

Using blockchain technology to drive operational excellence in perishable food supply chains during outbreaks

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**USING BLOCKCHAIN TECHNOLOGY TO DRIVE OPERATIONAL
EXCELLENCE IN PERISHABLE FOOD SUPPLY CHAINS
DURING OUTBREAKS**

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USING BLOCKCHAIN TECHNOLOGY TO DRIVE OPERATIONAL EXCELLENCE IN PERISHABLE FOOD SUPPLY CHAINS DURING OUTBREAKS

Abstract

Design/methodology/approach: A systematic literature review is performed to determine the dimensions of operational excellence in the food supply chain (FSC), then a single use-case analysis is conducted to explore the potential of blockchain in order to achieve operational excellence for perishable food supply chain (PFSC) during the pandemics by applying context, interventions, mechanism and outcomes (CIMO-logic).

Purpose: This paper aims to explore the potential of blockchain technology (BT) to support the operational excellence in PFSC during outbreaks by doing use-case analysis.

Findings: The findings of this study reveal that blockchain capabilities such as immutability & transparency, visibility, traceability, integration & interoperability, disintermediation & decentralisation, smart contracts, and consensus mechanism provide better sustainable operational excellence outcomes for PFSCs to be more responsive, flexible, efficient, and collaborative to cope with the impacts of COVID-19.

Research limitations/implications: This research employs only one real case with multiple PFSC participants. Statistical generalization is not possible at this stage of the research. However, the findings are not restricted to this single use-case.

Practical implications: This study provides a research direction to explore the potential of BT to achieve operational excellence in the PFSC during outbreaks and generates prescriptive knowledge for better managerial decision-making across the PFSC during outbreaks.

Originality: This research conducts semi-structured interviews with different participants in one blockchain ecosystem to understand multiple participants' perspectives of operational excellence within PFSC.

Keywords: Operational excellence, perishable food supply chain, blockchain technology, COVID-19, outbreaks, DSR, CIMO-logic

1. Introduction

The emergence of the COVID-19 outbreak has drastically disrupted all industries and business sectors around the world. The first wave uniquely impacted food-related industries in particular, including the perishable food supply chain (PFSC) from farm to fork with lockdown restrictions and containment measures causing significant changes in the business discipline of many companies in the food industry (Hamilton *et al.* 2020). From producers to customers, keeping the food product safe and free from contamination, fresh for the duration of its shelf life and at good quality remains a big challenge amid pandemics (Sehnem *et al.* 2019; Chin 2020).

Heck *et al.* (2020) describes the impact of the COVID-19 on FSCs as a crisis of interrupted connections between supply and demand, where consumers have no physical access to food and producers are deprived of marketing outlets due to lockdowns restrictions. The upstream supply chain (SC) was giving away or dumping their produce due to the perishable nature of the produce, while consumers were facing difficulties in accessing food to meet their daily dietary requirements (Chin 2020). Furthermore, COVID-19 also caused high absenteeism in workplaces, as the absence of skilled workers has resulted in labour shortages (Gray 2020). In several countries, many containers had to wait in quarantine at ports or terminals. This caused the cessation of logistic activities, extended cycle times, and increased product expiry risks. The deterioration rate and demand uncertainty of perishable food products such as fruits and vegetables, dairy, fish, meat, and frozen items trigger a lot of unsold products to be disposed of and product shortages at retailers (Yang *et al.* 2017a). SC mismatch increases the environmental pollution due to onward disposal of expired products (Griffin *et al.* 2009)

As food companies strive for operational excellence in the pandemic, they must be prepared to respond quickly and easily to changing business conditions and to changing prospective customers' behaviour (Bumblauskas *et al.* 2020). COVID-19 caused a sudden change in consumption patterns such as consumer panic buying and hoarding behaviour concerning key items (Sterman & Dogan 2015; Hobbs 2020; Naeem 2020a, Naeem 2020b). The customers seek alternative supply sources during outbreaks because of product shortages (Gonçalves *et al.* 2005). Home delivery has become more important since most customers prefer online shopping due to the perceived risk of infection with the virus (Seth 2020). Many consumers have switched to buying frozen foods as an alternative to closed restaurants, which increased the pressure on PFSC (Thundertech.com 2020).

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3 The grocery store response to new consumer preferences has not been enough to prevent
4 waiting times of several days to access very popular grocery pickup and delivery options (Gray
5 2020). Access to reliable and timely information about upcoming risks and their impact on
6 customer behaviour is very important for PFSC management (Göbel *et al.* 2015). Amidst
7 COVID-19 consumers are concerned about food hygiene (Abiral & Atalan-Helicke 2020) and
8 consider doing more to understand how and where the products originate (Bumblauskas *et al.*
9 2020). However, they often can lack transparency about their second- and third-tier suppliers
10 and beyond (Abeyratne & Monfared 2016).

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18 In recent years, an extensive body of research, which studies the ripple effect due to natural or
19 man-made disasters, evaluates the resilience of the food supply chains and supply chains in
20 general, and presents decision aids on this subject, has emerged (e.g., Ivanov *et al.* 2015; Dolgui
21 *et al.* 2018). However, the COVID-19 pandemic was unprecedented, and the disruption impact
22 on the PFSC was huge. Moreover, the COVID-19 pandemic has a diverse range of impact on
23 PFS such as operational factors among others production shutdown, price variation of
24 perishable products, cash flow constraints, poor delivery reliability, increased transportation
25 costs, behavioural factors among others panic buying and stockpiling, fear of violation of social
26 distancing guidelines, less physical buying and government policy, regulations such as closure
27 or limited operation of mandis, restriction on import-export and lockdowns, technological and
28 infrastructural factors such as poor transportation network, low area coverage of E-commerce
29 platforms for perishable goods, information distortion and poor packaging capabilities, which
30 are all interrelated (Shanker *et al.*, 2021). Thus, the topic of how to cope and recover from the
31 effects of the pandemic and to adapt to the “new normal” became most important for the PFSC.
32 Supply chain coordination, supply chain responsiveness, information and resource sharing and
33 digitisation of the process are key to a resilient FSC amid the COVID-19 pandemic (Kumar &
34 Singh, 2021). Mishra *et al.* (2021) emphasized proactive and reactive practices to cope with
35 disruptions, which require implementing knowledge management tools. Implementation of
36 emerging technologies such as Internet of Things (IoT), Artificial Intelligence/Machine
37 Learning (AI/ML), wireless sensor networks, Big Data Analytics (BDA), cloud computing, and
38 blockchain can improve the efficiency, quality, traceability, safety and visibility of PFSC
39 (Kayikci 2018; Kayikci 2020; Liu *et al.* 2020; Köhler & Pizzol 2020; Saurabh & Dey 2021).
40 There is growing interest in applying blockchain technology to SC operations (Lim *et al.* 2021),
41 and Kopyto *et al.* (2020) predict that this technology will be widely applied in future supply
42 chain management (SCM) systems by 2035 since it provides beneficial orientation and
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3 stimulating perspectives for decision-makers throughout the SC.
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6 Blockchain Technology (BT) is one of the emerging technologies in the era of Industry 4.0.,
7 which is defined as “*a digital, decentralized and distributed ledger in which transactions are*
8 *logged and added in chronological order with the goal of creating permanent and tamperproof*
9 *records*” (Treiblmaier 2018, p. 547). BT is an innovative technology that can provide end-to-
10 end visibility and track food products or batches at all stages across the PFSC, moving from
11 harvesting to processing, storage, distribution to retailing (Subramanian *et al.* 2020) and can
12 contribute to improving operational excellence (Upadhyay 2020). BT has the potential to
13 enhance product safety and security; improve quality management; reduce illegal
14 counterfeiting; improve sustainable SCM; advance inventory management and replenishment;
15 reduce the need for intermediaries; impact new product design and development; and reduce
16 the cost of SC transactions (Cole *et al.* 2019). Thus, BT impacts the profit and/or return on
17 investment of SCs and fosters better information management along with the FSC due to
18 improved information accessibility, availability, and sharing (Stranieri *et al.* 2021). However,
19 as Cole *et al.* (2019) pointed out, the state of practice and research surrounding blockchain is
20 immature and there is little evidence in the literature that blockchain has the potential to drive
21 operational excellence in the PFSC during outbreaks (Stranieri *et al.* 2021). Our motivation is
22 to reveal the generative mechanisms underlying operational excellence during an outbreak,
23 propose design solutions, and provide empirical evidence showcasing the potential BT as a
24 solution support tool. Therefore, this study focuses on the below research questions:
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40 RQ1: What are the dimensions for operational excellence in PFSC during outbreaks? and

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42 RQ2: How is the potential of BT to drive operational excellence in the PFSC during outbreaks?
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45 We employ Design System Research (DSR) to understand the problems caused by the COVID-
46 19 outbreak from different SC participants’ perspectives and to evaluate the potential of
47 blockchain solutions to the relevant field problem and therefore generate prescriptive
48 knowledge for better managerial decision-making across the PFSC during outbreaks. We aim
49 to analyse the blockchain potential for operational excellence in PFSC ecosystems during the
50 COVID-19 outbreak and generate prescriptive knowledge for outbreaks in general. We are
51 interested in solving a field problem, which is a specific and important issue and requires a
52 pragmatic validity of designs, generalizing the design, and examining the (social) mechanisms
53 producing system performance. DSR aims to cultivate a deep understanding of the field
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3 problem and to produce improvement-oriented knowledge. DSR is conducted to contextualize
4 and test the problem in context, the design, expected outcomes and the material and social
5 mechanisms producing these outcomes in the intended application domain (van Aken 2007;
6 van Aken *et al.* 2016).
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11 DSR has descriptive/explanatory and design/testing components. In this study the initial
12 descriptive/explanatory framework is derived from a review and analysis of the extant literature
13 on operational excellence and blockchain capabilities. A single use-case based on a context,
14 interventions, mechanism, and outcomes (CIMO-logic) configuration (Denyer *et al.* 2008) is
15 used to evaluate the blockchain capabilities to drive operational excellence across PFSC during
16 outbreaks. Case study data is matched with the initial framework to see how relevant and useful
17 blockchain-driven solutions produce desired outcomes in PFSC ecosystems. The design
18 propositions are obtained by balancing empirical knowledge based on use-case analysis with
19 theoretical knowledge from the literature of operational excellence in PFSC and BT.
20 Subsequently, a sensitivity analysis is performed to validate the design propositions and identify
21 which SC partners contribute significantly to the operational excellence in PFSC during
22 outbreaks. Figure 1 presents an overall view of the research design.
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36 The novelty of this research is that different participants in one blockchain ecosystem are
37 interviewed to understand multiple participant perspectives of operational excellence within
38 PFSC. There is no research conducted to the best of our knowledge, which links operational
39 excellence in PFSC with blockchain capabilities. The significant contribution of this study is to
40 provide a deep understanding of operational challenges, risks, and inefficiencies in PFSC
41 caused by COVID-19 and present a great insight to companies into developing and
42 implementing their blockchain-driven solutions to achieve operational excellence through
43 blockchain capabilities, particularly during outbreaks.
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51 The rest of the paper is organised as follows: Section 2 presents the systematic literature review
52 related to operational excellence in the PFSC during outbreaks and blockchain capabilities on
53 operational performance in the PFSC. Section 3 gives a brief theoretical background CIMO-
54 logic and single case study method and explains the use-case selection, data collection, and
55 analysis procedure in detail. Section 4 analyses the use-case and develops the framework of
56 operational excellence in PFSCs using CIMO-logic. Section 5 derives the design propositions
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3 and performs the sensitivity analysis. Section 6 discusses the theoretical and practical
4 implications of the findings. Section 7 concludes with future research directions.
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7 **2. Literature Review**

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10 The spread of the COVID-19 outbreak has severely impacted the operational capabilities of
11 many companies in the PFSC. In order to capture the relevant articles, the systematic literature
12 review approach suggested by Yadav & Desai (2016) is adopted in this section. The structured
13 keyword search was conducted on the ISI Web of Science (WoS) database. We are confident
14 that we have reached a holistic coverage on operational excellence indicators of PFSC in the
15 context of outbreaks in general and COVID-19 in particular, since WoS database is known to
16 have comprehensive coverage of high impact journals published in Springer, IEEE, Elsevier,
17 Taylor & Francis, etc. The following search strings were searched to be in title, abstract and
18 keywords:
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27 String 1. {"food supply chain" OR "food" OR "agriculture" OR "agri-food" AND "supply
28 chain" AND "outbreak" OR "COVID-19" OR "coronavirus" OR "pandemic" OR
29 "epidemic" OR "disaster" AND "operational excellence" OR "operational performance"}

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33 String 2. {"blockchain" AND "food supply chain" OR "food" AND "supply chain" AND
34 "operational excellence" OR "operational performance"}

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37 The first search string is aimed to extract the operational excellence enablers in PFSCs during
38 an outbreak. The second search string is used to collect the blockchain capabilities which drive
39 operational excellence in PFSCs. We restricted our search to the years of 2015-2021. String 1
40 returned 10853, and string 2 returned 9497 articles. We refined our search by including articles
41 strictly from operational research management science, industrial engineering,
42 multidisciplinary engineering, business, and management fields and restricted the number of
43 articles to 2348 and 1449. After removing duplicates and filtering for peer-reviewed impact
44 factor publications, 1965 and 736 articles remained for evaluation. We further eliminated
45 articles by reviewing the titles of these articles to assess if they fit our research questions and
46 restricted the number of articles to 343 and 97. We then reviewed the abstracts of these articles
47 to assess if they fit our research questions and restricted the number of articles to 122 and 73.
48 At this point, we cross-checked the number of articles that returned in both searches and
49 determined that 27 articles appeared in both samples. Thereby, the final number of articles we
50 have reviewed reached 168. Figure 2 represents the review process adopted for this study.
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We categorized our findings from the literature review in terms of sustainable operational excellence outcomes, operational excellence enablers, and blockchain capabilities, which will be explained in the below subsections.

2.1. Sustainable Operational Excellence for PFSCs

2.1.1. Economic Outcomes

Due to the outbreak, food producers are struggling to meet their normal operating costs, such as paying staff wages, paying the rent of factories and warehouses, covering utility bills, interest charges on bank loans, and other operating expenses due to reduced cash inflow. Thus, PFSC is threatened by layoffs and reduction in trade with SC partners resulting in closure or limited operations of distributors and trading partners (Chowdhury *et al.* 2020; Heck *et al.* 2020). In these dire conditions, the PFSC has to achieve economic operational excellence. We have uncovered three research clusters: production planning and inventory management, quality and customer orientation, profitability and pricing.

Companies within PFSC aim to position their brands to maintain stakeholder confidence in their ability to produce safe and wholesome food and establish brand equity (Manning 2007). It is vital to optimizing the quality and freshness of the food delivered (Musavi & Bozorgi-Amiri 2017; George *et al.* 2019; Bumblauska *et al.* 2020; Behnke & Janssen 2020). In the COVID-19 era, food safety and hygiene have gained importance. Thus, the ability to supply transparency for hygiene factors (Bastian & Zentes 2013) has become key operational excellence. Zhang & Su (2020) studied coordination mechanisms to improve quality visibility throughout PFSC and evaluated the impact of different contracts on quality visibility and associated costs.

The strategic aim of PFSCs is to increase revenue and profitability (Heard *et al.* 2018). Balaji & Arshinder (2016) provide practical insights for improved profitability. A strategic pricing strategy facilitates the maximization of channel profit (Chen *et al.* 2019; Yang *et al.* 2017b). Feng *et al.* (2020) explored alternative pricing strategies under supply disruptions and concluded that pure price adjustments are more advisable since they do not increase customer's order variability and reduce firm profits. Wang & Zhao (2021) showed that all SC participants benefit from collective cold chain investments and pricing strategies. Hanukov *et al.* (2021) determined pricing strategies based on customer preferences in a game-theoretic framework,

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3 where they simultaneously considered revenue from selling food, sojourn and balking costs,
4 capacity costs, and costs associated with food deterioration.
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7 Hendarlianpour (2020) suggested that consumer preferences are influenced by price and
8 freshness of products and developed a game-theoretic model for pricing and lot-sizing
9 decisions. Gholami-Zanjani *et al.* (2020) proposed a model for location-allocation and
10 inventory-replenishment decisions of PFSCs under ripple effects and identified readiness,
11 flexibility, and responsiveness as SC risk mitigation strategies.
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16 17 2.1.2. Social Outcomes 18

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20 The socio-economic impact of COVID-19 is difficult for most vulnerable populations, as their
21 purchasing power and access to markets have been disrupted due to pandemic (Heck *et al.*
22 2020). Price fluctuations caused by supply-demand shocks can lead to malnutrition and food
23 poverty, in the long-term, health impacts on children and the vulnerable (Abiral & Atalan-
24 Helicke 2020; Hamilton *et al.* 2020). Food security, defined as the constant availability of food
25 (Chin 2020; Deaton & Deaton 2020; Heck *et al.* 2020), become an important worldwide
26 concern facing developed and developing countries.
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33 The social aspects of PFSCs can be categorized predominantly into human capital management,
34 corporate social responsibility, collaboration, fair-trade, and ethical practice. Khan *et al.* (2020)
35 focused on employment in the PFSC and identified work-life balance and a safe and healthy
36 working environment as key indicators. According to Toussaint *et al.* (2020), good social
37 practices along the PFSC can be achieved through communication, transparency, and
38 commitment of all SC participants.
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45 Since improving one stakeholder positively affects the entire system, collaboration behaviour
46 improves quality performance and increases the mutual benefits of the SC participants (Dania
47 *et al.* 2020). Moon *et al.* (2020) explored alternative contracts between partners in PFSC by
48 considering the impact of fairness and found that the revenue sharing strategy combined with
49 investment cost-sharing provided the highest benefits for PFSC. Moreover, Daghar *et al.* (2020)
50 pointed out that collaborative interorganizational relationships facilitate SC risk mitigation.
51 Hernandez-Martinez *et al.* (2020) analysed socially responsible practices between suppliers and
52 buyers in smallholder PFSC and identified the settings under which total SC profit increased
53 by reducing the double marginalization effect and resulting in equitable outcomes for all
54 participants. The optimal markdown model was developed for perishable food pricing to
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3 optimize the food retailer revenue, and aspects were evaluated in terms of price fairness
4 perception (Wang *et al.* 2016).
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7 Consumers place great importance on ethical practices in eggs, meat, and dairy products.
8 Consumers preferred a reliable welfare-certified product, although it was costly (Spain *et al.*
9 2018). Eberhardt *et al.* (2020) evaluated whether consumers' subjective knowledge about fair-
10 trade food products and the reliability of perceived information influence purchase intention
11 and reported that perceived fairness positively influences purchase intention.
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16 17 2.1.3. Environmental Outcomes 18

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20 COVID-19 has caused air, soil, water, and environmental pollution due to an increase in
21 medical waste, random disposal of personal protective equipment, increase in municipal waste
22 and decrease in recycling activities (Rume & Islam 2020). The literature of the environmental
23 impact of PFSCs consists mainly of reducing energy consumption and CO₂-emissions,
24 mitigating food loss and waste (FLW), and reducing pollution due to packaging. Different
25 studies have been carried out considering the reduction of CO₂-emissions throughout the SC
26 (Bortolini *et al.* 2015; Bozorgi *et al.* 2014; Camanzi *et al.* 2017; Gallo & Accorsi 2017;
27 Govindan *et al.* 2014; Haass *et al.* 2015; Musavi & Bozorgi-Amiri 2017; Rahimi *et al.* 2017; S.
28 Wang *et al.* 2017). The cold SC has received special attention from researchers due to its high
29 CO₂-emissions generated during temperature-controlled storage and transportation activities
30 (Adekomaya *et al.* 2016). Saif & Elhedhli (2016) modelled the cold SC design problem by
31 considering capacity, transportation, inventory costs, and global warming impact. As'ad *et al.*
32 (2020) determined the optimal lot size by comparing the operational cost and carbon footprint
33 performance under alternative carbon cap policies. Liljestrand *et al.* (2015) proposed a decision
34 support tool with the aim of carbon footprint reduction, which incorporates the logistics
35 network's complexity by analysing the patterns in the shipment statistics. Cannas *et al.* (2020)
36 proposed a roadmap to support the shift to intermodal rail-road transportation in the dairy SC
37 to reduce CO₂-emissions, while Melkonyan *et al.* (2020) explored alternative distribution
38 network configurations to reduce the CO₂-emissions caused by last-mile logistics of food
39 products.
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55 Rohm *et al.* (2017) emphasized the importance of understanding consumer behaviour to
56 encourage food waste reduction. Makhil *et al.* (2020) suggested that the normalisation of
57 suboptimal produce could address the food waste problem. Kandemir *et al.* (2020) proposed a
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3 simulation model to reduce food waste by considering different household dynamics like
4 purchasing, storage, consumption. Borrello *et al.* (2017) evaluated the consumer's willingness
5 to participate in strategies to reduce food waste. Dossa *et al.* (2020) found that verticalized
6 operations and partnerships between buyers and suppliers facilitate circular economy practices.
7 Lombardi & Costantino (2020) emphasized the importance of building a sense of community
8 for better food redistribution. Mallidis *et al.* (2020) proposed a quantitative decision-making
9 tool that optimizes a retailer's replenishment policy to minimize discarded perishables. Ciulli
10 *et al.* (2020) revealed the importance of digital platform organizations bridging waste
11 generators and potential receivers in the FSC. Sundgren (2020) analysed the potential of
12 different SC structures to distribute surplus food.

21 Sumrin *et al.* (2021) pointed out the increasing packaging and related waste all along the supply
22 process and called for eco-design innovation in packaging. Hrabec *et al.* (2020) proposed a
23 model to optimize municipal solid waste management applying modern circular economy
24 principles, intending to increase the amount of food waste recycled and used for energy
25 recovery and decrease the amount of waste sent to landfills.

31 **2.2. Operational Excellence Enablers for PFSCs**

33 2.2.1. Responsiveness

36 In the COVID-19 era, food accessibility and availability (Abiral & Atalan-Helicke 2020; Chin
37 2020; Deaton & Deaton 2020) became primary concerns. Around the globe, consumers face
38 problems in finding basic necessities in the stores, reserving delivery time slots, items missing
39 from online orders, and late refunds (Abiral & Atalan-Helicke 2020). Thus, the responsiveness
40 of the FSC has become even more crucial. Responsiveness is defined as SC's ability to recover
41 from the disruptions and react swiftly to changing conditions through capacity expansion,
42 backup supplier, or product import (Gholami-Zanjani *et al.* 2020). Responsiveness is measured
43 as customer response time, fill rate, shipping errors, product lateness, customer complaints
44 (Stranieri *et al.* 2021). Due to the perishable nature of the produce, the time spent from farm to
45 fork is through reduction of down time/dwell time (Bumblauska *et al.* 2020) and minimization
46 of total customers waiting time (Esmaili & Sahraeian 2017) particularly important. Zanoni &
47 Zavanella (2012) documented that the impact of the storage time is costly for FSCs. Thus, the
48 SC has to become more responsive while remaining cost-efficient. Construction of lean SCs
49 with few tiers, few transactional intermediaries minimize the idle time during transportation,
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3 distribution, storage, and delivery (Bastian & Zentes 2013). Moreover, eliminating
4 intermediaries and auditors enables lower costs and increased efficiency (Bumblauska *et al.*
5 2020).
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8 9 2.2.2. Efficiency 10

11 The literature is rich regarding the improvement of cost efficiency in PFSC. The main body of
12 research is focused on minimization of the total cost (Saif & Elhedhli 2016; Accorsi *et al.* 2017),
13 operating cost (Bortolini *et al.* 2015), logistics costs (Govindan *et al.* 2014), total travel cost
14 (Esmaili & Sahraeian 2017) transportation cost (Musavi & Bozorgi-Amiri 2017; Wang *et al.*
15 2017). A nascent stream is concerned with the triple bottom line (Bozorgi *et al.* 2014) analysed
16 the trade-offs involved in making inventory decisions based on minimizing emissions versus
17 minimizing cost. Rahimi *et al.* (2017) aim to optimize total inventory and transportation costs
18 taking distribution service levels and environmental footprint into consideration.
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26 27 2.2.3. Flexibility 28

29 FSCs have to focus on capacity building and flexibility to prevent supply disruptions (Siddh *et*
30 *al.* 2018). Ramos *et al.* (2021) propose a conceptual model based on the dynamic capability
31 view (DCV) theory to analyse supply chain capabilities during the COVID-19 pandemic and
32 utilizing partial least square regression and a fuzzy-set qualitative comparative analysis
33 conclude, that organizational flexibility is a driver of higher agility in agri-food supply chains,
34 which positively affects supply chain performance. Personnel scheduling is the biggest
35 organisational challenge during the COVID-19 pandemic. The companies need to determine
36 schedules that divide the employees into mutually exclusive groups to reduce the risk of
37 contagion (Zucchi *et al.* 2020). COVID-19 absenteeism, particularly in highly specialized job
38 roles, further complicates the matter (Gray, 2020). Due to lock downs and travel restrictions,
39 supply-demand mismatch and the risk of product expiry have increased. In order to preserve
40 the shelf life of products (Gallo & Accorsi 2017), shelf space allocation has to be investigated
41 (Yang *et al.* 2017b), and products have to be either rotated within the store or else rotated
42 between stores, from low-traffic stores to stores with higher sales volumes (Chowdhury *et al.*
43 2020).
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Jiang & Zhao (2014) advocated that collaboration drives the commercial value accumulation of information technologies in downstream processes. If companies within the SC try to maximize their profits, they settle for suboptimal outcomes. Thus, the aim of the FSC should be to increase the profits of the whole SC, which requires collaboration and cooperation (Bumblauska 2020). Ramos *et al.* (2021) pointed out that external and internal supply chain integration directly impacts the responsiveness of agri-food supply chains during the COVID-19 pandemic, while Kumar *et al.* (2021) identified collaborative management as one of the top risk mitigation strategies for PFSC during the current pandemic.

Collaboration based on blockchain is helpful to lessen information asymmetry between upstream and downstream enterprises and effectively reduces the bullwhip effect by improving synergies throughout the FSC (Xue *et al.* 2021). Moreover, supply chain collaboration among food producers, processors, and distributors is of most importance for the food safety of the end consumers (Lu *et al.* 2021).

Alongside vertical integration, horizontal collaboration becomes important for operational excellence (Borrero 2019; Juma *et al.* 2019; Bumblauska *et al.* 2020). Moreover, collaboration and cooperation should be in the public-private partnerships. Farmers and small producers benefit from collective action and public-private partnerships to face competition from large producers (Narrod *et al.* 2009; Rais *et al.* 2019).

2.2.5. Information

Ding *et al.* (2014) present empirical evidence that information quality, strategic alliance, trust, and commitment positively affect food quality and highlight information quality as a key determinant. Chaudhuri *et al.* (2018) point out that continuous monitoring of conditions can support real-time decisions on food quality and life cycle management and provide historical information to understand patterns for redesigning the FSC. Yu *et al.* (2018) emphasized the importance of both internal and external information integration so that FSC can be reactive and proactive to risks. Thus, SC data's accuracy, accessibility, and actuality and efficient exchange of current data within the company and between SC partners (Bastian & Zentes, 2013) gained importance. Companies jeopardize the transparency and traceability of the PFSC by hiding information from their stakeholders, which they perceive as directly affecting their competitive advantage, sustainability, and efficiency (Mangla *et al.* 2021a). Although

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3 information sharing improves the FSC performance, it introduces new issues regarding data
4 security (Fernando *et al.* 2018; Fitzgerald *et al.* 2018; Richey *et al.* 2016).
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7 2.2.6. Technology 8 9

10 New technologies such as IoT, cyber-physical systems, and smart, connected products,
11 facilitate the development of digital SCs and smart operations (Fazili *et al.* 2017; Liao *et al.*
12 2017; Minner *et al.* 2017; Strozzi *et al.* 2017; Tran-Dang *et al.* 2017). RFID technology can be
13 used to track and trace perishable food, while IoT sensors can be used to measure temperature
14 and humidity during storage and transportation (Alfian *et al.* 2020). Smart packaging
15 technologies such as sensors, indicators, and data carriers monitoring the quality and the
16 freshness of perishable foods. These technologies provide a dynamic output about the quality
17 and safety of the produce, extend products' shelf life, and reduce food waste (Beshai *et al.*
18 2020).
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26 IoT-based delivery planning systems can formulate delivery routing, detect unexpected
27 incidents and re-route accordingly (Tsang *et al.* 2020). A layered architecture model was
28 proposed for the Internet of Perishable Logistics (Pal & Kant 2019). Kappelman & Sinha (2021)
29 proposed to use big data mining techniques to determine optimal supplier selection, which
30 reduces the rate of rejected products and maximizes the SCs expected profit.
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36 SC digital twin enables the simulation of various scenarios to assess the critical risks caused by
37 force majeure and operational risks inherent to PFSC (Kumar *et al.* 2019), their impacts and the
38 duration and recovery policies (Barykin *et al.* 2020). Deep learning can be employed for
39 operational tasks such as plant disease detection, fruit counting, yield estimation (Fountsop *et*
40 *al.* 2020). Osmanoglu *et al.* (2020) proposed a blockchain-based solution for yield estimation,
41 which identifies inefficiencies and enables planning precautions in advance. BT records, stores,
42 validates and secures real-time activity data of PFSCs and connects the PFSC to financial
43 institutions, increasing the likelihood of getting a loan (Rijanto 2020). In Table 1 we summarize
44 the excellence enabler constructs, variables, and main references.
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55 2.3. Blockchain Capabilities for Operational Excellence in PFSCs 56

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58 Blockchain is regarded as the next giant in the technology world, and it is studied in many
59 applications in business processes and sectors. It includes secure handling and storing of
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3 records. Blockchain is an essentially distributed database of records of public ledgers of all
4 transactions that is duplicated and distributed across the entire network. BT assures system
5 robustness by providing transparency in information flow and stability to data, decreases overall
6 costs in the SC like documentation fee, stationery expenditure, manpower, electricity, facility,
7 and time, improves overall performance in terms of efficiency, effectiveness, and speed by
8 standardization and reduction in complexity of the job, facilitates improved data safety and
9 decentralization, improves traceability, visibility, and identification of issues, facilitates
10 compliance with laws and policies, enable streamlined invoicing and improve inventory
11 management, increases customer satisfaction, facilitates better documentation and data
12 management and improves quality by elimination of human error and availability of full
13 information (Yadav & Sing 2020).
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23 The benefits of blockchain were highlighted in SCM with the help of a literature review, along
24 with the opinions of experts from the agricultural sector (Mukherjee *et al.* 2021). Furthermore,
25 the key factors were identified and analysed for Information Communication Technology (ICT)
26 applications for the sustainable growth of Small and Medium Enterprises (SMEs) in the Indian
27 food sector. Grey based Decision-Making Trial and Evaluation Laboratory technique was
28 applied for analysis of factors (Singh *et al.* 2019). The impact of BT in agriculture and FSC was
29 examined and presented on existing ongoing projects and initiatives and discussed overall
30 implications, challenges, and potential, with a critical view over the maturity of these projects
31 (Kamilaris *et al.* 2019).
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40 Empirical evidence demonstrates that blockchain can contribute to the business process to
41 reduce cost and enhance operational efficiency (Holotiuk *et al.* 2019; Oh & Shong 2017).
42 Similarly, other research papers (Ahmed & Broek 2017; Sander *et al.* 2018; Bumblauskas *et al.*
43 2020) showed that the adoption of BT enables traceability and transparency. BT is a value of
44 technology in SC management to extend traceability, transparency, SC digitalisation and
45 disintermediation, improved data security, and smart contracts (Wang *et al.* 2019a; Wang *et al.*
46 2019b; Wang *et al.* 2019c). Shoaib *et al.* (2020) prioritize accessibility, overall efficiency,
47 trackability, and traceability as the most important success factors of a blockchain-based supply
48 chain.
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56 2.3.1. Traceability/Visibility 57 58 59 60

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3 FSCs can increase food safety and mitigate fraud through traceability (Juma *et al.* 2019;
4 Katsikouli *et al.* 2020; Bumblauska *et al.* 2020; Behnke & Janssen 2020; George *et al.* 2019)
5 provenance/authenticity (Bumblauska *et al.* 2020), implementation of food safety pre-warning
6 systems (Wang & Yue 2017). Food quality management can be improved after blockchain
7 adoption (Chen *et al.* 2020).
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12 Blockchain plays an important role in preventing expired and mishandled food from reaching
13 customers in the medium and long-term. The potential impact of BT is reduced food waste
14 (Yiannas *et al.* 2018). The ability to share information among SC partners ensures timely
15 product picking, processing, and distribution. As a result, pipeline inventory, spoilage, and
16 energy consumption are reduced (Yakavenka *et al.* 2018). Food spoilage problems can be
17 reduced by planning the best delivery routine and shortening delivery time for perishable food
18 (Kayikci *et al.* 2020).
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26 This year consumers in North America stocked food at home during the COVID-19 pandemic.
27 The demand has risen almost 30% from a year ago. The increase in demand also creates delays
28 in the SC that lead to food contamination. This technology would help the food industry spot
29 contamination and fraud by tracking material from production to consumer. Currently, many
30 companies have created blockchain solutions for global food and agricultural supply chains.
31 (George *et al.* 2019)
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37 Another important issue in the PFSC is a food recall, which causes costs due to additional
38 operational activities and damages brands equity. Recalls are due to operational mistakes,
39 including contamination, mislabelling, undeclared ingredients, biological causes. Traceability
40 systems are designed to assure safe and good quality food while reducing the costs of food
41 recalls (Bumblauska *et al.* 2020; Qian *et al.* 2020) and improving recall efficiency (Duan *et al.*
42 2020). Blockchain applications enable transparency in labelling, presentation, and advertising
43 of foodstuffs, GMO labelling (Bastian & Zentes 2013), minimize consumers' concerns about
44 the authenticity of their intended purchase (Hughes *et al.* 2019), and enhance and sustain
45 consumer-based brand equity (Boukis 2019).
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54 2.3.2. Immutability & Transparency

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56 Food security can benefit from BT transparency, relatively low transaction costs, and instant
57 implementation (Ahmed & Broek 2017). The immutability of the data means that blockchain
58 can protect the data from any tampering and prevent data corruption. For instance, an SC partner
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3 can add a record but cannot edit or change it. The consumer can query a product's digital record
4 and verify credence claims. Thus, blockchain implementations enhance consumer trust and
5 contribute to the integrity of the FSC (Keogh *et al.* 2020). Furthermore, BT enables efficient
6 use of resources, reducing inefficient processes in the SC (Katsikouli *et al.* 2020) and FLW
7 (Astill *et al.* 2019).
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10 11 12 13 2.3.3. Integration/Interoperability

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15 In the blockchain context, interoperability means connecting multiple blockchains to access
16 information and act on it by changing the state of the own or another blockchain. Blockchain
17 interoperability is critical for scaling within the SC ecosystem and for mass adoption (Kayikci
18 *et al.* 2020). However, interoperability is not easily assured since the FSC cannot be fully digital
19 due to physical goods (Rogerson & Parry 2020). Furthermore, as blockchain networks exist in
20 different formats using different terminologies, coding languages, consensus algorithms, and
21 privacy measures, there is no standard and regulation in blockchain applications (U4SSC 2020).
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24 Developing general standards for data collection and sharing increases the interoperability
25 among FSC actors and improves data accessibility and accuracy (Kamble *et al.* 2020).
26 However, this is not an easy task since the FSC operates in a complex worldwide environment.
27 The development of blockchain-related regulations and laws is challenged by overlapping and
28 conflicting regulations and various laws at the national level (Galvez & Mejuto 2018).
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31 32 33 34 35 36 37 38 2.3.4. Smart Contracts

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40 Continuous real-time data tracking is facilitated through smart contracts across the SC, which
41 accelerates time-consuming activities of operations management and payments (Varriale *et al.*
42 2021). Moreover, smart contracts can lead to short task completion time, more simplicity, and
43 enhanced jobs (Wang *et al.* 2020). The automation provided by the deployment of the smart
44 contracts (Casino *et al.* 2020) model removed hidden costs and paper load from the FSC
45 traceability process. BT and smart contracts provide several advantages for fair-trade
46 throughout the SC (Kang & Indra-Payoong 2019). A blockchain-based credit evaluation
47 system, which gathers credit evaluation text from traders by smart contracts on the blockchain,
48 was provided to strengthen the effectiveness of supervision and management in the FSC (Mao
49 *et al.* 2018).
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59 60 2.3.5. Consensus Mechanism

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3 All parties in the SC agree to network verified transactions (Wang *et al.* 2020). Integrating with
4 IoT, the use of BT with appropriate consensus mechanisms in various SC echelons would
5 enable big data management, improved connectivity, intellectual property rights, and efficient
6 SC contacting (Dutta *et al.* 2020). Ontologies were used for blockchain design to determine
7 food supply provenance (Kim *et al.* 2018). BT is proposed as a way to organize records in a
8 distributed manner by means of consensus mechanism (Gao *et al.* 2018; Benčić *et al.* 2019).
9

14 2.3.6. Asset Management

16
17 Blockchain technologies provide a new data storage and verification architecture. The firm's
18 assets, business contracts, and transactions can be protected in this way (Rijanto *et al.* 2020).
19 BT provides proficient asset management (O'Leary *et al.* 2017). It was proposed that BT
20 empowers cybersecurity and enables better performance in asset management than centralized
21 IoT systems (Kshetri *et al.* 2017). BT also provides asset management by means of its proof-
22 of-concept algorithm, which assures transparency, reliability and efficiency (Cholewa *et al.*
23 2017). Model-driven engineering (MDE) helps reduce risks by combining proven code snippets
24 as per the model specification, which is easier to understand than source code. Therefore, an
25 approach was presented for integrated MDE across business processes and asset management
26 (Lu *et al.* 2020).
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35 2.3.7. Disintermediation/Decentralisation

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38 The appeal and primary feature of blockchain is its decentralization and disintermediation.
39 Decentralisation refers to removing control and decision-making power from a central authority
40 (individual, organization, or group) and transferring it to a distributed network (Kayikci 2020).
41 Therefore, blockchain requires a decentralized architecture and system. Disintermediation is a
42 functional feature of blockchain and its affiliated technology, smart contract, operates on a peer-
43 to-peer network to remove intermediaries (Subramanian *et al.* 2020). Besides, it also reduces
44 transaction costs and secures transaction, auditability, and data provenance (Tönnissen *et al.*
45 2020). Saurabh & Dey (2021) find that disintermediation is one of the most important
46 capabilities influencing the BT adoption-intention decision in the grape wine SC.
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54 2.3.8. Data Standardisation/Security/Sharing

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57 Every transaction powered by digital technologies is recorded in the blockchain with proper
58 data standards (e.g., QS1) (Kamilaris *et al.* 2019), where the different algorithms in blockchain
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3 provide data security (Kayikci *et al.* 2020; Duan *et al.* 2020). Blockchain can lead to more data
4 sharing through the usage of other technologies (e.g., sensors) (Behnke & Janssen 2020). The
5 more data is shared, the higher the value of the blockchain (Kayikci *et al.* 2020). In particular,
6 blockchain-based systems that integrate FSCs gather information on various food products and
7 generate and ensure food safety standards for governments (Ali *et al.* 2017). Furthermore,
8 blockchain helps empower audit and management traders and prevent the sale of illegal
9 products (Tse *et al.* 2017; Heinrich *et al.* 2019).

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16 The Figure 3 illustrates the stakeholders involved in the PFSC, which includes farmers,
17 distributors, packers, producers, processors, manufacturers, wholesalers, retailers, and
18 consumers, the relations of operational excellence enablers, and blockchain capabilities to
19 sustainable operational excellence outcomes of PFSC during pandemics.
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26 27 **3. Methodology**

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30 Case studies are often used for inductive exploration of yet unknown phenomena, i.e., theory
31 generation. Empirical research, traditionally used for theory building, theory testing, and
32 explanation, has received recent additional focus from researchers interested in discovery and
33 problem solving, leading to a distinction between explanatory and exploratory research. The
34 aim of explanatory research is to construct and demonstrate an explicit and novel theoretical
35 contribution, while exploratory research is interested in improving the solution design and
36 demonstrating its practical utility with empirical evaluation (Holmström *et al.* 2009).
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43 Our aim is to explore the potential of blockchain to achieve operational excellence for PFSCs
44 during the pandemics and to generate prescriptive knowledge on how to achieve this. Thus, our
45 research interest is in solving a practical problem, and our knowledge interest is pragmatic. Our
46 exploratory research approach proposes a rudimentary solution design based on a systematic
47 literature review and subject the rudimentary solution design to empirical testing. Thus, DSR
48 is appropriate for our research purposes. DSR is conducted under different scientific research
49 rubrics such as action science, action research, action innovation research, participatory action
50 research, participatory case study, academe-industry partnerships, and the like (Holmström *et*
51 *al.* 2009).
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3 This study uses a single use-case based on a CIMO-logic to evaluate the blockchain capabilities
4 to drive operational excellence across PFSC during outbreaks. The single case study context is
5 always unique. The empirical examination must always be balanced with a more general
6 theoretical examination. The case selection is based on access and appropriateness of the case
7 selected for the specific study. The study critically investigates a specific technology in the
8 PFSC, mainly BT. This study selects a paradigmatic case where blockchain implementation is
9 taken for granted. The research protocol and data collection are discussed openly to ensure
10 traceability. Information about coding procedures and analysis is laid out in detail to ensure
11 truth value. The study's general theoretical aim and interest and the study's result can be
12 analytically generalized through CIMO-logic ensuring transferability. The generative
13 mechanisms underlying operational excellence during an outbreak are revealed, and the
14 blockchain capabilities are evaluated (Gammelgaard 2017).

25 3.1. CIMO-Logic

26
27 Prescriptive knowledge has a central role in design science research and follows the logic of
28 the design propositions. Design propositions created with CIMO-logic contain information on
29 what to do (intervention), in which situations (context), to offer some understanding of why this
30 happens (a mechanism) and to produce what effect (outcome) (Pawson & Tilley 1997). Thus,
31 CIMO-logic enables a deep understanding of a system's social and technological components
32 and lets the researcher develop propositions on how to improve the system performance in
33 practice under the rubric of scientific research (Denyer *et al.* 2008).

34
35 On the one hand, CIMO-logic is employed to extract knowledge from the literature review in
36 various contexts (e.g., Rajwani & Liedong 2015; Holmström *et al.* 2017; Pilbeam *et al.* 2019;
37 Bin Makhshen *et al.* 2020). For these studies, research outcomes are design propositions to
38 develop a research agenda. On the other hand, CIMO-logic is employed in order to extract
39 knowledge from literature review and case study in various contexts (e.g., Ivert & Jonsson
40 2014; Santti *et al.* 2017; Brusset & Bertrand 2018; Costa *et al.* 2020; Konietzko *et al.* 2020;
41 Tanila *et al.* 2020; Reich *et al.* 2021). For these studies, outcomes are design propositions to
42 develop solution-oriented guidelines that are actionable in practice. Table 2 summarizes the
43 various application areas of CIMO-logic.

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3 Since the intent of CIMO-logic in the later research stream aligns with our aim, we will
4 formulate design propositions using the existing published research base and the use-case as
5 well. The problems in PFSC during outbreaks (context), their interventions, and outcomes have
6 been narrated by the PFSC participants. As researchers, our task is to link their interventions to
7 outcomes following CIMO-logic. We unearth intervention types by asking which blockchain
8 capability has facilitated this intervention. We address the mechanisms through which the
9 intended outcomes have been achieved. We identify the specified generative mechanisms by
10 asking which this blockchain capability has activated operation excellence enabler. We generate
11 prescriptive knowledge from use-case analysis and synthesizing previously published research.
12 Figure 4 depicts the rudimentary solution design based on our systematic literature review.

21 >INSERT FIGURE 4 HERE<

24 3.2. Single Case Study Method and Use-Case Selection

26
27 In this research, a single case study method was employed by incorporating semi-structured
28 interviews to collect and analyse empirical data to search for blockchain potential to achieve
29 operational excellence in PFSCs during the pandemic. Case studies on blockchain applications
30 are an appropriate approach to systematically transfer industry experience to benefit in
31 developing empirical (theory building and testing) and design science (design and evaluation)
32 research (Treiblmaier 2019). In PFSC, blockchain use-cases go beyond ensuring food safety
33 and adding operational excellence to the entire ecosystem (Subramanian *et al.* 2020). Therefore,
34 we used a single case study to analyse the potential of blockchain from the multiple PFSC
35 participants' perspectives in the same blockchain ecosystem.

42
43 We searched the potential use-cases in the agriculture and food sectors on the Internet to support
44 the purpose of our study. More than 20 start-up companies were identified and two appropriate
45 companies out of them were selected as blockchain use-case candidates to pursue the study and
46 analyse operational excellence aspects. We contacted the company speakers through LinkedIn.
47 At the end, one company responded and agreed to participate in our study. The selected
48 company is a technology company and one of the leading front lines of the intersections
49 between blockchain and agriculture. The company is headquartered in the USA and strives to
50 provide blockchain platform solutions for agriculture and food supply chains with a range of
51 customer segments, including farmers, food processors, distributors, consumer packaged goods
52 manufacturers, groceries, retailers, and large industry associations. The company implements

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3 blockchain solutions in different food products such as cocoa, coffee, palm oil, sugarcane,
4 barley. The value of the BT of this company allows an ecosystem of participants by digitizing
5 the trusted journey of the food product to verify transactions and share, record, and exchange
6 data securely, transparently, decentralized, and efficiently in a distributed ledger system provide
7 it to the stakeholders. This is necessary for the food supply chain to profoundly change and
8 improve industry objectives for sustainability, spoilage, reduction, safety, nutrition, and quality.
9 Therefore, the case company as a food and farm blockchain provider makes an ideal candidate
10 for in-depth exploration of blockchain potential to drive operational excellence in PFSC during
11 COVID-19 outbreaks.
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20 After having discussion with the blockchain provider, we decided to use one of the food supply
21 chains they were working on as a case study. The interviews were held with the blockchain
22 provider and five ecosystem participants from different tiers of the same blockchain ecosystem
23 within a single use-case. Firstly, we contacted the business development manager of the
24 blockchain provider, and five ecosystem participants, namely one farmer, one cooperative, one
25 food processor, one retailer, and one logistics provider, invited them for an interview. The food
26 supply chain is a global cocoa supply chain, which produces high-quality chocolates for
27 international markets. The farmer is Ecuador's cocoa farmer, the cooperative is Ecuador's cocoa
28 cooperative, the food processor is a Swiss factory, the retailer is a German retailer, and the
29 logistics provider is a Danish transport company. The pandemic-related lifestyle changes and
30 consumption behaviours affect the demand pattern of cocoa. According to the disclosed
31 information in this use-case, the total demand for cocoa has increased up to 21% compared to
32 2019, while cocoa production has decreased due to pandemic related operational bottlenecks
33 and severe disruptions. Because of this supply-demand mismatch, the use-case is a suitable and
34 informative example for analysing the operational excellence of blockchain-based PFSC during
35 outbreaks.
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48 The online interviews took place in between December 2020 and January 2021. After having
49 confirmations, we sent a brief email with the objective of our research aim and interview
50 protocol. A semi-structured interview protocol based on findings from the literature review was
51 conducted. Since the participants were not online at the same time, the interviews were planned
52 asynchronously. Each interview was held with a professional and took almost an hour. During
53 the interviews, the authors were present and took notes to ensure that the content of interviews
54 was not compromised. The participants were assured that there are no right or wrong answers
55 to reduce social desirability bias. Furthermore, the response anonymity was maintained to
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3 minimise apprehension in evaluation. After completion of the interviews, to minimise the
4 reporting bias a summary transcript was provided to each interviewee within a few days for the
5 validation and all were acknowledged and approved by emails.
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9 The transcript for each interview was prepared and analysed in-depth by two researchers
10 independently, and disagreements were resolved by involving the third researcher, in order to
11 assure inter-rater reliability. We read the notes and examined them carefully according to
12 CIMO-logic methodology. The contexts, interventions, mechanisms and outcomes were
13 identified from the interview transcripts. We discussed the analyses and finalized them. At the
14 end, the findings of the research, developed propositions, and frameworks were also verified
15 with the interviewees to ensure validity of the data collection and analyses. Figure 5 depicts the
16 flowchart for use-case analysis.
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26 27 **4.CIMO Analysis of the Selected Use-Case**

28 29 **4.1. Food Loss and Waste**

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32 Pandemic has disrupted the SCs globally and caused heavy wastage problems at the different
33 stages of the PFSC from post-harvesting, production, processing, transportation, and storage to
34 pre-consumers' stages. The food loss occurs during early and middle stages (close to the farm),
35 whereas the food waste occurs during the retail and post-consumer stages (close to the fork).
36 Due to lockdowns, travel restrictions, and border controls, the perishable products either
37 remained in the field or had to wait in containers on the way or were not sold out within their
38 lifecycle at retailers. BT provides solutions for SC participants to detect and communicate
39 inefficiencies in PFSC and certify the information holds true on the blockchain system. BT
40 enables promoting and strengthening farmers' organisation to balance the COVID-19 caused
41 supply and demand changes by sharing available capacities and collecting possible demands.
42 In this way, producer organizations have responded in different ways to the challenges of
43 COVID-19 by demonstrating the power of collective action. Additional yields can be
44 announced on the blockchain, and a networked landscape of buyers will be instantly informed,
45 supply and demand can be matched. Consumers access quality produce, while farmers increase
46 their profits. Instant knowledge of product's exact origin, treatment, quality, handling, and age
47 enables improved life cycle management.
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4.2. Food Quality & Safety

During the pandemic, the health of the soil, plants, animals, people, and the environment need to be ensured. So that the possible problems including food fraud, food safety, what constitutes quality, and even issues like food spoilage can be prevented. Blockchain records precision water, soil, and pest control, measures, and provides insights such as how much fertilizer is applied and how it affects the quality of the produce. The SC participants can be alerted of incompatibilities by real-time tracking and tracing perishable products powered by BT. So that they can manage food safety, food quality, inventory and product freshness to prevent food waste. BT promotes product quality differentiation against situation changes caused by COVID-19.

Beyond the information about physical products, consumers want to have visibility on ethical and sustainable practices. The blockchain ledger holds information such as food safety certification, organic certification, soil quality, animal welfare practices, and carbon certification. Moreover, the blockchain enables visibility on the origin of food and what is in food and on who handled the food. Thus, in the case of COVID-19 incidents among PFSC participants, contamination risk can be predicted, and possible contaminated food and packaging can be identified in seconds. Together with IoT sensors, BT can capture the environment in which the food was grown, transported, and processed, which improves transparency on food safety and hygiene and builds consumer trust.

4.3. Food Recalls

Food products can be contaminated during harvesting, manufacture, delivery, or while stored. While no problems of COVID-19 transmission through food or packaging have been encountered, BT offers opportunities to detect potential contamination exposures and enable faster and more efficient food recalls due to quality assurance failures or distribution issues. Only the tainted or contaminated food is discharged as opposed to the standard operating procedure of the mass recall, where distributors, retailers, and consumers had to discard perfectly safe food because it happened to coexist in time with a small amount of tainted or contaminated food. Standard tracking systems in companies involving phones, faxes, and emails take days to track unsafe food, while BT enables the digitization of the movement of food along with the SC by creating the digital twin of the physical movement as a virtual model

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3 of the process, product, and service and can track the amount and movement of unsafe food in
4 seconds.
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7 **4.4. COVID-19 Absenteeism**

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10 There is concern that operations could be adversely affected if a significant proportion of food
11 production and distribution employees are unable to work due to illness or government
12 restrictions. Due to COVID-19 absenteeism, crops were left in the field, food producers were
13 unable to utilize their full capacity, and shipping and distribution of perishable foods were
14 interrupted, which increased FLW and increased out-of-stock events. Since blockchain also
15 tracks employee data, it can predict the infection risk among employees and identify possible
16 bottlenecks in the operations. Thus, BT provides PFSC participants a means to develop
17 contingency plans e.g., capacity building through outsourcing or eliminating stock-outs through
18 alternative sourcing.
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26 **4.5. Disparate Systems**

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29 The PFSC is challenged by fragmentation and complexities, which lead to opaqueness and
30 inefficiencies. Blockchain allows the ecosystem to have one source of data and connects the
31 disparate systems and actors in the ecosystem. BT connects the disparate systems and increases
32 the accuracy of the records by providing integrity within PFSC. Blockchain can enhance
33 interoperability within the systems. There are different IT landscapes in PFSC that do not
34 communicate well with each other. Blockchain will provide the ability to unify these disparate
35 systems through interoperability that can facilitate end-to-end visibility throughout the PFSC.
36 In this way, the use of BT at all levels in the ecosystem helps agricultural stakeholders make
37 evidence-based decisions and alerts.
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46 **4.6. Financing, Operating Costs, Liquidity**

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49 Due to economic stagnation caused by the COVID-19 the economic problems inherent to the
50 PFSC, such as securing loans especially for small farmers and producers, optimizing operating
51 costs, and maintaining liquidity for all SC participants, have been intensified even more.
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55 Blockchain records data on previous loans and enables forecasts on produce based on historical
56 data, which can be provided to banks and other lending agencies. Through visibility, the
57 likelihood of securing a loan increases, which improves the livelihoods of small farmers and
58 producers. Blockchain records precision water, soil, and pest control measure enables farmers
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3 and producers to identify inefficiencies, and allows decreased input and labour cost. Blockchain
4 utilizes smart contracts to shorten the time between fulfilment and receipt of payment leading
5 to better cash flows and reducing layoffs and bankruptcy risk. In addition, BT connects
6 ecosystem participants with government agencies to facilitate their access to credits or subsidies
7 and insurance companies to protect them against contamination or other pandemic-related
8 exposures.
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14 In Table 3, we classify the problems faced by PFSC participants during outbreaks, propose an
15 intervention type to invoke the generative mechanisms to solve the problems, and evaluate
16 whether the desired outcomes have been delivered.
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23 **5. Results**

24 **5.1. Sustainable Operational Excellence Outcomes**

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29 Blockchain-driven PFSC offers greater potential to achieve operational excellence for
30 ecosystem participants in performance and life-cycle assessment and validation. The
31 blockchain mechanism enables monitoring the perishable food product throughout the entire
32 lifecycle in every stage of the SC and collecting and analysing relevant data to overcome
33 potential inefficiencies and operational risks and obstacles. We outline the specific blockchain
34 capabilities in terms of economic, social, and environmental sustainability aspects that impact
35 the operational excellence of the PFSC ecosystem. In terms of this result, the study is in line
36 with Martinez *et al.* (2019), suggesting that BT improves the efficiency of the process, reduces
37 the number of operations, reduces the average time of orders in the system, reduces workload,
38 shows traceability of orders and improves visibility to various supply chain participants.
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46 **5.1.1. Economic**

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50 COVID-19 has severely disrupted PFSCs globally. The ecosystem participants from farmers to
51 retailers faced sudden, unexpected, and simultaneous shocks both on the demand and supply
52 side, triggering financial vulnerability. In this use-case, the blockchain platform improves
53 economic sustainability to combat the operational and financial problems caused by COVID-
54 19. The mechanism improves operational responsiveness and promotes flexibility in business
55 processes. If coronavirus is caught in food at retailers, blockchain enables efficient food recall,
56 instead of recalling entire products, it can quickly identify which batches are affected and where
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3 they are distributed. In this way, recall costs can be reduced. This blockchain-enabled recall
4 process is also important for other possible food contaminations (e.g., salmonella bacteria,
5 norovirus, aflatoxins), so that contaminated batches are monitored along PFSC while products
6 are quickly recalled and the society can be protected from any foodborne diseases (Kayikci *et*
7 *al.* 2020). Furthermore, by including temperature and humidity in the blockchain record, the
8 safety of a particular perishable food shipment and storage can be proactively tracked and traced
9 (Kayikci *et al.* 2020). This can protect all connected processes in the PFSC system before any
10 sudden event occurs. Farmers need to optimize their operating costs with higher crops, lower
11 livestock losses, less water usage, and utilize their capacities through smart contracts which
12 facilitate the collaboration of cross-organizational business processes to reduce the heavy
13 impact of a pandemic. In particular, the consensus mechanism allows proof checking and
14 enables participants cheaper and faster access to affordable financing and liquidity in funds.

25 **5.1.2. Social**

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27 COVID-19 pandemic has caused employee absenteeism. The shortage of skilled staff from field
28 workers to truck drivers to senior managers can greatly affect the efficiency of PFSC. Therefore,
29 there is a need to predict employee absenteeism during COVID-19. In this use-case, the
30 blockchain platform improves social sustainability to combat absenteeism problems caused by
31 COVID-19. The blockchain tracks employees' health conditions and their infection risk and
32 identifies possible absenteeism resulting in bottlenecks, and warns the entire system to take
33 prompt measurements (e.g., staff sharing). Furthermore, blockchain can also improve animal
34 welfare and animal health, support animal safety, and control production including
35 pharmaceuticals, antibiotics, vaccines, genomics and toxicology etc., for food safety.
36 Blockchain can help facilitate transparency for direct trade and assure consumers that farmers
37 or cooperatives are paid a fair price for commodities.

47 **5.1.3. Environmental**

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49 During the COVID-19 pandemic, almost all companies involved in PFSC have experienced
50 significant environmental problems, particularly FLW. In this use-case, the blockchain platform
51 improves environmental sustainability to combat ecological problems caused by COVID-19.
52 The mechanism enables food traceability and transparency along the lifecycle in the entire
53 PFSC. The available inventory can be monitored through asset management. If necessary, the
54 surplus food can be circulated by redistribution and reallocation in the ecosystem. This can help
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3 to avoid FLW and also can be prevented from being dumped. Also, this use-case enables the
4 carbon-neutral, eco-labelled and environmentally friendly practices to enable tracing of carbon
5 footprints throughout the PFSC.
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8 9 **5.2. Propositions**

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12 The design propositions are derived for PFSCs that can support different types of generative
13 mechanisms of operational excellence: responsiveness, flexibility, efficiency, technology,
14 information, and collaboration. Here, it is essential that the blockchain solution instantly
15 monitors the state of the SC during outbreaks to identify inefficiencies and take corrective
16 actions such as timely redistribution/reallocation of excess food and disintermediation and
17 overcome potential operational risks and obstacles such as operational bottlenecks, product
18 shortages, food fraud & safety, cessation of logistic activities, COVID-19 absenteeism. Table
19 4 shows the formation of design propositions based on CIMO-logic. The propositions cover the
20 vertical and horizontal aspects of CIMO. Specifically, we used a format shown in Figure 5 as
21 “to achieve outcome *O* in context *C*, enact intervention *I* to trigger mechanism *M*” for
22 developing propositions. As a result, we propose the following five propositions:
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32 **>INSERT TABLE 4 HERE<**
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35 P1: To achieve food safety during outbreaks, enact blockchain capabilities, visibility,
36 traceability, disintermediation/decentralisation and smart contracts to trigger operational
37 excellence enablers information, technology, and responsiveness.
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41 P2: To achieve food accessibility during outbreaks, enact blockchain capabilities, immutability
42 & transparency, traceability, and integration/interoperability to trigger operational excellence
43 enablers efficiency, responsiveness, flexibility, information, technology, and collaboration.
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47 P3: To achieve food security during outbreaks, enact blockchain capabilities, immutability &
48 transparency, integration/interoperability, consensus mechanism, smart contracts to trigger
49 operational excellence enablers technology, information, and collaboration.
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53 P4: The blockchain-driven PFSC solution enables ecosystem participants to identify
54 inefficiencies during outbreaks through real-time status monitoring to achieve operational
55 excellence
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3 P5: The blockchain-driven PFSC solution enables ecosystem participants to anticipate possible
4 operational risks and obstacles during outbreaks and execute contingency plans to achieve
5 operational excellence.
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8 9 **5.3. Sensitivity Analysis: Perspectives of Three PFSC Operational Stages**

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12 Sensitivity analysis is used to examine the impact of using different thresholds, such as different
13 decision makers and/or different sub-attributes, on the result. In this study, the perspectives of
14 different decision-makers involved in the three operational stages of PFSC were used to validate
15 the propositions in the frame of sensitivity analysis. The outcomes from the whole PFSC and
16 three operational stages for upstream PFSC (farmer and cooperative), Work in Progress (WIP)
17 (food processor), and downstream PFSC (retailer and logistics provider) were analysed for the
18 validation of propositions. For instance, the whole PFSC condition considers blockchain
19 capabilities and operational excellence outcomes with all PFSC stakeholders, while the
20 upstream PFSC condition considers blockchain capabilities and operational excellence with
21 only upstream stakeholders. Table 5 summarizes the analysis of the whole PFSC with three
22 operational stages of PFSC for the aforementioned five propositions and the details are depicted
23 in the Appendix.
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34 Proposition 1 has been fully supported by WIP and downstream PFSC, while upstream PFSC
35 provides partial support. WIP and downstream PFSC are held accountable on every aspect of
36 food safety, whereas upstream PFSC is not responsible for food provenance & food threat and
37 food recall, leading them to enact a limited set of blockchain capabilities to ensure food safety
38 across the PFSC.
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44 Proposition 2 has been fully supported by WIP and downstream PFSC, while upstream PFSC
45 provides partial support. WIP and downstream PFSC are held accountable on every aspect of
46 food accessibility, whereas upstream PFSC is not responsible for life cycle management and
47 shelf management, leading them to enact a limited set of blockchain capabilities to ensure food
48 accessibility across the PFSC.
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54 Proposition 3 has been supported by upstream PFSC, whereas downstream PFSC provides
55 partial support. Upstream PFSC is challenged by all aspects of food security and enacts
56 blockchain capabilities to ensure food security throughout the PFSC, while upstream PFSC
57 enacts blockchain capabilities such as consensus mechanisms and smart contracts to ensure
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liquidity. There is no evidence that WIP enact blockchain capabilities to detect and react to inefficiencies to ensure food security.

Proposition 4 and 5 have been supported by all decision-makers regarding two operational excellence dimensions. All decision-makers enact blockchain capabilities to detect food safety and food accessibility problems and execute contingency plans accordingly. However, there is only partial support from the upstream PFSC for the food security dimension.

>INSERT TABLE 5 HERE<

6. Discussion and Implications

The pandemic not only had a disruptive effect on the FSC but also exacerbated existing problems inherent to the PFSC. Before the pandemic, the FSC was already entangled with deep rooted economic, social and environmental challenges (Kumar *et al.* 2019). The extensive literature review by Li, Lee & Gharehgozli (2021) asserts that BT enables visibility, transparency, interoperability, and efficiency and is beneficial for overcoming these challenges. Thus, our results align with the literature on blockchain capabilities and operational excellence in FSC in general.

Following most recent studies on operational excellence in FSC during outbreaks (Kumar & Singh, 2021, Kumar *et al.* 2021; Mishra *et al.* 2021), the present study postulates that flexibility, collaboration, and responsiveness to identify inefficiencies and anticipate possible operational risks and obstacles is essential to develop supply chain resilience during outbreaks. Kumar & Singh (2021) identify the interrelatedness of operational, logistical, financial, and socio-economic impacts of COVID-19 and determine the possible strategies for improving the resilience of the agri-food supply chains as supply chain correlation, supply chain responsiveness, coordination between stakeholders, information, and resource sharing, digitisation of the process, which are in turn all interlinked. Mishra *et al.* (2021) emphasize proactive and reactive implementations to cope with disruptions. According to Mishra *et al.* (2021) proactive demand-side practices are trust-building and transparent communication, proactive supply-side practices are supplier resilience, collaboration with competition, long term contracts, implementation of knowledge management tools and reconfiguration of supply chain network design, proactive logistics side practices are logistics capabilities, security and transparency are most important. Kumar *et al.* 2021 propose that collaborative management,

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3 proactive business continuity planning and financial sustainability are the top risk mitigation
4 strategies for PFSC during the current pandemic.
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7 Similar to Kumar & Singh *et al.* (2021), Kumar *et al.* (2021), and Mishra *et al.* (2021) we
8 provide a nuanced overview of the complexity of the PFSC and design solutions for operational
9 excellence during an outbreak; and find similar results regarding COVID-19 impacts and
10 coping mechanisms. Furthermore, we evaluated the potential of a practical tool for operational
11 excellence utilizing real data from use-cases and demonstrated that various blockchain
12 capabilities facilitate key operational excellence drivers reactively and proactively. Most
13 notably, this real case revealed that blockchain-based collaboration between stakeholders along
14 the cocoa supply chain during the pandemic resulted in around %25 cost reduction, 17%
15 revenue growth, and 15% sourcing efficiency and productivity increase.
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24 The theoretical implication of this research is that in-depth systematic literature review and
25 CIMO-logic methodology based on a real blockchain-driven PFSC solution were used to
26 demonstrate the blockchain capabilities driving operational excellence in PFSC during
27 outbreaks. The findings will provide insight into the mechanisms that deliver the outcomes of
28 sustainable operational excellence. In this research, the blockchain capabilities driving
29 operational excellence in PFSC were analysed from the perspective of a qualitative study (use-
30 case). This can also be analysed from the perspective of quantitative studies by applying a wide
31 range of simulation, modelling, and numerical analyses techniques as a theoretical background.
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39 The managerial implication of this research is that the findings of the presented study will help
40 companies in PFSC understand the potential operational challenges, risks, and inefficiencies
41 caused by any outbreak such as COVID-19. Moreover, the companies in the food industry will
42 gain great insight into developing and implementing their own blockchain-driven solutions,
43 particularly during outbreaks. As companies are often sceptical about whether BT can add value
44 in achieving operational excellence. With the finding of this study, it will be possible for them
45 to understand the potential of the blockchain better, keeping in mind that this study focuses on
46 a real case where BT is already implemented, and the design propositions apply to PFSC, where
47 BT is adopted to some extent. We are aware that, like any other new technology adoption, BT
48 is not immune to cultural barriers such as resistance to change and organizational inertia, which
49 can either complicate the transition period or hinder the adoption of new technology altogether.
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58 However, we would like to refer the reader interested in the new adaptation of technologies in
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3 FSC such as blockchain and artificial intelligence in FSC to Vivaldini (2021) and Dora *et al.*
4 (2021), respectively.
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7 As demonstrated by Mangla *et al.* (2021b) the most prominent societal implications of BT for
8 delivering SDGs as providing safe food, promoting good health and better well-being for all.
9 The COVID-19 pandemic has unprecedented and far-reaching effects on economic, social, and
10 environmental systems, with the immediate threats to SDG1-No Poverty due to economic
11 recession, layoffs, and bankruptcy; SDG2-Zero Hunger due to increased food insecurity;
12 SDG3-Good Health and Well-Being due to food accessibility and safety; SDG8-Decent Work
13 and Economic Growth due to layoffs and bankruptcy; SDG13-Climate Action and SDG14-Life
14 Below Water due to increased single-use packaging by increased food hygiene concerns;
15 SDG15-Life on Land due, to increased food waste caused by the demand-supply mismatch.
16 The developed CIMO-logic framework can guide governments and policy makers pointing out
17 which operational excellence parameters of PFSC should be promptly driven by blockchain
18 capabilities in the event of an outbreak. Hence, this study also provides social implications of
19 implementing blockchain-based solutions to achieve SDGs.
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31 **7. Conclusion and Future Research**

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33 In this research, we conducted a structured literature review to identify operational excellence
34 enablers and blockchain capabilities and also analysed a real single use-case through CIMO-
35 logic involving semi-structured interviews with different stakeholders to reveal blockchain
36 capabilities to drive operational excellence PFSC during outbreaks.
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41 COVID-19 pandemic disrupted the functioning of markets, institutions, and social capital and
42 weakened the resilience of food systems unlike any other natural disaster, such as drought,
43 floods, and pests, and had unprecedented and far-reaching economic, social, and environmental
44 impacts on PFSCs. The PFSC has to rely on collaboration, technology, and information sharing
45 to become more responsive, flexible, and efficient to cope with the impacts of COVID-19. BT
46 benefits all stakeholders in the agri-food system (global cocoa supply chain), as its
47 implementation can help improve supply chain performance such as reducing crop losses,
48 improving yields, decreasing transaction time and cost, optimizing product storage, avoiding
49 food contamination & spoilage, improve recall efficiency, manage operational risks and
50 maximize profits and provide sustainability benefits such as promote fair trade, track carbon
51 emissions, minimize food loss & waste. Blockchain capabilities, such as traceability/visibility,
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3 immutability & transparency, integration/interoperability, and smart contracts facilitate the
4 identification of inefficiencies and anticipation of possible operational risks and obstacles and
5 execute contingency plans during outbreaks.
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9 The blockchain-driven PFSC ecosystems have greater potential than other solutions to achieve
10 operational excellence. However, the level of integration, automation, and data sharing among
11 trusted ecosystem stakeholders on the blockchain platform plays a major role in revealing
12 blockchain capabilities. The more data is shared, the higher the value of the blockchain. Its
13 development, especially in terms of data interoperability for cross-blockchain interactions, will
14 facilitate seamless data transactions between different food ecosystems, thereby enabling
15 greater operational excellence. Furthermore, the use of other emerging technologies and digital
16 tools such as sensors, IoT, AI/ML in blockchain platforms can foster integration and automation
17 and further increase the capabilities of blockchain to drive operational excellence in PFSC.
18 Governmental regulations are also important to disseminate the use of BT to establish food
19 safety standards and food security. In this way, PFSC can be better monitored, protecting public
20 health, balancing capacities, and preventing food waste during outbreaks.
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31 The main limitation of this research is that only one real case is employed. Thus, statistical
32 generalization is not possible at this stage of the research. However, the findings are not
33 restricted to this single case. DSR provides an in-depth understanding of the topic and requires
34 pragmatic validity based on saturated evidence. The CIMO-logic-based framework and the
35 propositions of this study can be adapted to the other food related SCs such as agriculture, dry
36 food, dry legumes, since the operational excellence enablers derived in this study are food-
37 related.
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44 The findings of this study are presented based on the current state-of-art of blockchain. As an
45 emerging technology, BT is still in its infancy, and therefore, it has some technical
46 shortcomings. The sooner this technology matures, the more the blockchain capabilities will
47 drive operational excellence in PFSC. As new technology adoption, BT adoption is not immune
48 to cultural barriers along the supply chain and within the organization. This study focuses on a
49 real case where BT has been adopted and derives the design propositions based on the
50 assumption that the PFSC already adopted BT to some extent. However, a fruitful future
51 research avenue is examining various barriers to adopting BT in PFSC and corresponding
52 solution mechanisms.
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3 In addition, this study analyses the blockchain capabilities as a response to COVID-19
4 pandemic in the PFSC context. On the one hand, the perishable food sector is not the only sector
5 affected by the pandemic. The research design of this study can be applied to other system-
6 relevant sectors as well by reproducing sector-specific operational excellence drivers. On the
7 other hand, BT is not the only emerging technology to mitigate the disruptive effects of the
8 COVID-19 pandemic. Thus, the research design can evaluate the capabilities of emerging
9 technologies such AI, IoT, and automation to drive operational excellence across PFSC during
10 outbreaks. In this research, SC participants of one blockchain-driven PFSC ecosystem have
11 been interviewed. Thus, the analyses have been conducted from multiple participant
12 perspectives within one PFSCs. For future research, more use-cases can be added to compare
13 different blockchain-driven PFSC ecosystems in terms of their blockchain capabilities and
14 observe interactions among SC partners within one ecosystem and interactions among different
15 ecosystems.

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27 This study focuses heavily on the forward flow of perishable goods due to two reasons. First,
28 due to the COVID-19 pandemic, there are more pressing matters to tackle in the forward supply
29 chain compared to the backward supply chain. Second, the packaging of cocoa products is not
30 recyclable & reclaimable, and the investigated cocoa supply chain does not engage in circular
31 economy activities. COP 26 has emphasized nature's critical role in achieving the goal of
32 limiting global temperature rises to 1.5 C and called upon more action towards preserving our
33 oceans and land to mitigate climate change. Thus, post-pandemic the transition to a circular
34 economy has utmost urgency and evaluating blockchain capabilities for driving operational
35 excellence regarding circular economy is a noteworthy future research avenue.

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APPENDIX – Details on Sensitivity Analysis

	Context 1	Interventions	Mechanisms	Outcomes
Downstream	Food Quality Food Provenance & Fraud Threat Food Safety & Hygiene Food Recall	Primary Capabilities: Visibility, Traceability Supporting Capabilities: Smart Contracts Disintermediation/Decentralisation	Detect=> Information, Technology React=> Responsiveness	Economic: Brand equity Social: Food Safety Environmental: Minimization of Food Waste
	Context 2	Interventions	Mechanisms	Outcomes
	Supply- Demand Mismatch Food Loss & Waste Life Cycle Management & Shelf Management Production planning & Personnel scheduling	Primary Capabilities: Immutability & Transparency, Traceability Supporting Capabilities: Integration/interoperability	Detect=> Information, Technology React=> Efficiency Responsiveness Flexibility Collaboration	Economic: No Supply- Demand Mismatch Social: Food Accessibility Environmental: Minimization of Food Waste
	Context 3	Interventions	Mechanisms	Outcomes
	Liquidity	Primary Capabilities: Consensus mechanism, Smart contracts Supporting Capabilities: Integration/interoperability, Consensus mechanism, Smart contracts	Detect=> Information, Technology React=> Collaboration	Economic: Improved Liquidity Social: Food security

	Context 1	Interventions	Mechanisms	Outcomes
WIP	Food Quality Food Provenance & Fraud Threat Food Safety & Hygiene Food Recall	Primary Capabilities: Visibility, Traceability Supporting Capabilities: Smart Contracts Disintermediation/Decentralisation	Detect=> Information, Technology React=> Responsiveness	Economic: Brand equity Social: Food Safety Environmental: Minimization of Food Waste
	Supply- Demand Mismatch Food Loss & Waste Life Cycle Management& Shelf Management Production planning &Personnel scheduling	Primary Capabilities: Immutability & Transparency, Traceability Supporting Capabilities: Integration/interoperability	Detect=> Information, Technology React=> Efficiency Responsiveness Flexibility Collaboration	Economic: No Supply- Demand Mismatch Social: Food Accessibility Environmental: Minimization of Food Waste

Upstream	Context 1	Interventions	Mechanisms	Outcomes
	Food Quality Food Safety & Hygiene	Primary Capabilities: Visibility, Traceability	Detect=> Information, Technology React=> Responsiveness	Economic: Consumer Trust Social: Food Safety Environmental: Minimization of Food Waste
	Context 2	Interventions	Mechanisms	Outcomes
Supply- Demand Mismatch Food Loss & Waste Production planning & Personnel scheduling	Primary Capabilities: Immutability & Transparency, Traceability	Detect=> Information, Technology React=> Flexibility	Economic: No Supply- Demand Mismatch Social: Food Accessibility Environmental: Minimization of Food Waste	
Context 3	Interventions	Mechanisms	Outcomes	
Financing Operating Costs Liquidity	Primary Capabilities: Consensus mechanism, Smart contracts Supporting Capabilities: Integration/interoperability, Consensus mechanism, Smart contracts	Detect=> Information, Technology React=> Collaboration	Economic: Better Financing, Lower Operating Costs, Improved Liquidity Social: Food security	

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Table 1: Operational Excellence Enablers

Construct	Variables	Main References
Responsiveness	Product availability	Abiral & Atalan-Helicke 2020, Chin 2020; Deaton & Deaton 2020
	Customer response time	Gholami-Zanjani <i>et al.</i> 2020, Stranieri <i>et al.</i> 2021, Esmaili & Sahraeian 2017, Bumblauska <i>et al.</i> 2020
	Food & Loss Waste	Tian 2016, Astill 2019, Astarita <i>et al.</i> 2020
	Food Recall	Bumblauska <i>et al.</i> 2020, Qian <i>et al.</i> 2020, Duan <i>et al.</i> 2020
Efficiency	Cost efficiency	Zanoni & Zavanella 2012, Govindan <i>et al.</i> 2014, Bozorgi <i>et al.</i> 2014, Bortolini <i>et al.</i> 2015, Saif & Elhedhli 2015, Camanzi <i>et al.</i> 2017, Accorsi <i>et al.</i> 2017, Rahimi <i>et al.</i> 2017, Esmaili & Sahraeian 2017, Wang <i>et al.</i> 2017, Musavi & Bozorgi-Amiri 2017, Patidar & Agrawal 2020
	Elimination of intermediaries and auditors	Zhu 2017, Bumblauska <i>et al.</i> 2020
	Energy consumption & GHG emission	Zanoni & Zavanella 2012, Haass <i>et al.</i> 2014, Bozorgi <i>et al.</i> 2014, Govindan <i>et al.</i> 2014, Bortolini <i>et al.</i> 2015, Saif & Elhedhli 2015, Liljestrang <i>et al.</i> 2015; Adekomaya <i>et al.</i> 2016, Accorsi <i>et al.</i> 2017, Camanzi <i>et al.</i> 2017, Rahimi <i>et al.</i> 2017, Ghadge <i>et al.</i> 2017, Wang <i>et al.</i> 2017, Gallo & Accorsi 2017, Musavi & Bozorgi-Amiri 2017, Cannas <i>et al.</i> 2020, Jouzdani & Govindan 2020, Melkonyan <i>et al.</i> 2020
	Resource Recovery & Efficiency	Hrabec <i>et al.</i> 2020, Kandemir <i>et al.</i> 2020, Krishnan <i>et al.</i> 2020, Mallidis <i>et al.</i> 2020
Flexibility	Life Cycle Management	Gallo & Accorsi 2017, Yang, Xiao, & Kuo 2017, Chowdhury <i>et al.</i> 2020, Hendalianpour 2020
	Shelf Space Management	Gallo & Accorsi 2017, Gholami-Zanjani <i>et al.</i> 2020
	Personel Scheduling	Siddh <i>et al.</i> 2018, Chowdhury <i>et al.</i> 2020; Heck <i>et al.</i> 2020, Gray 2020, Moon <i>et al.</i> 2020, Zucchi <i>et al.</i> 2020
Collaboration	Coordination	Zhang & Su 2020
	Collaboration (Vertical/Horizontal)	Borrero 2019, Juma <i>et al.</i> 2019, Bumblauska <i>et al.</i> 2020, Dania <i>et al.</i> 2020, Daghar <i>et al.</i> 2020, Dossa <i>et al.</i> 2020, Kumar <i>et al.</i> 2021, Lu <i>et al.</i> 2021, Ramos <i>et al.</i> 2021, Wang & Zhao 2021
	Public Private Partnership	Narrod <i>et al.</i> 2009, Pant <i>et al.</i> 2015, Rais & Jain 2019
	Fairness/ Fair Trade	Wang <i>et al.</i> 2016, Tao <i>et al.</i> 2019, Katsikouli <i>et al.</i> 2019, Bumblauska <i>et al.</i> 2020, Hernandez-Martinez <i>et al.</i> 2020
Technology	Food Safety & Fraud Threat	Wang & Yue 2017, Juma <i>et al.</i> 2019, Katsikouli <i>et al.</i> 2019, Bumblauska <i>et al.</i> 2020, Behnke & Janssen 2020, George <i>et al.</i> 2020
	Food Quality	Musavi & Bozorgi-Amiri 2017, George <i>et al.</i> 2019, Bumblauska <i>et al.</i> 2020, Behnke & Janssen 2020

	Plant Safety & Hygiene	Bastian & Zentes 2013, Bumblauska <i>et al.</i> 2020
Information	Accuracy, accessibility and actuality of SC data	Bastian & Zentes 2013, Xiao <i>et al.</i> 2017, Galvez <i>et al.</i> 2018, Borrero 2019, Katsikouli <i>et al.</i> 2019, Bumblauska <i>et al.</i> 2020, Behnke & Janssen 2020, Mangla <i>et al.</i> 2021
	Data Security	Richey <i>et al.</i> 2016, Fernando <i>et al.</i> 2018, Fitzgerald <i>et al.</i> 2018
	Digital Continuity	Fazili <i>et al.</i> 2017; Liao <i>et al.</i> 2017; Minner <i>et al.</i> 2017; Qu <i>et al.</i> 2017; Strozzi <i>et al.</i> 2017; Tran-Dang <i>et al.</i> 2017; Yang <i>et al.</i> 2017

Table 2: Studies using application areas of CIMO-logic

Authors	Application Area
Rajwani & Liedong (2015)	To present evidence of the impact of Corporate political activity on firm value through a literature review using CIMO-logic
Holmström et al. (2017)	To evaluate the potential of direct digital manufacturing-based practices through a literature review using CIMO-logic
Pilbeam et al. (2019)	To design safer working interventions through a literature review using CIMO-logic
Bin Makhashen et al. (2020)	To explore the role of ambidexterity and coopetition in designing resilient fashion supply chains through a literature review using CIMO-logic
Ivert & Jonsson (2014)	to investigate how Advanced planning and scheduling systems support planning tasks and when to be used in sales and operations planning through single-case study using CIMO-logic
Santti et al. (2017)	to explore the effects of business model development project activities on organizational culture through multi-case study using CIMO-logic
Brusset & Bertrand (2018)	To provide a methodology to evaluate the weather effects on supply chains and design the relevant bespoke financial instrument to mitigate the effects of adverse weather through multi-case study using CIMO-logic
Costa et al. (2020)	To design an collaborative networks between industrial business associations and SME mediated by digital platforms through case study using CIMO-logic
Konietzko et al. (2020)	To identify principles for circular ecosystem innovation through case study using CIMO-logic
Tanila et al. (2020)	To explain the value formulation of digital health interventions through multi-case study using CIMO-logic
Reich et al. (2021)	To develop a solution framework for global supply chain network design problem through case study using CIMO-logic

Table 3: CIMO Analysis of the Single Use Case for the Supply Chain Participants

Context narrated by PFSC participant	PFSC participant	Intervention narrated by PFSC participant	Intervention Blockchain Capabilities synthesized from previously published research	Mechanism Operational Excellence Enablers synthesized from previously published research	Outcome Sustainable Operational Excellence Outcomes narrated by PFSC participant
Food Loss	Farmer, Cooperative, Food Processor, Retailer	Additional yields can be announced on the blockchain	Immutability & Transparency	Information, Technology	Supply and demand are matched. Consumers access quality produce, while farmers increase their profits
Food Loss & Waste	Food Processor, Retailer, logistics provider	Digital twin of the PFSC can be created	Immutability & Transparency, Integration/ Interoperability	Collaboration, Efficiency	It provides solutions for users in order to detect and communicate inefficiencies in fresh products and certify the information holds true on the blockchain system
Life Cycle Management & Shelf Management	Food Processor, Retailer	Digital twin of the PFSC can be created	Traceability, Asset Management	Responsiveness, Flexibility	instant knowledge on product's exact origin, treatment, quality, handling, and age
Food Quality	Farmer, Cooperative, Food Processor, Retailer, Logistics Provider	Precision water, soil, and pest control measures can be recorded	Traceability	Information, Technology	Farmers get information on everything from temperature, soil quality to humidity and how it affects the quality of the produce
Food Provenance & Fraud Threat	Food Processor, Retailer	Digital twin of the FSC can be created, blockchain ledger hold information on organic certification	Traceability, Disintermediation/ Decentralisation	Information, Technology	Consumers understand the origin of their food, who handled the food and what is in their food.

Context narrated by PFSC participant	PFSC participant	Intervention narrated by PFSC participant	Intervention	Mechanism	Outcome
Fairness & Fair-Trade	Farmer, Cooperative, Food Processor, Retailer	blockchain ledger hold information on sustainable practices and animal welfare practices	Transparency, Visibility	Information, Technology	Alignment with consumer values, brand equity
Food Safety & Hygiene	Farmer, Cooperative, Food Processor, Retailer, Logistics Provider	Together with IoT sensors the environment in which the food was grown, transported and processed can be captured	Visibility, Traceability	Information, Technology	Consumer trust
Food Safety & Hygiene	Farmer, Cooperative, Food Processor, Retailer, Logistics Provider	the blockchain ledger holds information on who handled the food	Visibility, Traceability, Smart Contracts	Responsiveness	In case of COVID-19 incidents among PFSC participants, possible contaminated food and packaging can be identified in seconds
Food Recall	Food Processor, Retailer, Logistics Provider	Digital twin of the PFSC can be created	Traceability, Integration/ Interoperability	Responsiveness	Enables more faster and efficient food recalls. Only the tainted or contaminated food is discharged as opposed to the standard operating procedure of the mass recall
COVID-19 Absenteeism	Farmer, Cooperative, Food Processor, Retailer, Logistics Provider	Blockchain ledger holds information on employees and can predict the infection risk among employees and identify possible bottlenecks	Visibility, Traceability	Flexibility	Contingency plans to prevent stock out occurrences due to COVID-19 Absenteeism
Disparate Systems	Retailer	It allows the ecosystem to have one source of data	Immutability & Transparency, Integration/ Interoperability, Data Standardisation/ Security/ Sharing	Collaboration, Efficiency, Information, Technology	It offers interoperability for all participants.

Context narrated by PFSC participant	PFSC participant	Intervention narrated by PFSC participant	Intervention	Mechanism	Outcome
Financing	Farmer, Cooperative	Data on previous loans and forecast on produce based on historical data can be provided to banks and other lending agencies	Immutability & Transparency Integration/ Interoperability, Consensus mechanism	Collaboration, Technology, Information	Access to loan, improve livelihoods of small farmers and producers
Operating Costs	Farmer, Cooperative	Precision water, soil, and pest control measures can be recorded	Immutability & Transparency	Efficiency	Decrease input and labour costs through precision water, soil, and pest control measures
Liquidity	Farmer, Cooperative, Retailer	Utilize smart contracts to shorten the time between fulfilment and receipt of payment	Smart Contracts, Consensus Mechanism	Collaboration	Improves livelihoods of small farmers and producers

Table 4: The Formation of Design Propositions

Context 1	Interventions	Mechanisms	Outcomes
Food Quality Food Provenance & Fraud Threat Food Safety & Hygiene Food Recall	Primary Capabilities: Visibility, Traceability Supporting Capabilities: Smart Contracts Disintermediation/Decentralisation	Detect=> Information, Technology React=> Responsiveness	Economic: Brand equity Social: Food Safety Environmental: Minimization of Food Waste
Context 2	Interventions	Mechanisms	Outcomes
Supply- Demand Mismatch Food Loss & Waste Life Cycle Management & Shelf Management Production planning & Personnel scheduling	Primary Capabilities: Immutability & Transparency, Traceability Supporting Capabilities: Integration/interoperability	Detect=> Information, Technology React=> Efficiency Responsiveness Flexibility Collaboration	Economic: No Supply-Demand Mismatch Social: Food Accessibility Environmental: Minimization of Food Waste
Context 3	Interventions	Mechanisms	Outcomes
Financing Operating Costs Liquidity	Primary Capabilities: Immutability & Transparency Supporting Capabilities: Integration/interoperability, Consensus mechanism, Smart contracts	Detect=> Information, Technology React=> Collaboration	Economic: Better Financing, Lower Operating Costs, Improved Liquidity Social: Food security

Table 5: Sensitivity Analysis

Propositions #	Whole PFSC	PFSC Stages		
		Upstream	WIP	Downstream
P1	complete	partial	complete	complete
P2	complete	partial	complete	complete
P3	complete	complete	no evidence	partial
P4	complete	complete	partial	partial
P5	complete	complete	partial	partial

Figure 1: Research Design

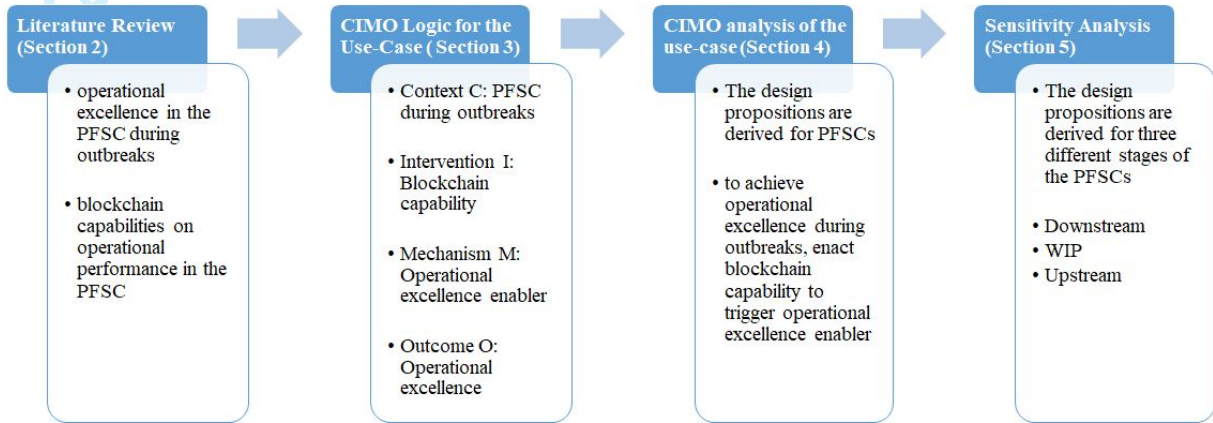


Figure 2: Flowchart for Article Selection

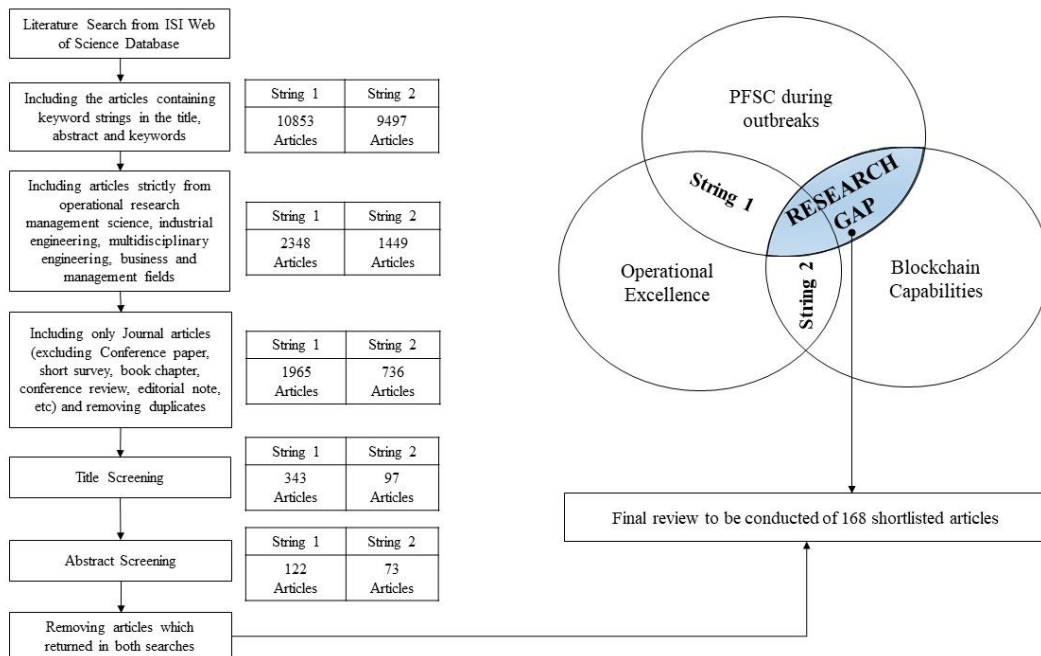


Figure 3: System Dynamics of PFSC during Outbreaks

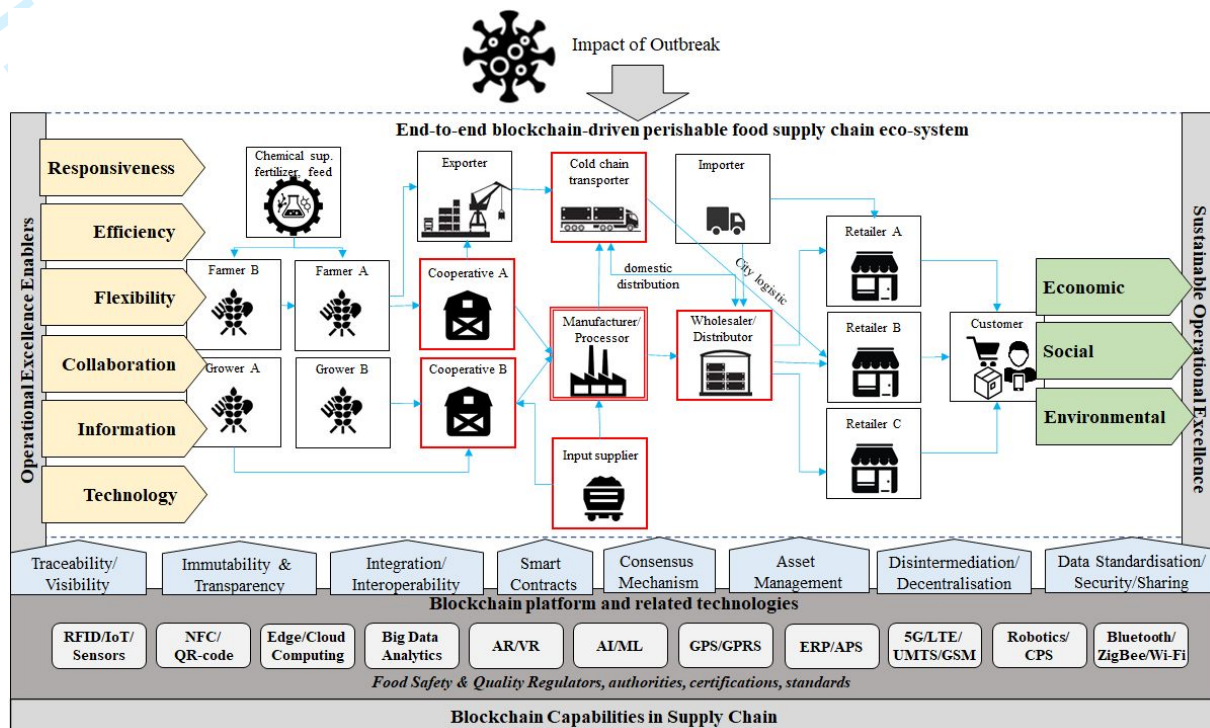


Figure 4: CIMO-Configuration for Use-Case (based on Denyer *et al.* 2008)

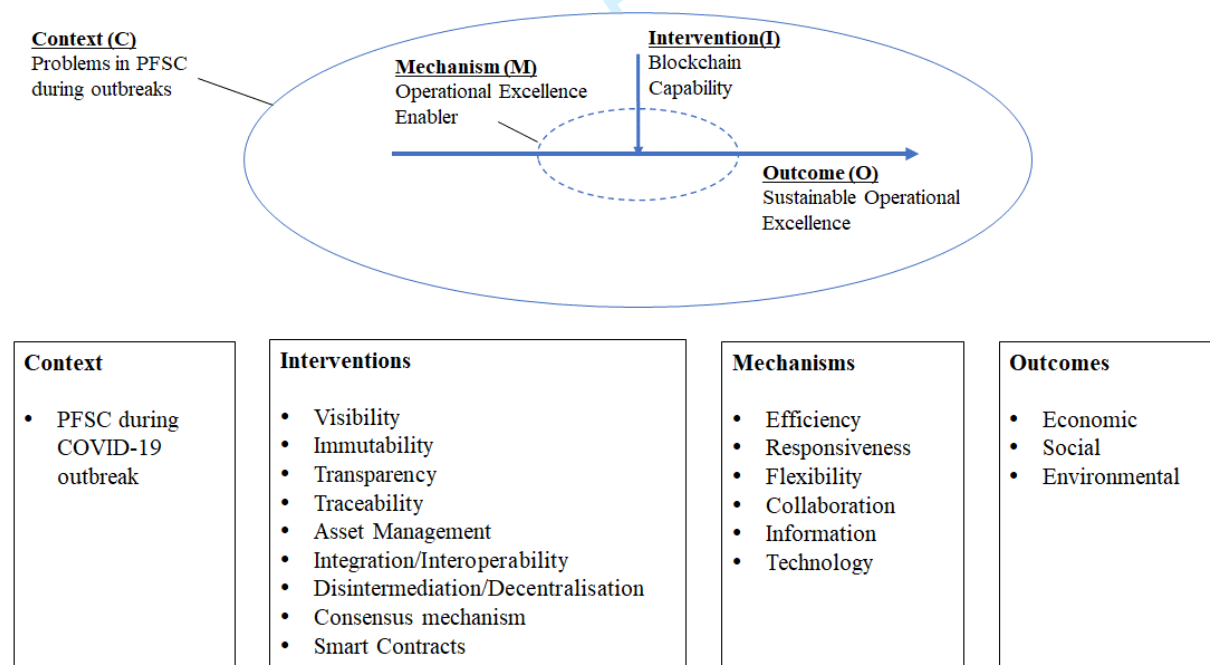


Figure 5: Flowchart for Use Case Analysis

