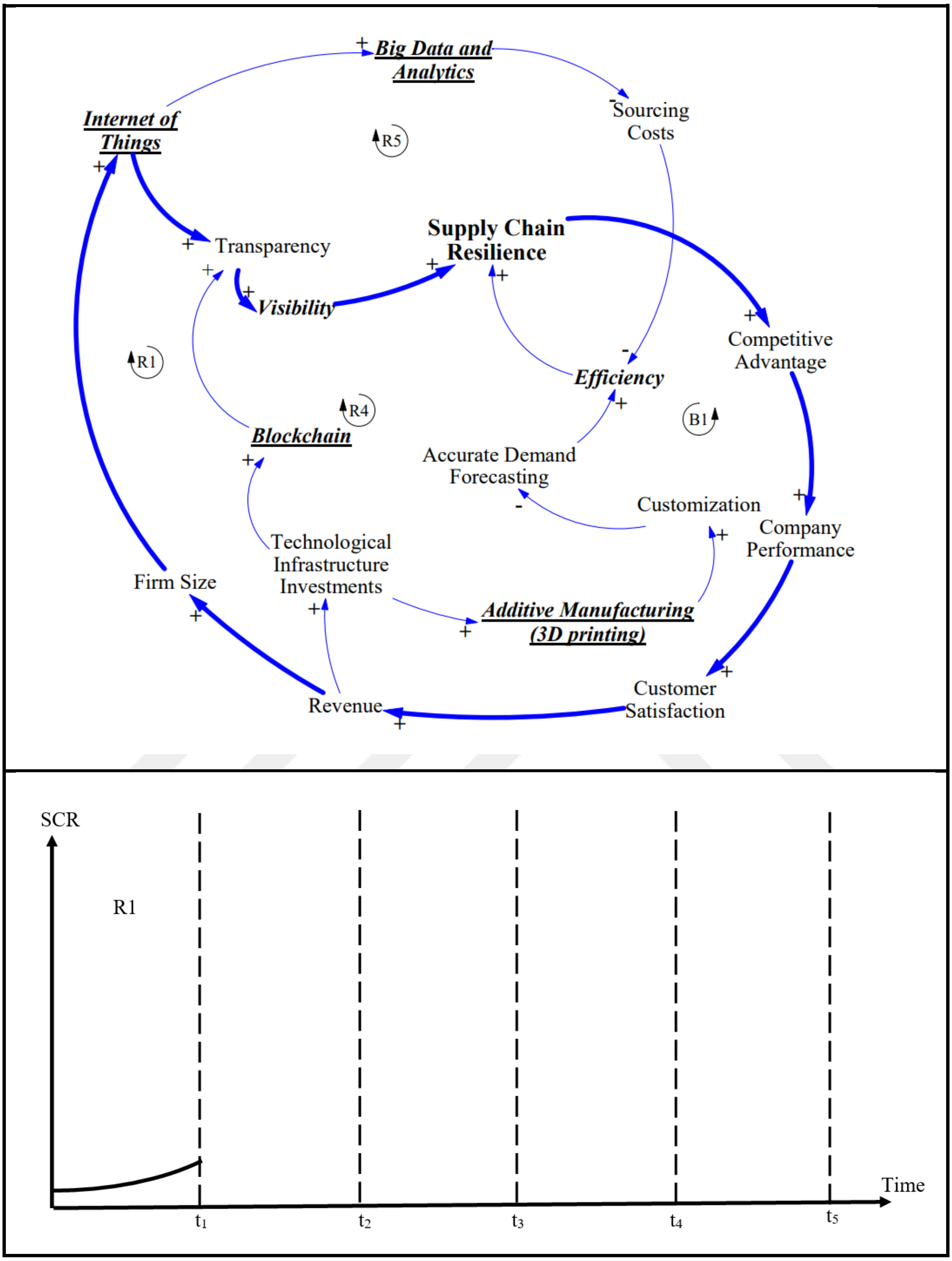

Figure 9. 17. RBP for IoT Implementation Phase of the Scenario 3

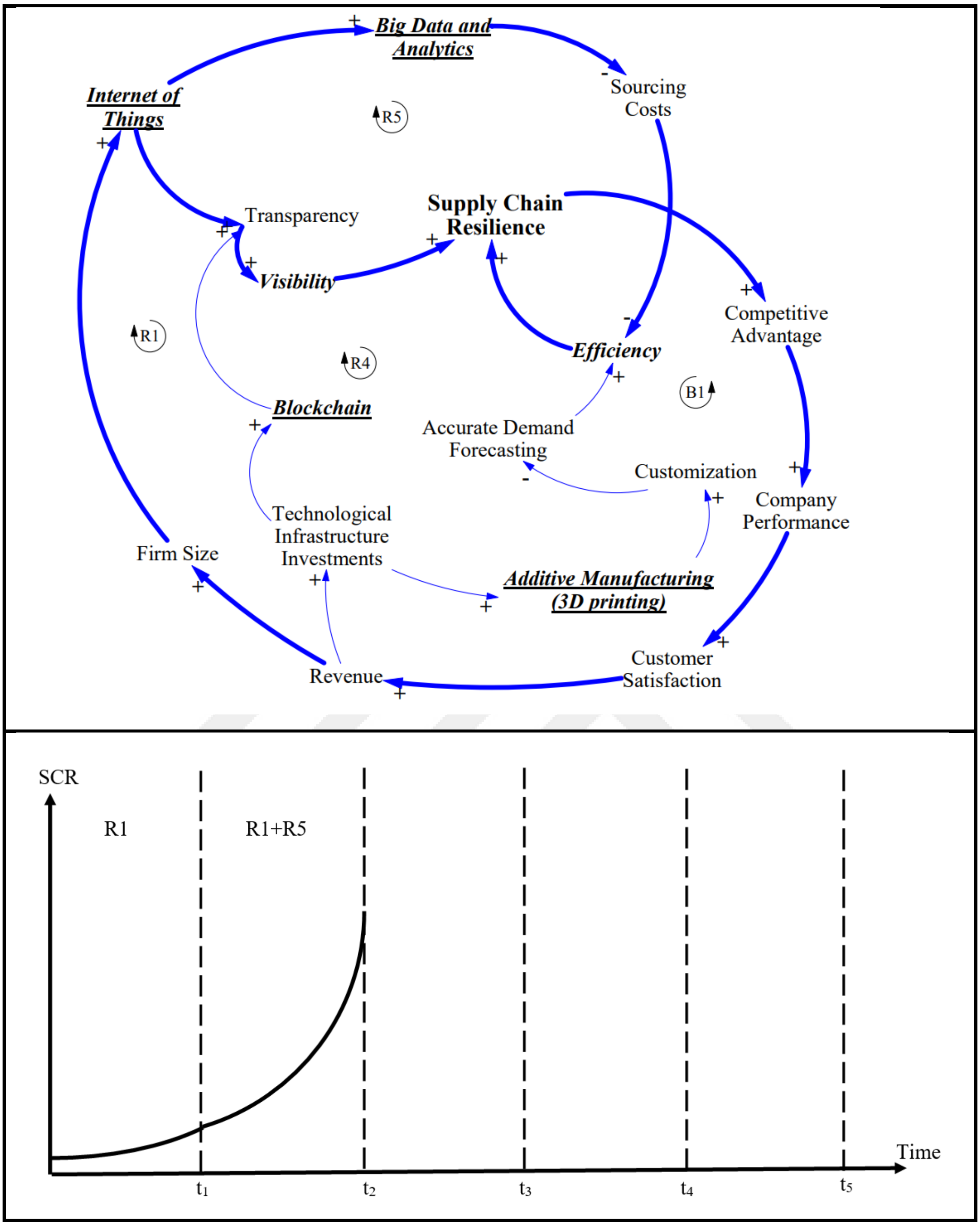

Figure 9. 18. RBP for IoT and BDA Implementation Phase of the Scenario 3

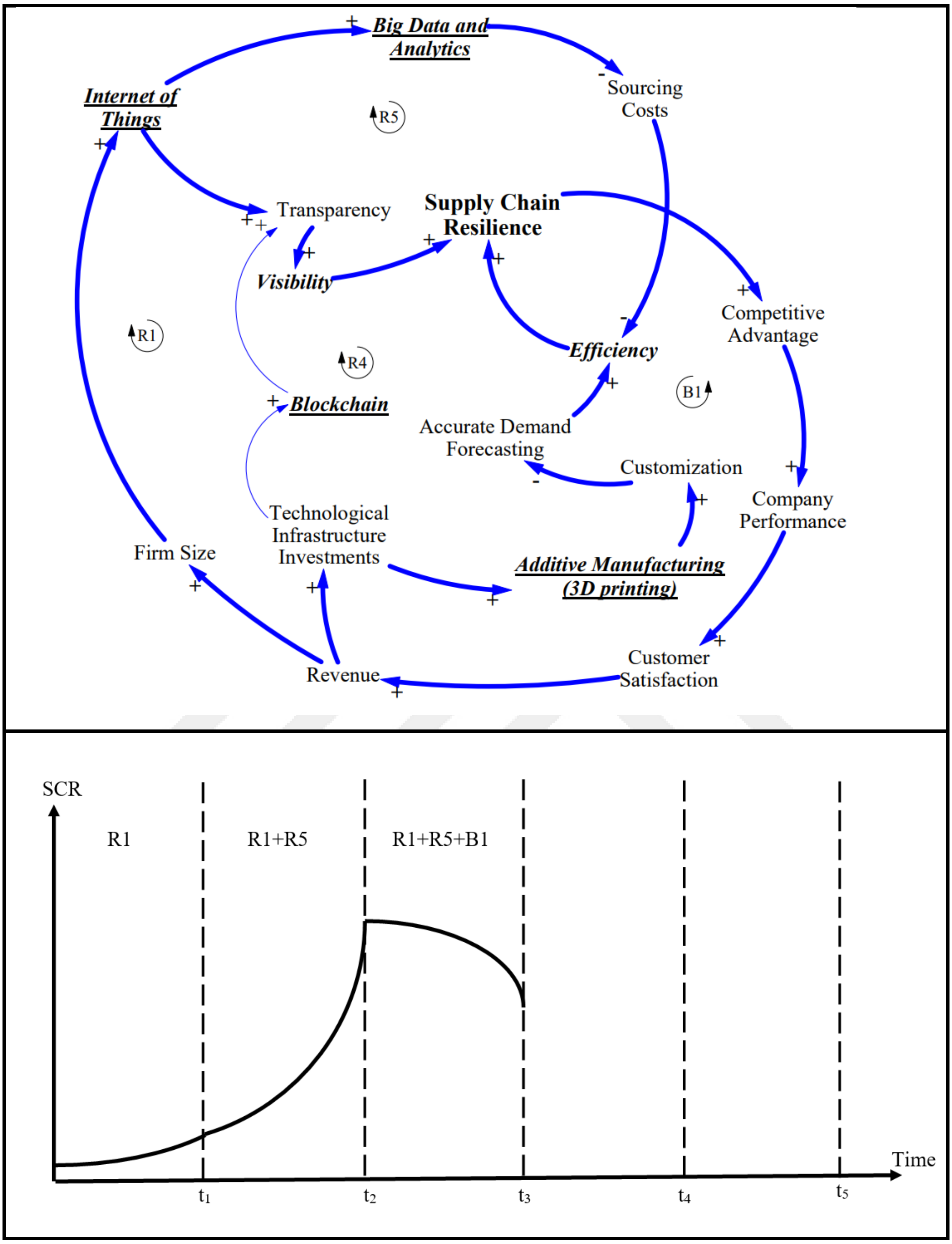

Figure 9. 19. RBP for IoT, BDA and Additive Manufacturing (3D Printing) Implementation Phase of the Scenario 3

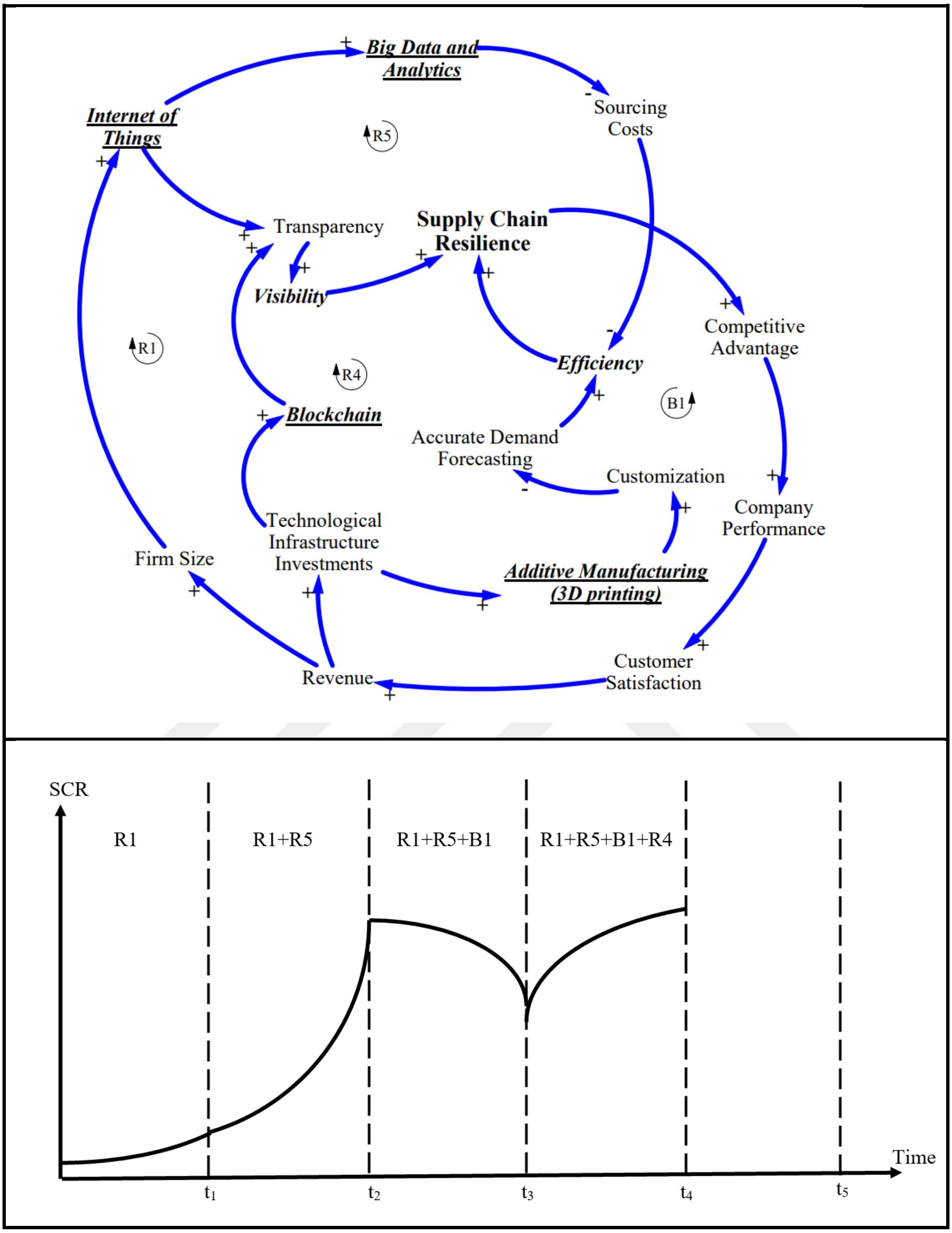

Figure 9. 20. RBP for IoT, BDA, Additive Manufacturing (3D Printing) and Blockchain Implementation Phase of the Scenario 3

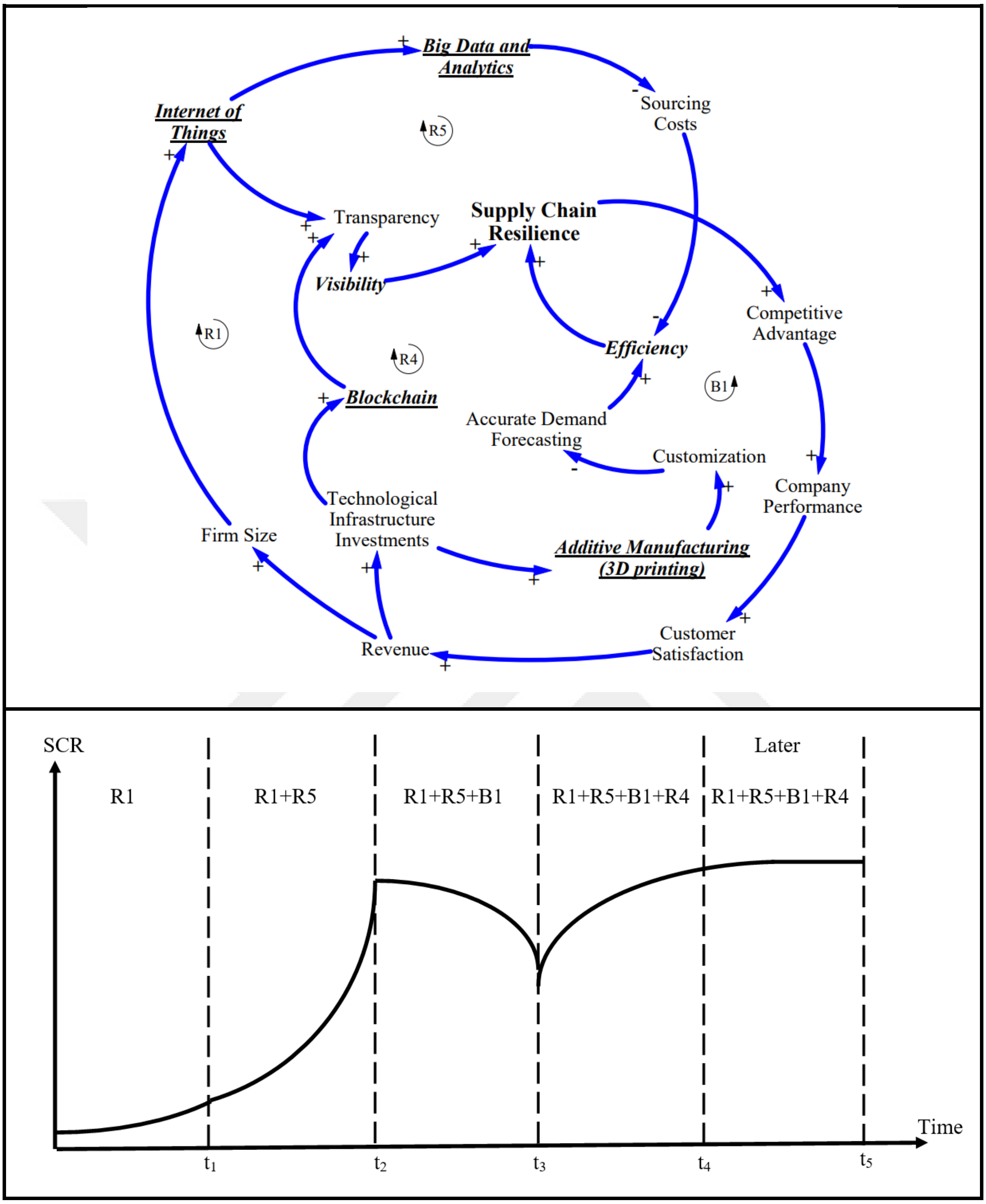

Figure 9. 21. Balancing Phase of the Scenario 3

10. CONCLUSION

Applications of technological developments within the scope of Industry 4.0 in different sectors have gained momentum in recent years. The logistics sector is one of these sectors. With the concept called Logistics 4.0, it refers to technological developments and digitalization in all imaginable logistics activities such as transportation, material handling, stock management.

In this study, the effects of logistics 4.0 technologies on supply chain resilience have been tried to be revealed. In this context, supply chain resilience elements have been determined and logistics 4.0 technologies that have effects on these elements have been mentioned. A causal loop diagram was created using the system dynamics approach to reveal the impact of each technology on each supply chain resilience. VENSIM software was used to create this diagram.

By examining the created causal loop diagram, the effects of the elements on other elements can be seen in detail. The effects of reinforcement and balancing loops in the diagram can be analyzed separately.

The overall effect of the loops in this diagram on the system is demonstrated by the reference behaviour pattern. In this context, a 12-month behavioural pattern has been established. When the pattern was examined, it was seen that the system improved with the effect of reinforcement loops, but then it came to balance at some point with the effect of balancing loops.

Scenario analyzes were carried out to examine the situations in which not all of the determined logistics 4.0 technologies are used. First, a representative loop was selected to express the effect of each technology on the SCR. Accordingly, 3 different scenarios involving different technologies were produced, and the appropriate application sequence for these technologies was determined by using the literature. Afterwards, RBP graphs were created and interpreted.

With this study, it has been tried to answer the question of ‘What is the effect of logistics 4.0 on supply chain resilience?’. In the literature, logistics 4.0 and supply chain resilience are frequently studied separately. However, there is no other study that brings these issues together by revealing the effects of logistics 4.0 with a causal loop diagram. Therefore, this study is aimed to be a guide for companies planning to implement logistics 4.0 technologies. Furthermore, the scenario analysis performed is intended to give an idea to companies that want to implement particular technologies.

In future studies, the impact of applications of industry 4.0 in other areas on supply chain resilience can be revealed. In addition, the effects of logistics 4.0 technologies on concepts other than supply chain resilience can be examined. The causal loop component of the system dynamics approach was used in the study. The study can be developed using the Stock and Flow Diagram. Apart from this, similar issues can be studied with different approaches apart from system dynamics.

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