**Circular Dairy Supply Chain Management Through Internet of Things-Enabled Technologies**

**Abstract**

Internet of Things enabled technologies help to collect data and make it understandable, especially in supply chain processes, thus minimizing the problems that may arise in supply chains. It is extremely important to support this process with Internet of Things-enabled technologies, especially in supply chains that are vulnerable to disruptions such as the dairy supply chain. Moreover, dairy supply chains are the type of supply chains where the most waste is generated; evaluating this waste is very beneficial to the circular economy. Therefore, monitoring data in dairy supply chains and using Internet of Things enabled technologies prevent losses; it is critical to have Internet of Things enabled circular dairy supply chains in operation. The aim of this study is to determine the success factors of Internet of Things enabled circular dairy supply chains based on the various stages of these chains; we hope to match each dairy supply chain stage with a success factor of Internet of Things enabled technology and determine a ranking for these factors. Hence, six success factors of Internet of Things enabled circular supply chains are weighted for each stage of the chain; Internet of Things enabled digital technologies are then matched with each stage of the chain and the success factor is determined. The ranking of factors can then be drawn up through the integration of Step Wise Weight Assessment Ratio Analysis (SWARA) and Technique for Order Preference Similar to Ideal Solution (TOPSIS). The outcome of this study will provide managers and policy makers with insights into Internet of Things enabled circular dairy supply chains.

**Keywords:** Dairy Supply Chain, Circular Economy, Success Factor, IoT-Enabled Technologies, SWARA-TOPSIS

**List of Abbreviations**

BDA – big data analytics;

CE- circular economy;

DSC – dairy supply chain;

IoT- Internet of Things;

SWARA- Step Wise Weight Assessment Ratio Analysis;

TOPSIS- Technique for Order Preference by Similarity to Ideal Solution

**Introduction**

Internet of Things (IoT) is defined as a dynamic network system created to monitor and optimize structures connecting objects with integrated embedded systems (Atzori et al., 2010; Zhang et al., 2017). Businesses can improve their operations via IoT enabled technologies such as radio frequency identification (RFID), big data, addictive manufacturing and embedded systems etc. by providing real-time data and by controlling and monitoring operations in the supply chain (Verdouw et al., 2016; Akhigbe et al., 2021). Besides, IoT enabled technologies have several advantages such as decreasing cost, enhancing efficiency, increasing quality by providing real time data and converting this data into meaningful information (Aheleroff et al., 2020; Bashir et al., 2021; Yadav et al., 2021).

IoT enabled technologies have become important in the dairy supply chain (DSC) (Kelepouris et al., 2007). Nowadays, the need for transparency in the DSC is evident; as we witness a rapid increase in population and consumer demand, customer awareness is also growing. Digital technologies need to adapt DSCs in order to detect foodborne disease outbreaks rapidly and to deal with risk management problems in food production (Zhong et al., 2017; Moosavi et al., 2021). In addition, the food supply chain has become more complex due to stakeholders encouraging a transition to a circular economy (CE); transparency thus becomes a significant issue in supply chain management (Yontar and Ersöz, 2021). Therefore, DSC requires a more advanced tracking system to tackle issues with perishable products and their related safety concerns (Hassan et al., 2021; Theophilus et al., 2021). Virtual systems in the dairy supply increase traceability by categorizing information related to location and product history (Kassahun et al., 2014; Yadav et al., 2020). Different dairy product parameters, such as temperature and moisture, can be obtained with IoT enabling technologies (Jedermann et al., 2014). DSCs have a multi-stakeholder structure, meaning that having real-time data is vital to tackle the complexity of the network.

Moreover, through IoT enabled technologies, supply chain actors can interact and exchange required data to coordinate and control operations (Tian et al., 2014). Via IoT enabled technologies, current phases of DSC can be recorded at anytime and anywhere to ensure the validity of information sources (Aryal et al., 2018). Therefore, IoT enabled technologies are necessary to reduce food waste and improve performance in DSCs (Astill et al., 2019). Besides, the adoption of circularity in DSCs that encourages the use of renewable and recyclable materials is important in minimizing waste and preventing negative environmental impacts (Kumar et al., 2021; Joensuu et al., 2020; Oliveira et al., 2021).

Thus, the research questions of this study can be stated as follows:

* **RQ1.** What are the success factors of IoT enabled circular DSCs?
* **RQ2.** What are the potential IoT enabled technologies to achieve success factors in DSC?
* **RQ3.** What is the ranking of success factors of IoT enabled circular DSCs based on stages and determining which IoT enabled digital technologies should be used at each stage of the DSC?

To find answers to these research questions, six different success factors of IoT enabled circular DSCs are proposed in this study. After validation of these factors, the first step of the methodology is to carry out Step Wise Weight Assessment Ratio Analysis (SWARA); depending on the determined factor weights and their ranks, each success factor is matched with each DSC stage. The second step of the implementation sees the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) used to provide success factors in supply chain stages with IoT enabled digital technologies.

As a motivation of the study, integrating IoT enabled technology becomes extremely important in processes such as DSCs which include perishable products (Biuki et al., 2020); these chains are becoming more complex with the globalization of trade and the current business environment (Mangla et al., 2021; Haji et al., 2020). The DSC has a complex structure like other globalized supply chains (Talukder et al., 2021). As a result, it faces many problems in terms of transparency, traceability and operational aspects. (Liu et al., 2021; Leung et al., 2021).

As a research gap, although the use of technology is extremely important in circular DSC, studies on the subject are limited. In particular, there is no study that offers separate technology alternatives for each stage of the supply chain. Therefore, as a unique factor of this study, there is a need to determine critical success factors of IoT enabled circular DSC stages. We aim to propose IoT enabling technologies for these success factors at every stage of DSCs.

In summary, the complex structure of circular DSCs requires the use of IoT enabled technologies. It is necessary to determine the success factors of IoT usage initially and then to identify the technologies for each stage of the supply chain. Therefore, the first contribution of the paper is to determine success factors of IoT enabled circular DSCs and match each success factor with every DSC stage. The second major contribution of this study is to propose IoT enabled technologies for every stage to achieve every success factor.

The paper is organized as follows. Section 2 discusses a literature review related to the success factors of IoT enabled circular DSCs; IoT enabled technologies for DSCs are examined. Section 3 presents research methodologies while section 4 includes applications of the study. Discussions and implications are proposed in section 5. Finally, conclusions of the study are given in section 6.

**2. Literature Review**

The literature review includes two sections; success factors of IoT enabled circular DSCs and a proposal of potential technologies. Firstly, success factors of IoT enabled circular DSCs are explored in detail.

* 1. **Determining Success Factors of IoT Enabled Circular DSCs**

IoT enabled technologies, such as embedding systems, big data and RFID, provide firms with the means to deal with supply chain disruptions (Zhang et al., 2019; Anser et al., 2021; Ali et al., 2021), food quality and sustainability issues in DSCs (Verdouw et al., 2016). Real-time data about conditions is essential to ensure food safety and security in the DSC. All stages of the DSC need IoT enabled digital technologies to increase food safety and enhance efficiency.

DSCs include various stages from food production to consumption. IoT enabled technologies provide a variety of advantages to handle different issues at every stage of a DSC. With the help of RFID and QR code technologies, tracking and recording product features is possible. A data analytics tools is also helpful to extract and manage useful information in the DSC (Li et al., 2017). After dairy production stages, products are transported to the processing stage. IoT-enabled tracking and tracing systems are significant in dealing with the short shelf lives of dairy products and quality issues at the transportation stage. The transportation stage is followed by the production process stage. Food safety increases with the use of IoT enabled technologies in the packaging stage; this increases confidence in consumers and has a positive effect on public health. After the packaging of dairy products, goods move through the distribution stage to reach end-users (Jouzdani and Govindan, 2021). Figure 1 indicates the DSC stages.



**Figure 1.** Stages of DSC

For all stages, it is vital for the determination of critical IoT enabled digital technologies to achieve strategic advantages in the dynamic business environment. Thus, based on the literature review, six success factors of IoT enabled circular DSCs are determined by experts from academia and industry by considering the entire supply chain. These factors were validated by experts working in different departments of well-known dairy companies and academicians who are experts in their fields. Six different success factors of IoT enabled circular DSCs are proposed based on semi-structured interviews conducted with the experts. The success factors identified are Technological Infrastructure, Performance Improvement, Strategic Alignment, Reliable and Accurate Data, Innovation and Competitiveness plus Knowledge Accessibility. These are shown in Table 1.

|  |  |
| --- | --- |
| ***Success Factors*** | ***Author(s)*** |
| Technological Infrastructure | Agus and Ahmad (2017); Astill et al., 2019; Mangla et al., 2018 |
| Performance Improvement | Zhang et al., 2012; Zhou et al., 2016; Ben-Daya et al., 2019 |
| Strategic Alignment | Yadav et al., 2020; Schroeder et al., 2020 |
| Reliable and Accurate Data | Zhang et al., 2017; Cannas et al., 2020; Gholizadeh et al., 2020 |
| Innovation and Competitiveness | Affia et al., 2019; Li and Li, 2017; Kweh et al., 2021 |
| Knowledge Accessibility | Zhao et al., 2018; Mangla et al, 2018; Raut et al. 2019 |

**Table 1.** Success Factor of IoT Enabled Circular DSC

*Technological Infrastructure (SF1):* Technological infrastructure is a key driver of the success factors (Astill et al., 2019). Such technologies require significant infrastructure to provide secure connections among stakeholders and to increase virtualization within tracking systems (Agus and Ahmad 2017). With this infrastructure, related data can be made accessible to all stakeholders who need access to any information. Transition to CE needs significant technological developments in the DSC; this can be achieved by implementing successful information management systems with technology infrastructure (Mangla et al., 2018).

*Performance Improvement (SF2):* One of the most important IoT enabled success factors is performance improvement. These technologies are useful to enable effective decision making and to enhance supply chain performance by improving communication, tracking and transmission of data (Ben-Daya et al., 2019). Since IoT enabled technologies deal with reducing waste and enhancing food safety (Zhou et al., 2016), they improve food supply chain performance and sustainability (Zhang et al., 2012).

*Strategic Alignment (SF3):* Strategic alignment is a critical success factor in adapting IoT enabling technology for DSCs; this is crucial to sustain competitive advantages (Schroeder et al., 2020). Collaboration enhances transparency and quality while also providing integrity from different perspectives to manage the complexity of a DSC. By improving coordination among stakeholders, IoT enabled technologies allow effective strategic decisions to be made in the supply chain (Yadav et al., 2020). With increasing stakeholder involvement due to the closing loop, management becomes more effective; strategic alignment thus becomes a critical success factor in the context of CE (Bressanelli et al., 2021).

*Reliable and Accurate Data (SF4):* Obtaining reliable and accurate information from different supply chain actors for DSC stages, such as processing, storage and distribution, increases trust and safety in the DSC (Zhang et al., 2017). With the transition to CE, the amount of data has increased because of the addition of reverse activities and thus tracking becomes more complex (Mahtab et al., 2021). In this environment, reliable and accurate data can be obtained by IoT enabled technologies such as RFID and artificial intelligence (Shahsavar et al., 2021). For instance, sensor technologies provide intelligent monitoring systems by gathering temperature and humidity data during farming and the transportation stage of fresh products (Cannas et al., 2020).

*Innovation and Competitiveness (SF5):* The food supply chain has to adapt to rapidly changing technology to maintain both quality and the company's position in order to gain competitive advantages (Li and Li, 2017). IoT enabled technologies improve supply chain performance by enhancing productivity and competitiveness in an aggressive business environment (Affia et al., 2019; Rasheed et al., 2021). IoT enabled technologies provide improvement in processes by influencing the levels of innovation and competition. This leads to competitive benefits such as recognition and reliability. Thus, innovation and competitiveness are key success factors for adopting IoT enabled technologies.

*Knowledge Accessibility (SF6):* It is critical for IoT enabled technologies based on data integration systems to be able to present all knowledge to stakeholders and enhance collaboration among them. Information that can be accessed simultaneously by every stakeholder also enhances security and trust issues in the DSC (Raut et al., 2019). The CE concept has caused greater security and trust problems in DSCs because of the increase in the number of stakeholders (Mangla et al., 2018). These technologies enable the exchange of business information and transactions with reliable knowledge; access is made available as required (Zhao et al., 2018).

This study aims to determine success factors of IoT enabled technologies in circular DSCs. We propose to use IoT enabled technologies to identify every success factor for each stage of the DSC. Specific IoT enabled technologies are discussed in the next section.

* 1. **Proposing IoT Enabled Technologies for DSC**

IoT enabled technologies such as big data, artificial intelligence, addictive manufacturing, embedded systems, machine learning and radio frequency identification (RFID) provide advantages by presenting real-time data into dairy operations to increase efficiency (Aryal et al., 2018; Yadav et al., 2020; Kazancoglu et al., 2021). These technologies are vital for companies to gain strategic advantage due to the increasing multi-stakeholder and complex nature of business (Jayasena et al., 2021). In order to identify each success factor presented in Table 1, IoT enabled technologies are discussed below.

One of the most important IoT enabled technologies is artificial intelligence. This technology can also be used to obtain and integrate data by tracing customer requirements and orders. Artificial intelligence technology is suggested as an appropriate method to obtain accurate demand forecasting in order to deal with the perishable features of dairy products (Toorajipour et al., 2021).

Big data analytics (BDA) is an efficient tool to cope with decreasing raw material dependency; it can enhance efficiency by creating flexible processes (Koot et al., 2021). Shamim et al., 2020, proposed that BDA is a suitable IoT enabled technology for sharing required data among DSC stakeholders; it can provide real-time data about processes to deal with quality problems due to the perishability of products (Gholizadeh et al., 2020). BDA is useful to learn how supply chain processes should be designed, how they can best be operated and how supply chain networks can be analyzed (Sahebjamnia et al., 2018; Gupta et al, 2019).

Another useful IoT technology is addictive manufacturing; this can be used at different stages of DSC, such as design and packaging, in order to enhance food quality issues (Wang et al, 2019). Besides, intelligent packaging systems that need to integrate IoT enabled digital technologies are important in decreasing food loss by preventing spoilage of dairy products. This technology can track permanently through the entire product life cycle and provide relevant customer data (Müller and Schmid, 2019; Wang and Zhang, 2021).

Embedded systems are proposed to detect IoT-enabled success factors. Embedded systems consist of integration of physical devices to enhance information systems; security and connectivity of operations can be improved to create more transparent DSCs (Addo-Tenkorang and Helo, 2016). Reuse, recycle, repair or recover can create a sustainable supply chain when monitored throughout the product lifecycle with sensor embedded systems (Manavalan and Jayakrishna, 2019; Fathollahi-Fard et al., 2021).

Machine learning, an established IoT enabled technology, enables the system to learn the process and make decisions with new information (Seyedan and Mafakheri, 2020). An effective decision-making process is ensured by integrating the stakeholders into the process. The concept of sustainability and CE, which requires a significant infrastructure, can be established quickly and safely with machine learning (Ren et al., 2021). Through these technologies, companies can contribute to environmental and social concerns by decreasing greenhouse gas emissions (Liu et al., 2020).

Dairy products require to be monitored at every stage of the supply chain to reach end users in a wholesome condition. Due to the perishable features of dairy products, real-time and reliable data needs to be acquired (Cannas et al., 2020). Unique features of dairy products, such as temperature and humidity when cooling milk, must be taken into account; systems must be embedded to the internet to obtain accurate data and required information for the entire DSC (Balaman, 2019). RFID is a key IoT enabled technology that uses different nodes of supply chains such as production and processing. (Atzori et al., 2010; Zhang et al., 2017; Zhou et al., 2021). Thus, RFID is an important technology for ensuring product quality and safety by identifying dates and times to distinguish different batches (Verdouw et al., 2016). This technology helps to identify physical conditions such as temperature, humidity and food quality parameters. Pal and Kant, 2018, investigated the opportunities provided by sensor-based RFID technologies to monitor the whole process in a DSC for improving food safety. Bibi et al., 2017, have conducted a systematic literature view of RFID sensors for monitoring a process to decrease levels of waste in products in the DSC. This technology can be of significant use in the DSC; because of the perishable features of many items, tracking is important to manage potential inventory problems (Haji et al., 2020). In summary, IoT enabled technologies can identify key success factors in the DSC. This study discusses success factors of IoT enabled technologies and proposes specific technologies to ascertain a success factor for each stage. Therefore, in order to meet these objectives, the research methodology is discussed in the next section.

1. **Research Methodology**

Before explaining in detail the research methodology, a flowchart is provided in Figure 2 to illustrate the rationale. By considering a detailed literature review, the success factors of IoT enabled circular DSCs are determined and corresponding IoT enabled digital technologies are derived. These factors and technologies are validated with five experts - an academician, governmental experts and industry experts. Experts involved in the validation process are people who have vast experience in the field. Therefore, the evaluation of the factors by this expert group ensures that an accurate result can be achieved. These individuals were asked to evaluate the list of factors and, based on a unanimous vote, additions and deletions were made to the list. After a validation process, these factors were matched with each IoT enabled digital technology for each stage of DSC. In this study, the integration of SWARA and TOPSIS methods are used in the implementation. While the determination of the factor weights is specified according to the expert opinions, the agreed weighting is also integrated into the application of the TOPSIS method. In this way, a stage-based IoT enabled digital technology selection can be made with accurate results.

In the implementation of the study, firstly, the SWARA method is used to find the weights of the success factors for each stage of the DSC. Secondly, the TOPSIS method is implemented to rank the IoT enabled digital technologies for each stage of DSC.

**Determination of Success Factors of IoT enabled Circular Dairy Supply Chains and IoT enabled Digital Technologies**

**Literature Review**

**Identification Framework for Success Factors of IoT enabled Circular Dairy Supply Chains and IoT enabled Digital Technologies**

**Expert Validation**

**Interpretation of Findings**

**Data Collection for Identification of Weights for Each Success Factor of IoT enabled Circular Dairy Supply Chains for Each Stage of Dairy Supply Chain**

**Determination of Ranking for IoT Enabled Technologies for Each Success Factor of IoT enabled Circular Dairy Supply Chains and Each Stage of Dairy Supply Chains**

**Discussion and Implications**

**NO**

**YES**

**SWARA**

**TOPSIS**

**Figure 2.** Flowchart of the Study

In the following section, the methods used are explained in detail.

* 1. **SWARA**

 SWARA, one of the criterion weighting methods, has recently been used in various fields. "Step Wise Weight Assessment Ratio Analysis" is an appropriate method for this research (Saraji et al., 2021). The SWARA method was first introduced by Keršuliene, Zavadskas and Turskis, 2010. When literature about the SWARA method is examined, this shows how it has been used to solve many problems (Alvand et al., 2021). The SWARA stages are as follows:

*Stage 1:* The criteria are listed from the most important to the least important.

*Stage 2:* The relative importance levels are determined for each criterion by starting with the second criterion. For this, criterion $j$ is compared with the previous criterion $(j-1)$. It is represented as $s\_{j}$.

*Stage 3:* The coefficient $(k\_{j})$ is determined by Eq. 1 given below.

$k\_{j}= \left\{\begin{matrix}1&j=1\\s\_{j}+1&j>1\end{matrix}\right\}$ (1)

*Stage 4:* The importance vector $(w\_{j})$ is calculated from Eq. 2.

 $w\_{j}= \left\{\begin{matrix}1&j=1\\\frac{x\_{j-1}}{k\_{j}}&j>1\end{matrix}\right\}$ (2)

*Stage 5:* The weighting of the criteria is calculated by using Eq. 3.

$q\_{j}=\frac{w\_{j}}{\sum\_{k=1}^{n}w\_{k}}$ (3)

* 1. **TOPSIS**

TOPSIS was developed by Hwang and Yoon in 1980 and has many applications. It is a recognized MCDM method (Mansory et al., 2021). Evaluation of alternatives is based on two basic points, the ideal solution and the negative ideal solution (Alao et al., 2021). TOPSIS measures the shortest distance from the positive ideal solution and the farthest from the negative ideal solution (Feng et al., 2019; Anamisa et al., 2021). It aims to determine the decision option in the distance (Arya et al., 2021).

The implementation steps of the TOPSIS method are given below.

**Step 1:** The decision matrix is ​​created. The decision matrix is ​​an $nxm $matrix created by the decision maker after the decision options and evaluation criteria are determined. Here, $n$ and $m$ are the number of decision options and evaluation criteria, respectively (Chen, 2021).

**Step 2:** The normalized matrix is created (Lin et al., 2021).

**Step 3:** A weighted standard decision matrix is ​​created (Dutta et al., 2021).

**Step 4:** Positive ideal and negative ideal solution values ​​are obtained (Lin et al., 2021).

**Step 5:** The distance values ​​to the positive ideal and negative ideal solution values ​​are obtained (Chen, 2021).

**Step 6:** The relative closeness coefficients to the ideal solution are calculated (Chen, 2021).

1. **Implementation of the Study**

In this study, DSC stages are considered. A total of six stages of DSCs are identified - dairy production, dairy transportation, dairy processing, packaging, distribution and consumer. In this study, the opinions of five experts are taken into account for implementation. The information provided by the experts is as shown in Table 2.

**Table 2.** The Characteristics of Experts

|  |  |  |
| --- | --- | --- |
| **Experts** | **Profession** | **Work Experience (year)** |
| 1 | Supply Chain Management | 6 |
| 2 | DSC Operations | 8 |
| 3 | Digitalization in Supply Chain Management  | 17 |
| 4 | DSC  | 11 |
| 5 | DSC | 9 |

The factors obtained from the literature review and the experts are summarized in Table 3.

**Table 3.** Summary Table of Success Factors

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Success Factors of IoT enabled Circular DSCs | SF1 | SF2 | SF3 | SF4 | SF5 | SF6 |
| Technological Infrastructure | Performance Improvement | Strategic Alignment | Reliable and Accurate Data | Innovation and Competitiveness | Knowledge Accessibility |

Five experts on DSCs are asked to rank the criteria with the most important first and to determine their level of importance. Table 4 is given as an example - produced by expert 1 - and deals with the dairy production stage of the DSC.

**Table 4.** An Example Table of Expert 1 for Dairy Production Stage of DSC

|  |
| --- |
| **Expert 1 (Dairy Production Stage)** |
| **Factors** | **Importance Order** | **Importance Level** |
| SF2 | 1 | - |
| SF4 | 2 | 0,15 |
| SF1 | 3 | 0,05 |
| SF3 | 4 | 0,1 |
| SF5 | 5 | 0,3 |
| SF6 | 6 | 0,15 |

Similarly, five expert opinions are taken at each stage and the same process is repeated for the six stages of the DSC. The factor weights are determined, based on the opinions of the experts for each stage of the DSC. These are shown in Table 5.

**Table 5.** Results of Expert Opinions

|  |  |  |  |
| --- | --- | --- | --- |
| **Stages/Factors** | **Dairy Production** | **Dairy Transportation** | **Dairy Processing** |
| **Weights** | **Rank** | **Weights** | **Rank** | **Weights** | **Rank** |
| SF1 | 0,18 | 3 | 0,17 | 3 | 0,18 | 3 |
| SF2 | 0,14 | 6 | 0,15 | 5 | 0,21 | 1 |
| SF3 | 0,19 | 1 | 0,17 | 2 | 0,20 | 2 |
| SF4 | 0,19 | 2 | 0,21 | 1 | 0,14 | 4 |
| SF5 | 0,15 | 4 | 0,16 | 4 | 0,14 | 5 |
| SF6 | 0,14 | 5 | 0,13 | 6 | 0,13 | 6 |
| **Stages/Factors** | **Packaging** | **Distribution** | **Consumer** |
| **Weights** | **Rank** | **Weights** | **Rank** | **Weights** | **Rank** |
| SF1 | 0,24 | 1 | 0,18 | 2 | 0,18 | 2 |
| SF2 | 0,19 | 2 | 0,17 | 3 | 0,17 | 3 |
| SF3 | 0,18 | 3 | 0,13 | 6 | 0,15 | 5 |
| SF4 | 0,15 | 4 | 0,17 | 5 | 0,17 | 4 |
| SF5 | 0,14 | 5 | 0,17 | 4 | 0,19 | 1 |
| SF6 | 0,10 | 6 | 0,19 | 1 | 0,14 | 6 |

According to Table 6, the most important factor for dairy production stage was determined as strategic alignment (SF3). While the most important factor for the dairy transportation stage was reliable and accurate data (SF4), the most important factor for the dairy processing stage was performance improvement (SF2). The most important factor for the packaging stage was seen to be technological infrastructure (SF1). While the most important factor for the distribution stage was determined as knowledge accessibility (SF6), the most important factor for consumer was determined as innovation and competitiveness (SF5). According to the determined factor weights, the most important factor ranking was obtained for each stage. According to the results obtained, TOPSIS is applied in the next step to find solutions to the supply chain stages with IoT enabled digital technologies. IoT enabled digital technologies are given in Table 6.

**Table 6.** IoT Enabled Digital Technologies

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| IoT Enabled Digital Technologies | DT1 | DT2 | DT3 | DT4 | DT5 | DT6  |
| Artificial Intelligence | Big Data | Addictive Manufacturing | Embedded Systems | Machine Learning | RFID |

In order to determine the IoT enabled digital technologies that should be used at each stage of the DSC, the five experts are asked to evaluate the six stages of DSC. This evaluation aims to determine which digital technology is required for each stage of the supply chain, considering the criterion weights obtained from the SWARA method.

By following the steps of TOPSIS, with contributions from the expert evaluations, the final weighted values are determined as shown in Table 7.

**Table 7.** The final weighted values of IoT enabled digital technologies for each stage of DSCs

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Stages/ IoT enabled Digital Technologies** | **Dairy Production** | **Dairy Transportation** | **Dairy Processing** | **Packaging** | **Distribution** | **Consumer** |
| DT1 | 0,3386 | 0,3942 | 0,3696 | 0,5540 | 0,4599 | 0,4025 |
| DT2 | 0,5331 | 0,5447 | 0,5853 | 0,5158 | 0,6569 | 0,4699 |
| DT3 | 0,4951 | 0,5758 | 0,5330 | 0,3784 | 0,5314 | 0,5818 |
| DT4 | 0,5398 | 0,5873 | 0,5804 | 0,4811 | 0,4368 | 0,5901 |
| DT5 | 0,4697 | 0,3633 | 0,3368 | 0,5210 | 0,3076 | 0,6227 |
| DT6 | 0,6407 | 0,5351 | 0,5715 | 0,5312 | 0,6628 | 0,5403 |

Table 8 shows the ranking of IoT enabled digital technologies for each stage of DSCs.

**Table 8.** The Ranking of IoT enabled digital technologies for each stage of DSCs

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Ranking | Dairy Production | Dairy Transportation | Dairy Processing | Packaging | Distribution | Consumer |
| 1 | DT6 | DT4 | DT2 | DT1 | DT6 | DT5 |
| 2 | DT4 | DT3 | DT4 | DT6 | DT2 | DT4 |
| 3 | DT2 | DT2 | DT6 | DT5 | DT3 | DT3 |
| 4 | DT3 | DT6 | DT3 | DT2 | DT1 | DT6 |
| 5 | DT5 | DT1 | DT1 | DT4 | DT4 | DT2 |
| 6 | DT1 | DT5 | DT5 | DT3 | DT5 | DT1 |

By considering SWARA and TOPSIS results, the summary figure is given in Figure 3. The figure shows success factors of IoT enabled circular DSCs and IoT enabled digital technologies for each stage of DSC.

Technological Infrastructure (SF1)

Performance Improvement (SF2)

Strategic Alignment (SF3)

Reliable and Accurate Data (SF4)

Innovation and Competitiveness (SF5)

Knowledge Accessibility (SF6)

**Figure 3.** Summary of the results

In summary, according to Figure 3, strategic alignment (SF3) is the most important success factor of IoT enabled circular DSCs for the dairy production stage of DSCs. Moreover, reliable and accurate data (SF4) for the dairy transportation stage, performance improvement (SF2) for the dairy processing stage and technological infrastructure (SF1) for the packaging stage of DSCs are essential factors. For the distribution stage, knowledge accessibility (SF6) is the most important factor; innovation and competitiveness (SF5) is the most important factor for the consumer stage of DSCs.

For the dairy production stage of DSCs, DT6 is an essential IoT enabled technology; for the dairy transportation stage, DT4 is essential. Moreover, while DT2 is the most suitable IoT enabled digital technology for the dairy processing stage of DSCs, for the packaging stage, DT1 is the IoT enabled digital technology most needed. DT6 and DT5 are the most crucial IoT enabled digital technologies for the distribution and consumer stages of DSCs, respectively.

1. **Discussion**

This study proposes success factors of IoT enabled digital technologies based on DSC stages. Also, specific IoT-enabled technologies are suggested considering each stage of the supply chain. Results show that each stage has a unique success factor by nature and to recognize this success factor, IoT enabled technologies can be used in the DSC.

One of our key success factors in this study is performance improvement. Similarly, Zhang et al., (2017) suggested that acquiring real-time data by providing traceability plays a vital role in improving performance. Thus, IoT-enabled technologies ensure information sharing in the entire supply chain and they provide optimization of performance improvement. Astill et al., 2019, stated that IoT enabled technologies required significant technological infrastructure to provide connections for the improvement of tracking systems. Another important key success factor suggested in this paper is reliable and accurate data. Farooq et al. (2019) stated that IoT enabled technologies aim to control processes to ensure reliable and accurate delivery of all products. To this end, accurate and reliable information is obtained and shared in the processes monitored. In line with this work, Jagtap et al. (2021) proposed that IoT applications in the food supply chain causes increased tracking systems by using real-time data; thus, accurate and reliable data is a vital success factor to stimulate IoT enabled technologies in the DSC. Similar to our results, innovation and competitiveness were suggested by Kweh et al (2021) as an important IoT enabled success factor. They stated that IoT enabled technologies can promote innovations and operational efficiency to gain competitive advantages. Another important key success factor proposed in the study is knowledge accessibility. Raut et al., 2019, stated that knowledge needs to be available for every stakeholder by improving collaboration to overcome security and trust issues in the DSC. In agreement with our studies, Schroeder et al., 2020, recommended strategic alignment as a critical success factor to motive IoT enabled technology in the DSC to gain competitive advantages.

There are various studies that have discussed the advantages of IoT enabled technologies in DSCs (Bibi et al., 2017; Pal and Kant, 2018; Gholizadeh et al., 2020). However, this study provides a unique contribution by considering success factors of IoT enabled technologies and proposing specific IoT enabled technologies to achieve these factors based on supply chain stages.

1. **Implications**

The results of this study highlight a range of managerial and governmental implications. Reducing food losses, increasing efficiency in processes and ensuring cooperation among supply chain stakeholders are critical problems in managing the food supply chain. Therefore, governmental policies should be developed to ensure reliable and accurate information and increase transparency in the food supply chain process.

Transition to CE causes both an increase in data and greater complexity in relationships of the stakeholders. These issues can only be overcome by integrating IoT enabled technologies which ensure continual monitoring of the supply chain processes. By investing in these technologies, companies can obtain reliable data and information with permanent tracking. Companies need to make technology investments and develop resource planning in order to obtain regular data and monitor processes effectively. Ensuring increased traceability by IoT enabled technologies such as RFID requires new technological infrastructure. Government incentives should therefore be introduced.

IoT enabled technologies can be used to cope with the increasing complexity and increasing activities of a CE in the food supply chain. IoT enabled technologies investment contributes to the improvement of data management, resulting in increased agricultural productivity. As more stringent regulations and policies for DSCs are introduced, technology can help to deal with environmental issues such as increased gas emissions and waste.

When traceability can be guaranteed in all processes, stakeholders can then make more effective strategic decisions. IoT enabled technologies such as BDA enable companies to estimate accurate demand management, providing them with a sustainable competitive advantage. In this way, it is expected that companies can reach a level of operational excellence in processes and minimize losses with the help of technological investments.

Innovation has an important role in reducing food waste in the food supply chain. Data collected through RFID and QR code can be collected and stored in a reliable way. Companies should organize their operations and investments to improve their data collection process. This has implications for management. Food waste can be minimized by tracking the process with IoT enabled technologies through all supply chain stages, from design to the end user.

**Conclusion**

IoT enabled technologies provide supply chain visibility by collecting, analysing and converting useful information related to the chain (Affia et al., 2019; Balamurugan et al., 2021). These technologies are important in food supply chains to increase the acquisition of data and to accelerate decision making processes. By acquiring real-time data, actions can be taken rapidly to decrease food waste and improve supply chain performance (Manavalan and Jayakrishna, 2019). Food quality issues are a significant problem in dairy supply and need to be managed effectively (Ben-Daya, 2021). Thus, IoT enabled technologies provide several advantages; they create improved tracking and tracing systems to provide more reliable and accurate data for every stage of DSC dairy production - transportation, processing, packaging, distribution and consumption (Mastos et al., 2021).

This paper proposes six success factors of IoT enabled circular DSCs based on a literature review and expert input. The methodology is a mixed approach, using SWARA and TOPSIS, and is aimed at matching each DSC stage with a success factor; a ranking of these factors is determined. With TOPSIS, IoT-enabled digital technologies are presented for every stage and each success factor. Therefore, the main contribution of this study is to identify success factors of IoT enabled circular DSCs and to determine a critical success factor for every DSC stage. Another contribution of this study is to propose IoT enabled technologies for every stage to achieve every success factor.

The results show that strategic alignment is the most important success factor in IoT enabled circular DSCs for the dairy production phase. In addition, obtaining reliable and accurate data for the dairy transportation phase of milk supply chains, performance improvement for the dairy processing stage and technological infrastructure factors for the packaging stages are also important success factors. While knowledge accessibility is an important factor for the distribution stage, innovation and competitiveness are identified as the most important factors for the consumer stage of DSCs.

Stage-based IoT-enabled technologies are identified to realize the success factors. RFID technologies are required for the dairy production phase of milk supply chains and an embedded system is required for the dairy transportation stage of DSCs. Big data is considered to be a useful IoT enabled technology for dairy processing. For the packaging stage of DSCs, the best IoT enabled digital technology is addictive manufacturing; machine learning is suitable for the distribution stage. Finally, in order to achieve a success factor for the consumer stages of DSCs, artificial intelligence is an appropriate tool. Thus, this paper presents a unique contribution by proposing success factors for every stage and then by matching IoT enabled technologies with each stage of the DSC.

A limitation of the study is recognized since the study is conducted specifically for the DSC. Therefore, the results and factors obtained may differ for different supply chains and sectors. Furthermore, there is a disparity in DSC research in current literature as it is a difficult and resource-constrained field for study. Depending on the resources examined, it is expected that results will vary in country-based studies. Further research will be valuable since this study covers only DSC. In future studies, the sector can be differentiated or expanded as a food supply chain. In addition, the study can be customized for both developed and developing countries. Based on this study from an academic point of view, different studies can be planned in this field to help close the gap in present literature. As different studies are carried out on the subject in academic terms, it is expected that the perspectives on the subject will increase.

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