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Decision-making framework for a resilient sustainable production system during COVID-19: An evidence-based research

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ABSTRACT

This work presents a decision-making framework for integrating resilience and sustainability in managing production systems during COVID-19. An operationalization scheme manifested via a case study at a manufacturer in the food production sector supports the proposed framework. The focus is laid on the tactical and operational decisions within the production system. Through the discussion of the introduced changes to mitigate risks emanating from COVID-19, a set of findings related to the deployment of digital solutions, new dimensions of sustainability and resilience, the introduction of new workforce scheduling rules, the importance of alignment and coordination across supply chain members, and the approach of risk management are identified. This work contributes to a better understanding of the decision-making process during the pandemic and to building up knowledge for the management of resilient and sustainable production systems.

1. Introduction

The integration of sustainability and resilience in supply chain design and management represents one of the essential and recently introduced paradigms (Ivanov, 2018a). Literature and practice have shown the joint occurrence of the two important concepts of sustainability and resilience (Roostaie et al., 2019). Supply chain sustainability is defined as maintaining business continuity in order to reduce long-term business risks (Ivanov et al., 2017; Ivanov, 2018b, 2018a); while supply chain resilience is “the ability of a system to return to its original state or move to a new, more desirable state after being disturbed” (Christopher & Peck, 2004). Both concepts are multi-dimensional and correlated (Roostaie et al., 2018; Balugoni et al., 2020) with several intersections between them (Ivanov, 2018b) and play a key role in strategic decision-making (Ardebili & Padoano, 2020). Supply chain sustainability and resilience have recently attracted researchers’ interest due to the significant increase in supply chains’ complexity (Ramezankhani et al., 2018; Ivanov & Dolgui, 2019). Globalization, outsourcing, and Information and Communications Technology (ICT) led to supply chain developments to be extended, interconnected, more complex, and thus more vulnerable to disruptive events (Thomas et al., 2016; Behzadi et al., 2018; Singh et al., 2019; Vishnu et al., 2019). Furthermore, the growing concern about sustainability has led to organizations and supply chains considering management of sustainability-related supply chain risks, which focus on the effect of risks on the ecosystem, corporate reputation, and compliance with laws (Giannakis & Papadopoulos, 2016).

The COVID-19 outbreak globally has led to unprecedented supply chain disruptions with a series of shocks worldwide, testing thus the resilience and sustainability of supply chains (Ivanov, 2020a). Concerns about human health, which have been identified as the most strongly correlated factor to social sustainability (Staniˇksiene & Stankeviˇciute, 2018), increased drastically, leading to more attention to social sustainability. Business continuity has been severely disrupted, and all areas of the economy and society have been immensely affected, raising a series of completely novel decision-making settings for supply chain researchers and practitioners (Ivanov, 2020a). Realizing the negative impacts of disruptions, companies more than ever, attempt to create and be part of more resilient supply chains (Christopher & Peck, 2004; Jabbarzadeh et al., 2018). Hence, there is a growing trend calling for the development and improvement of integrating the two drivers of sustainability and resilience (Mohammed, 2019). The development of models and decision-supporting tools can improve decision-making for resilient and sustainable supply chains (Ivanov, 2018b). Zavala-Alcivar et al. (2020) emphasized the need to improve sustainability and resilience by managing strategic, tactical, and operational processes in

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supply chains. However, research on combined supply chain sustainability and resilience is still limited, and literature lacks frameworks that consider the operationalization of the decision-making process for resilient and sustainable production systems and supply chains.

Food production systems and agri-food supply chains were identified as important applications for integrating sustainability and resilience due to their importance and criticality (Duminy & Grosser, 2018; Das, 2019; Hassan et al., 2019). This was evident in agri-food literature due to growing supply chain volatility (Stone & Rahimifard, 2018) as sustainability (Akerman et al., 2010; Zhu et al., 2018; Zhu & Krikke, 2020) and resilience (Zhao et al., 2017; Bezdzi et al., 2018; Stone & Rahimifard, 2018; Gimenez-Escalante et al., 2020; Singh et al., 2020) have received significant attention in recent years to address risk and vulnerability issues. The importance of resilient and sustainable food supply chains has increased significantly due to the COVID-19 outbreak (Singh et al., 2020), given their vital role in both regional and global economies, direct impact on the daily lives of the entire society (Zhu et al., 2018), and being a critical requirement for the survival and wellbeing of society (Das, 2019).

This paper presents evidence-based research through practice-based analysis to help understand the impact of the COVID-19 pandemic on production systems and supply chains. It further identifies new solutions, novel practices, and management strategies for increasing the sustainability and resilience of production systems and food supply chains. The contribution of this research is twofold. First, it develops a decision-making framework for production systems management within supply chains integrating sustainability and resilience dimensions to cope with traditional and sustainability-related risks during low-frequency-high-impact events as pandemics. Second, it introduces an operationalization scheme of a sustainable and resilient production system illustrated via a case study during the outbreak of COVID-19.

The remainder of the paper is organized as follows. Section 2 reviews the literature focusing on sustainability and resilience relationship and their integration in supply chain management. Section 3 presents the adopted research method. Section 4 describes the proposed decision-making framework, while Section 5 delineates the case findings encompassing the operationalization of the proposed framework using the case study and the decisions made in the case company to encounter the impact of the COVID-19 pandemic. Section 6 discusses the research findings, and finally, conclusions are drawn in Section 7.

2. Literature review

2.1. Sustainability-resilience relationship in supply chain management

Marchese et al. (2019); Roostaie et al. (2019); Roostaie et al. (2018); and Renn (2020) identified different views and concepts of the relationship between sustainability and resilience. In the context of supply chain management, four different views have been reported in the recent literature as will be shown next: (1) resilience is a basis for sustainability, (2) sustainability is a basis for resilience, (3) resilient practices influence on sustainability varies, and (4) tensions and trade-offs between them exist and may complicate their integration.

The first view considers resilience as an essential enabler for supply chains to become sustainable. In the last two decades, resilience became a pivot point in sustainable development (Ardebili & Padoano, 2020) and a success factor to advance sustainable competitive advantages (Rajesh, 2019) through the ability to respond rapidly and effectively to threats and to mitigate them effectively (Thomas et al., 2015). Business continuity, which is one of the fundamental characteristics of supply chain resilience, can help achieve supply chain sustainability (Ivanov, 2018a). Besides, Duminy and Grosser (2018) suggested that resilience is a basis for sustainability in production supply chains for essential consumer goods, and Thairaprayoon et al. (2019) claimed that supply chain resilience has a significant impact on sustainability performance. Thus, the resilience of supply chain operational processes is a requirement for achieving supply chain sustainability (Zavala-Alcívar et al., 2020).

The second view considers sustainability as an essential enabler for supply chains to become resilient. With increased economic, social, and environmental wellbeing, supply chains were less likely to be impacted by the range of possible business disturbances (Marchese et al., 2019). Sustainability initiatives and practices can influence supply chain capability to face unexpected disruptions; Marchese et al. (2019) give the following examples for the three pillars of sustainability fostering supply chain resilience. A supply chain with a diverse economic portfolio (economic sustainability) faces potentially reduced impact resulting from industry or location-specific depression. For an environmentally sustainable manufacturer avoiding toxic materials, the effect of profit loss due to chemical spills is potentially minor. A company that provides quality occupational safety and healthcare for its employees (social responsibility) has better potential to overcome losses in the workforce due to a disease outbreak. Hence, to analyze supply chain sustainability, it is necessary to address the effect of sustainability initiatives on system resilience (Fahimnia & Jabbarzadeh, 2016). Therefore, operational sustainability practices are considered a component of and promoter of a firm’s resilience (Balugani et al., 2020).

The third view acknowledges that resilient practices may influence supply chains sustainability but claims that this is not always the case. Although resilience and sustainability are considered strictly correlated, their relationship may be complex and may vary according to the context due to the multidimensionality of the two concepts, different definitions, and fields of applicability (Balugani et al., 2020). Hence, a supply chain being resilient does not mean it is sustainable. Zavala-Alcívar et al. (2020) highlighted different examples where resilient practices have different impacts on the sustainability of supply chains. For instance, redundancies required to deal with disruptions increase resource consumption and inventory use, which affect a fundamental principle of sustainability, namely the efficient use of available resources in the supply chain. On the other hand, maintaining redundancies in the supply chain implies having geographically dispersed suppliers and flexible supply policies to ensure continuity of operations, positively affecting the social dimension of sustainability.

The fourth view considers sustainability and resilience as two contradicting objectives that cannot be easily integrated. Roostaie et al. (2019) and Roostaie et al. (2013) highlighted some indications of tensions between sustainability and resilience in supply chains and suggested that those tensions may complicate their integration. These include having different goals and research focuses, different assumptions of normality, approaches in pursuing their objectives, and emphasizing different values (Roostaie et al., 2019). Balugani et al. (2020) highlighted trade-offs between sustainability and resilience on a small scale. Thus, the integration of sustainability and resilience should achieve a compromise (Zavala-Alcívar et al., 2020).

2.2. Integration of sustainability and resilience in supply chain management

Despite the different views and interpretations of sustainability and resilience, most supply chain management literature supports sustainability and resilience integration (Roostaie et al., 2019). Zavala-Alcívar et al. (2020) highlighted the need to integrate resilience and sustainability in supply chain management to increase competitiveness.

Research efforts in integrating sustainability and resilience in supply chains have been identified in the literature. Fahimnia and Jabbarzadeh (2016) investigated how supply chain sustainability analysis and resilience improvement can be integrated for developing resilient, sustainable supply chains at the strategic supply chain design level. Ivanov (2018a) proposed a resilient supply chain structure design regarding ripple effect mitigation and sustainability increase. Jabbarzadeh et al. (2016) addressed the interactions between supply chain resilience and sustainability performance at the strategic network design phase. Shin and Park (2019) addressed improvement planning for supply chain
resilience for higher sustainability and competitive advantage. Rajesh (2019) focused on identifying social and environmental risk management drivers in resilient supply chains and acknowledging the importance of these drivers towards implementing enterprise social and environmental risk management practices. Although sustainability and resilience practices significantly influence the different levels of decision-making, literature has mainly focused on the strategic level, while little work has addressed both tactical and operational levels.

In the context of production systems, research on sustainability and resilience integration is limited. Hassan et al. (2019) suggested a strategy for optimal production maximizing resilience and sustainability in industrial dairy farms. Thomas et al. (2016) identified the tools, methods, and models that UK manufacturing companies adopt and apply to achieve resilient and economic sustainability. Gimenez-Escalante et al. (2020) proposed a distributed localized manufacturing strategy to increase the sustainability and resilience of food production.

2.3. Performance measurement

Measuring the performance of resilience and sustainability across the supply chain or within the production system is key to continuous improvement. Numerous measures have been developed to assess sustainability (Erol et al., 2011; Schaltegger & Burritt, 2014; Ahi & Searcy, 2015; Malak-Rawlikowska et al., 2019) and resilience (Son et al., 2014; Cardoso et al., 2015; Li et al., 2017; Singh et al., 2019; Han et al., 2020) across the supply chain. Due to the multi-dimensional nature of both concepts, in addition to the conflicting views on the relationship between sustainability and resilience, no unified measure can be found in the literature (Roostaie et al., 2018). Guidelines for defining metrics for integrating sustainability and resilience have not been explicitly defined in the literature reviewed (Zavala-Alcivar et al., 2020). The integration of sustainability and resilience mandates the development of new combined tools or modifying the existing sustainability frameworks to include resilience indicators and provide a more comprehensive understanding of the relevant capabilities (Roostaie et al., 2018; Balugani et al., 2020).

The literature shows some efforts in integrating both concepts in the supply chain design (Fahimnia & Jabbarzadeh, 2016; Ramezankhani et al., 2018; Ivanov, 2020a) and operations management (Hassani et al., 2019; Zhu & Krikke, 2020). Selected performance measures have been used to assess sustainability and resilience. Costs (Fahimnia & Jabbarzadeh, 2016; Ivanov, 2020a), logistics service provider shipment time (Zhu & Krikke, 2020), number of employees, and employee satisfaction (Ramezankhani et al., 2018) represent different Key Performance Indicators (KPIs) used for sustainability. For resilience measurement, lost sales rate (Zhu & Krikke, 2020), average inventory (Ramezankhani et al., 2018), and service level (Ivanov, 2020a) have been commonly used.

The integration approach has been achieved mainly via multi-objective optimization (Fahimnia & Jabbarzadeh, 2016) or hierarchical objective function (Hassani et al., 2019) integrating the different sustainability and resilience measures.

2.4. Research gaps

Based on the conducted review, the following research gaps have been identified. In the last five years, research on a joint supply chain sustainability and resilience analysis has emerged (Zavala-Alcivar et al., 2020) and is still at the beginning of its development (Ivanov, 2018a; Jabbarzadeh et al., 2018). There is still a gap in the knowledge of specific tools, techniques, and models and their application by manufacturing organizations to achieve sustainable and resilient organizations (Thomas et al., 2016). The broader impact of sustainability interventions on the supply chain’s overall resilience has remained unexplored (Fahimnia & Jabbarzadeh, 2016). The literature lacks frameworks developed based on industry collaboration (Thomas et al., 2016) and lacks conceptual frameworks for integrating sustainability and resilience (Roostaie et al., 2018; Roostaie et al., 2019; Zavala-Alcivar et al., 2020). A performance measurement framework that can address sustainability and resilience dimensions concurrently in the supply chain context is lacking (Ramezankhani et al., 2018). Despite the strong correlation between sustainability and resilience in supply chain management, literature addressing the tools and models for the joint consideration of these two aspects is just starting to develop (Mohamed, 2019).

Moreover, more investigations are needed at the tactical and operational planning levels to explore how trade-off decisions can be affected by disruptions (Fahimnia & Jabbarzadeh, 2016). Adopting sustainability and resilience concepts at an operational level, which is lacking in literature (Thomas et al., 2016), has recently become mandatory for supply chains to survive in the highly dynamic competitive market environment (Ramezankhani et al., 2018). Furthermore, the impact of COVID-19 on production and supply chain activities is still not discussed enough (Singh et al., 2020). Therefore, emerging disruptions and risks stemming from the COVID-19 pandemic have doubled the importance and need for research on sustainability and resilience integration.

3. Research method

The current work emphasizes developing a decision-making framework for sustainable and resilient production systems given the COVID-19 outbreak. The development of the proposed framework is primarily based on the literature review covering the relationship between sustainability and resilience and their integration. It was further developed through industrial collaboration. The industrial partner has successfully implemented a number of measures to mitigate the impact of COVID-19. These included risk management, monitoring of COVID-19 cases, as well as taking tactical and operational decisions including digitalization of its activities. Based on the literature review findings and the implemented industrial practices, the authors developed a framework streamlining the decision-making process for a resilient and sustainable production system. Fig. 1 illustrates the methodology applied in this work. Findings from the case study offer guidelines and implications for practitioners seeking sustainability and resilience to face similar potential disruptions.

3.1. Case study design

A single case research method is adopted to explore the different mitigation strategies that the industry has implemented to mitigate the effect of COVID-19. As revealed through the literature review, research on integrating sustainability and resilience has recently emerged (Zavala-Alcivar et al., 2020) and is still at the beginning of its development (Ivanov, 2018a; Jabbarzadeh et al., 2018). Hence, the exploitation of the decision-making process, which jointly considers sustainability and resilience is essential. Furthermore, the literature lacks frameworks developed based on industry collaboration (Thomas et al., 2016) and lacks conceptual frameworks for integrating sustainability and resilience (Roostaie et al., 2018; Roostaie et al., 2019; Zavala-Alcivar et al., 2020). Case-based research has been identified as a suitable means for serving the purpose of exploration, i.e., uncovering areas for research and theory building (Voss et al., 2002). It lends itself...
to the current situation of exploring the decisions made to mitigate the unprecedented risks initiated through the pandemic outbreak while ensuring production system sustainability. Specifically, a single case study has been selected to allow for an in-depth investigation that matches the exploration requirements (Voss et al., 2002).

The research framework is described in Fig. 2. Since the case study approach possesses the strength of answering the why, what, and how questions with a relatively complete understanding of the “nature and complexity of the complete phenomenon” (Benbasat et al., 1987; Meredith, 1998), it was intended to investigate how the tactical and operational decisions to face the COVID-19 disruptions were affected and how these decisions are guided by sustainability and resilience.

Data was collected through semi-structured interviews and content analysis of documents. The funnel model was adopted in the interview design. Having identified the initial set of research questions, first, broad questions were posed regarding the nature of the plant and how it was affected by the pandemic. Then, questions were focused on the details of implementation strategies.

A list of questions used in the semi-structured interview is presented in the Appendix A. A series of zoom-based interviews were conducted. Meetings expanded over a 3-months period starting in July 2020. The data collected and analyzed reflected the decisions and actions the company made to mitigate the impact of the first wave of COVID-19. The principal informant in this case research is the plant manager, who has complete information about tactical and operational decisions made during the effort to mitigate potential disruptions resulting from the pandemic outbreak. A total of eight meetings took place, each having an average duration of 60 min. Other interviewees covered the middle and operational management, specifically the Safety and Health Environment Manager, the Manufacturing Manager, the Quality Manager, the Technical Manager, and the Manufacturing Excellence Manager. The case validation has been achieved through the Safety and Health Environment Manager and the Regional Manufacturing Excellence Director.

3.2. Case description

The operationalization of the proposed decision-making framework for a resilient, sustainable production system presented in the previous section is demonstrated via a case study at one of the food and beverage manufacturers belonging to a global supply chain. During the pandemic, this food supply chain importance and criticality increased due to changes in consumer behavior as panic buying and the occurrence of supply, production, and transportation disruptions.

The production facility under study is Lipton Jebel Ali (LJA) Factory, located in UAE and belonging to Unilever. Unilever has 30 tea factories worldwide. LJA factory is one of Unilever’s top 5 tea factories worldwide for volume, sales, and degree of development. It is a global supply chain member with around 26 suppliers and fulfilling demand for about 40 countries, expanding over the six continents. LJA follows the sustainability policy set by Unilever as well as the concepts of World Class Manufacturing (WCM). Furthermore, the factory has taken steps towards the digitalization of its activities, starting in 2017. Prior to the global pandemic outbreak, the strategies followed by the production system were:

1. Agile manufacturing: a responsive supply chain that delivers quick changeovers, launches products faster, easily flexes capabilities to accommodate customer and consumer expectations, and rapidly adapts to new market conditions.
2. Reshape cost and asset base: exploit asset base to drive margins, cash, savings, and return on assets while transforming the manufacturing operation to the digital age.
3. Care for people and the planet: deliver the company’s commitments as set out in Unilever Sustainable Living Plan (USLP) and Unilever Compass.

Hence, the factory under study has sustainability and resilience aspects incorporated in its management practices. Before the pandemic outbreak globally and particularly in the UAE, the supply chain network was streamlined and optimized. However, during and post the first wave of COVID-19, consumer needs and spending levels have changed, some patterns of panic-buying were observed in the market as customers and consumers started to up-stock necessity products, suppliers faced multiple delays due to operational issues, and logistical delays arose due to curfew and the increase in clearance lead times. All those factors demanded a shift in the supply tactics and priorities that will be outlined in Section 5.

The present case study aims at illustrating the challenges the production system faced during the COVID-19 outbreak and how decisions on tactical and operational levels have been affected in light of the virus risk and the resulting supply chain disruptions, particularly production disruption. The case study has also been used to discuss how the established approaches of sustainability, safety practices, and digitalization have paved the way for managing a resilient, sustainable production system during the pandemic.

4. Decision-making framework for resilient sustainable production systems

The supply chain risks categorized as process, supply, demand, control, and environmental risks (Christopher & Peck, 2004) affect different stages of the supply chain, causing different types of disruptions, including supply, transportation, production, and demand disruptions. Another set of supply chain risks has arisen from the thrive for sustainability, which is sustainability-related risks. These focus on the effect of risks on the ecosystem, corporate reputation, and compliance with laws (Giannakis & Papadopoulos, 2016). Sustainability-related risks may be mapped to the three pillars of sustainability and categorized into operational, social, and environmental risks, where operational risks reflect the economic dimension (Xu et al., 2019). The outbreak of pandemics has been identified as an example of an exogenous social risk for supply chains (Giannakis & Papadopoulos, 2016). Hence, besides the evident effect of the COVID-19 outbreak on the operational aspects of supply chains and the disruptions it has caused (Queiroz et al., 2020; Singh et al., 2020), the effect of sustainability-related risks cannot be overlooked. Based on these aspects and the conducted literature review, a decision-making framework, as depicted in Fig. 3, is proposed. The developed framework focuses on managing production disruptions emerging from environmental and sustainability-related risks that the manufacturer faces due to the COVID-19 pandemic.

In order to mitigate supply chain risks, an efficient risk management approach has to be adopted. It entails the classical stages of risk identification, assessment, mitigation, and monitoring. The decision-making process is mainly integrated into the stage of risk mitigation. Here, different measures have to be taken to mitigate the effect of risk before, during, and after the disruption. The mitigation approaches affect the management of the supply, demand, product, and information, where disruption management approaches can be proactive or reactive.

The pandemic outbreak has mandated decision-makers to include new dimensions in their decision-making process and integrate them
with existing drivers and policies. The driving forces of society, consumer awareness, and international organizations continue to exist. However, the need for and strive for business survival during the pandemic is becoming an enormous driver for decision-making. Hence, the decision-making process, as illustrated in Fig. 3, is driven by numerous aspects. The first driver is the sustainability driver, which encompasses the balance between economic growth, environmental protection, and social development motivated by the existing pressure from society, workers, and international organizations. Second, the resilience driver aims to ensure the production system can overcome the disruption and cope with the new normal after the pandemic. Resilience has been broken down into various components. Flexibility and robustness have been the most commonly used components of resilience (Carvalho et al., 2014; Heinicke, 2014a, 2014b, 2016; Thomas et al., 2015; Pocillo, 2016; Dolgui et al., 2018; Baghersad & Zobel, 2020). Robustness reflects the production system’s capability to withstand disruptions, i.e., its resistance to changes, while flexibility reflects the capability to smooth interaction to disruptions while controlling cost (Ivanov et al., 2014; Mohammed, 2019). Thus, these two frequently used criteria have been selected in the proposed framework to seek a resilient production system given the global pandemic.

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Additionally, the decision-making process is fed and guided by several existing and emerging guidelines, standards, and legislation related to COVID-19. The guidelines address workplace and worker safety and the standards that ensure product safety. The World Health Organization (WHO) has a leading global role in identifying risks and indicators and setting up workers and public safety guidelines. Similarly, the International Labor Organization (ILO) published several guidelines covering resuming activity in a safe work environment during the pandemic. On the country level, national public health authorities and organizations have also developed guidelines for a safe workplace.

Furthermore, legislation on the country, regional, municipality, and sectoral levels pose restrictions on the decision-making process. These restrictions include lockdown decisions, limiting work hours, curfew, use of public transportation. The two drivers of conforming to legislation and guidelines and standards help mainly in the mitigation decisions of sustainability-related risks, since following these drivers contributes to improving corporate image, product safety, and workers’ health and safety.

The identified drivers guide the decision-making process on strategic, tactical, and operational levels. Hence, on the strategic level, they affect the formulation of organizational policy, the design of the supply network, transportation mode, and setting production capacity, among others. Tactically, identifying inventory policy, setting up the production and maintenance plans are all decisions to be made in light of sustainability, resilience, guidelines, and legislation. Finally, on the operational level, the affected decisions include scheduling machines and the workforce, work design, material, worker flow, and quality control activities. Thus, it is evident that the decision-making process under the current situation is challenging and that all areas and levels of the organization are affected. Applying the health guidelines, such as social distancing, is an operational decision, yet it has implications on setting the production capacity, the product mix, and the inventory and distribution policies. Management needs to keep its workforce safe, ensure business continuity, and be flexible and robust. Thus, the decision-making process aims at providing a resilient, sustainable
A selected set of KPIs is necessary to assess the efficiency of the decision-making process. These should reflect the main drivers of sustainability and resilience and allow for trade-off analysis.

5. Case findings

5.1. Operationalization of the decision-making framework

For the production system to mitigate the potential risk of the supply chain disruptions emanating from the pandemic outbreak, the decision-making and the risk management processes need to be coordinated. During the pandemic, the production system decision-making process has been mainly guided by the legislation and regulations on regional and national levels and global company policies. For food safety, guidelines set by ISO 22,000 for Food Safety Management System, European Food Safety Agency (EFSA), and the European Center for Disease Prevention and Control (ECDC) were followed, and guidelines published by WHO for mitigating the risk of virus transfer among personnel. The social dimension of sustainability has been set at the highest priority as far as the health and safety of personnel and product (food) safety were concerned. Social sustainability under the pandemic was a means of ensuring business continuity and, thus, economic sustainability. The resilience of the production system expressed in terms of flexibility and robustness has been the main driver and sustainability for decision-making on tactical and operational levels, as detailed in Section 5.

Risks that stemmed from the pandemic have been managed on the supply chain level by the Company’s Global Manufacturing Excellence Team, and a set of operational practices have been identified based on the risk level identified through risk assessment. The operational practices are mainly dependent on external (country-related) approaches and workers’ vulnerability for getting infected. The different levels have been named tiers, and operational practices are associated with each tier. The more severe the conditions are (reflected by the number of COVID-19 cases), the stricter the operational practices are. Guided by the developed tier system, the management of the production system has implemented the decision-making framework with an emphasis on risk management and by applying the quality management approach of the Plan-Do-Check-Act (PDCA) cycle as indicated in Fig. 4. The scope of risk management was mainly to mitigate risk during the pandemic. In doing so, lessons are learned to set future policies for pre-disruption mitigation, increasing the preparedness of the production system for future risks and enhancing its resilience.

The first step of the PDCA cycle requires establishing a plan. This is achieved in light of the risk management stage of identifying and assessing risks. The risks have been classified as internal (endogenous)
and external (exogenous) risks. The former pertains to the organization, while the latter originates from external global, regional, and local conditions. Based on the identified risks and data collected from international and regional authorities, risks are assessed, and based on their level, the relevant tier is identified.

Goals are set accordingly and shared within the manufacturing plant. The three goals were: a) people safety, b) protecting Unilever brand, and c) complying with legal requirements. Then, the Do step of the PDCA cycle follows by implementing the operational practices to comply with the identified tier. These practices target the mitigation of the risk of virus transmission within the production system. Risk monitoring is achieved by identifying any occurrence of COVID-19 cases to check the plan’s implementation while practicing tier compliance (the Check step). A detailed plan for identifying and tracing potentially infected personnel is set, as illustrated in the following section. Based on the outcome of the Check step of the PDCA cycle, if a plant shutdown is mandated, the Act step involves following the pre-developed shutdown plan. The plan entails conforming to all procedures required by local and regional authorities, the disinfection of the affected workplaces, and plant restart preparation. The Act step also verifies the completion of all action items and gives feedback to the Plan step to close the PDCA cycle by reporting internal conditions of the production system and problems faced while practicing the operational practices given in the tier system. These result in updating the list of internal risks and thus the plan goals.

5.2. Monitoring of COVID-19 cases in the production system

Risk monitoring activities are of vital importance in the case of the pandemic. It strongly affects the level of risk and the severity of the resulting disruptions. Therefore, having an implementable efficient plan is vital for achieving resilience and sustainability goals and ensuring business continuity. While the company has developed an action plan to reduce the likelihood of any virus transmission, every factory was requested to tailor the plan based on the specific need of its production system. Therefore, management of the production system has developed a detailed plan with clear instructions on the procedures followed in case of a suspected or confirmed COVID-19 case. Fig. 5 presents a flowchart of monitoring and mitigating the risk of virus transmission among workers and employees.

The described procedures differentiate between 4 classes of cases: suspected, confirmed (subject 0), subject 1, and subject 1a cases. Subject 1 refers to personnel being in direct contact with a confirmed case for more than 15 min and within proximity of two meters or less. Subject 1a are personnel who have been in direct contact with subject 1. As described in the flowchart, when any person is suspected of having caught COVID-19, they conduct the PCR test and self-isolate until test results are announced. Simultaneously, tracing is conducted to create a subject 1 list who undergoes a PCR test if the suspected case was confirmed as a COVID-19 case. If the test results are negative for all the suspected and subject 1 cases, they resume work; if not, they are confirmed as COVID-19 cases and have to self-isolate for 14 days and re-conduct the PCR test. They are allowed to return to work when the PCR test result is negative.

In the case of any confirmed COVID-19 cases, the subject 1a list is created. If the list exceeds 5% of the total workforce, then the factory needs to connect with the top management to decide on operations continuity based on the risk and virus transpiration level, which might result in a shutdown to avoid any risks to employees or wider society. In case the shutdown is mandatory, and the PCR test is available for all, then it is to be conducted, and personnel self-isolate until test results are out. Based on the results, all confirmed cases must self-isolate until recovery, while personnel testing negative may resume work based on local and regional regulations, and the shutdown procedure described in the previous section is followed. In case the list of subject 1a is less than 5%, based on the PCR results of subject 1 cases, an action is taken. If Subject 1 tests positive, then subject 1a is considered Subject 1, and contact tracing is conducted for this personnel, and they are required to take the PCR test. If the PCR of subject 1 is negative, no further actions are needed for subject 1a.

In addition to this flowchart, detailed instructions on safely transferring suspected or confirmed cases to reduce the risk of virus transmission have been developed. The detailed instructions and a straightforward procedure of dealing with COVID-19 cases present a tool for risk monitoring and mitigation. It directly affects health and
safety in the production system and other health and safety planning activities that are followed.

5.3. COVID-19-related planning decisions

Several tactical and operational decisions have been made in the production system to prevent or mitigate the negative impact of disruptions associated with the COVID-19 pandemic. Analyzing the different decisions has led to the following observations. Although flexibility and responsiveness were usually chased, the practices adopted during the pandemic followed traditional management tools commonly considered as less flexible to ensure operational effectiveness and continuity during the pandemic. The supply chain of the studied case was transformed from a pull (reactive/demand-based) to a push (proactive/supply-based) system to adapt to the changes in the market, demand, and consumer patterns initiated by the pandemic and to be able to respond efficiently to the emerging disruptions and uncertainties. This has affected tactical decisions such as demand, production, inventory planning, and operational decisions such as shop floor operations, quality control, and health and safety planning. Table 1 presents the main changes in the tactical and operational decisions introduced to mitigate risks during the pandemic. The former or usual policy that has been followed before the outbreak of the pandemic is indicated, along with the new shift in decisions. The table further states the drivers behind each decision along with the measures that reflect the introduced change. Finally, based on a discussion with the principal informant, subjective potential impacts on both sustainability and resilience pillars are presented in Table 1. It is worth noting that the pillars of sustainability and resilience that have been illustrated in Table 1 are the ones that are potentially most directly affected by each decision made. However, other pillars (e.g., economic sustainability) might be affected indirectly by most of the decisions given the multi-dimensional nature of sustainability and resilience.

5.3.1. Tactical decisions

5.3.1.1. Demand planning. In the area of demand planning, two main decisions have been observed. First, changing products portfolio from a complex to a simpler portfolio by reducing the number of Stock Keeping Units (SKUs) produced and focusing on the core and priority ones.

The driver behind this decision is the change in the preferences of consumers. Consumer spending is directly proportional to future confidence in their income. Because of the COVID-19 pandemic, people feel insecure; hence, they favor Value for Money (VFM) SKUs, leading to demand disruptions. This is reflected in the number of SKUs sold. Moving from a pull system (responsive-oriented supply chain) to a push system (efficiency-oriented supply chain) by producing fewer SKUs may positively impact the economic sustainability of the production system and increase its robustness.

Second, the Sales and Operations Planning (S&OP) cycle has been shifted from monthly to weekly and has been transformed into Sales and Operations Execution (S&OE) to adapt to the emerging situations and to allow for better reaction to market changes and potential fluctuations in demand. This is reflected in the number of weeks of the horizon. In addition to achieving robustness and economic advantage, S&OE may improve the production system flexibility during this highly dynamic period.

5.3.1.2. Production planning. Production planning was adjusted to align with the supply chain’s modifications and demand planning decisions by moving from “produce when needed” to “produce when available” tactic. Thus, production runs and Days Between Next Run (DBNR) have been shifted from short to long runs and from more to fewer changeovers,

| Planning Level | Decision Area | From | To | COVID-19 related Driver(s) | Measures | Potential Impact on Sustainability and Resilience Pillars |
|----------------|---------------|------|----|---------------------------|----------|--------------------------------------------------------|
| Demand planning | Products Portfolio | Complex (multiple SKUs) | Simple (priority SKUs) | Consumer spending & demand uncertainty | Number of SKUs sold | Economic-Robustness |
| S&OP | Monthly cycle | Weekly cycle | Demand fluctuations | Number of weeks of horizon | Economic-Flexibility-Robustness |
| Production planning | Production run/ DBNR | Short/more changeovers | Long/less changeovers | Supply & demand disruptions | Percentage of the changeover loss in the OEE loss tree | Economic-Environmental-Robustness |
| Inventory planning | Inventory policy | Demand-based pull system | Supply-based push system | Supply disruption, better flexibility & responsiveness | Days on hand | Economic-Social-Flexibility-Robustness |
| Shop floor operations planning | Manning per line | Flexible crews | Fixed crews | Personal contacts reduction, virus transmission avoidance, & safer production system | Number of workers per line per zone | Social-Robustness |
| Shoulder-to-shoulder activities Teams | Allowed (manual) | Not allowed (automated) | Remote (virtual) | The social distance between workers | Percentage of virtual teams | Environmental-Social-Robustness |
| Quality control planning | Documentation of sanitization | NA | Documented | Personal contacts reduction, virus transmission avoidance, & safer production system | Number of subject 1 cases | Social-Robustness |
| Inspection automation | Manual | Digital | Personal contacts reduction, virus transmission avoidance, & safer production system | Percentage of reduced errors & cost reduction | Economic-Social-Robustness |
| Health and safety planning | Social distance control | NA | Digital | Personal contacts reduction, virus transmission avoidance, & safer production system | Number of subject 1 cases & further virus transmission | Social-Robustness |
| Access control & log | Digital (RFID-based) | Digital (computer vision-based) | Social-Robustness |
| Temperature monitoring | Manual | Digital | Social-Robustness |
| Track & trace | NA | Digital | Social-Robustness |
respectively. The goal was to better respond to market demand changes by producing and pushing the core and priority products to the market and increasing their stock levels as much as possible. Traditionally, responsive production systems and supply chains are expected to provide various SKUs with multiple changeovers. On the contrary, during the pandemic, the high utilization of the available production time is essential, and thus changeovers need to be minimized. This practice can mitigate the impact of possible supply disruptions and is reflected in the percentage of the changeover loss in the Overall Equipment Effectiveness (OEE) loss tree. The adjusted production plan, with fewer changeovers, has reduced waste in time, water, and cleaning material. This may positively impact both economic and environmental sustainability as well as improve the production system’s robustness.

5.3.2. Operational decisions

5.3.2.1. Shop floor operations planning. Several changes have been introduced in the shop floor operations planning to control and reduce personal contact on the shop floor and within the production system, thus avoiding or minimizing virus transmission among employees. Although flexible crews were favored within the production system to achieve better flexibility, the high possibility of virus transmission has forced the production system to implement the zoning approach. Zoning means splitting the entire production system into zones, assigning each employee to a specific zone, limiting movements across zones only to the necessary ones, and maintaining records of both assignments and movements daily. The zoning approach can help the management to track and trace contacts of any suspicious COVID-19 case. However, this required a change in manning per line operations. Crews became fixed and rigid instead of being flexible, which is reflected in the number of workers per line per zone.

Similarly, in order to align with WHO guidelines of social distancing, shoulder-to-shoulder activities became prohibited. Automation has been considered as a replacement for some activities to ensure social distancing. For example, installing a robot palletizing system replaced manual palletizing (a typical shoulder-to-shoulder operation) to load and unload boxes to and from pallets. This is reflected in the minimum distance between workers. Another example is stopping manual packing operations. These two practices allowed for complying with social distancing restrictions, reducing the number of employees in each zone, and minimizing the virus transmission among employees, thus improving social sustainability and production system robustness.

Furthermore, because the virus transmission occurs through infected people via mouth and nose secretions, teams have been shifted from factory-based (face-to-face) to remote (virtual) teams. This is reflected in the percentage of virtual teams—for example, asking non-factory-based roles to work remotely from home to reduce the number of people within the production system, reducing the risk of virus transmission. Hence, less commuting reduced the use of fuel, which may positively impact environmental sustainability. Additionally, these practices provided better health and safety conditions for the employees, improved social sustainability, and improved the production system’s robustness.

5.3.2.2. Quality control planning. In quality control, two main decisions have been made to control and reduce personal contact within the production system, avoid virus transmission among workers and customers through packaging material, and maintain a safer production system. Although sanitization is recommended and implemented all over the production system, the documentation of sanitization activities has been emphasized to monitor and control sanitization. For example, they recorded sanitization activities before and after maintenance activities to avoid virus transmission between maintenance workers and the fixed crew on each machine or line. Additionally, a virtual quality inspector (automated inspection) has replaced the manual inspection activities in the production system. This is achieved via a computer vision program that detects faulty boxes after the packaging process and automatically diverts them to be reworked. Eliminating, or at least reducing, manual activities that include worker intervention has led to ensuring food safety, reducing operational costs, and improving operational efficiency. This practice was favored from a health and safety perspective and is considered a good step towards process automation and factory digitalization. Achieved improvement is reflected in the percentage of reduced inspection errors (i.e., efficiency) and the cost reduction. Therefore, the economic and social pillars of sustainability may be improved and the robustness of the production system.

5.3.2.3. Health and safety planning. The outbreak of the pandemic has mandated introducing and implementing health and safety-related initiatives and practices. These range from the use of Personal Protective Equipment (PPEs) to advanced digital solutions. Several PPEs that were not needed before the pandemic have been introduced, such as face masks, face shields, safety glasses, and gloves. A computer vision program has been used to monitor and control the recommended minimum social distance between employees in different areas of the production system (e.g., canteen). Although digital solutions were used for access control, such as Radio Frequency Identification (RFID), new and more advanced digital solutions have been used, such as computer vision. A digital access control device has been installed at the site entrance to conduct three functions during card tagging, including face recognition (even if employees are wearing a face mask), temperature measurement, and accordingly allowing or denying access to the site. Another digital access control example uses a thermal camera to measure employees’ temperature to approve access to the site. Despite manually keeping an access log for the site, a digital device has been installed at the site entrance to measure entrants’ temperature and record data. This allows for acquiring data without human intervention. The thermal camera has been used in common and high traffic areas to monitor personnel temperature and notify the management via email alerts if an abnormal temperature has been detected. A Bluetooth-based mobile application that functions as a proximity sensor has been used to monitor and control the social distance between employees. Also, when an infected case has been confirmed, the application can be used to efficiently track and trace the suspected cases by identifying who came in contact with who. These solutions’ main goals are to control and reduce personal contact, avoid virus transmission, and maintain a safer production system, which is reflected in the number of subject 1 cases and further virus transmission through them. Health and safety planning decisions may positively impact the production system’s robustness and social sustainability, whether within the production system or on the supply chain level.
6. Discussion

6.1. New interpretation of sustainability and resilience

Based on the case study findings, it is evident that the impact of the COVID-19 outbreak has brought to light a new dimension in the interpretation of sustainability and resilience of production systems and supply chains. As shown in Table 1, various tactical decisions were made, including demand, production, and inventory planning, potentially impacting all the pillars of both sustainability and resilience. On the other hand, the potential impact of the operational decisions was affecting the robustness as well as prevailing on all sustainability pillars.

6.1.1. Sustainability

The outbreak has emphasized the importance of understanding sustainability-related risks and the mitigation of their consequences on the ecosystem, corporate reputation, and compliance with laws, in line with the concerns of Giannakis and Papadopoulos (2016). There has been a mixed impact of the COVID-19 outbreak on the three main elements of sustainability. The social sustainability aspect has been put in the foreground, and its vital role and strong relation to the economic dimension reflected in business continuity became evident. Hence, the production system and supply chain have been looking for new solutions to stop economic and social losses. The key in the case study was a set of safety-related initiatives (Table 1) to ensure safer production systems (support social sustainability) and allow for business continuity (support economic sustainability). New safety-related dimensions have emerged in the supply chain, including facilities safety, employees’ occupational and mental safety; social safety; and food safety (Haghani et al., 2020). Safety-related measures that were implemented in the case study have been proven an efficient means for the operationalization of sustainability (Nawaz et al., 2019). From the employees’ point of view, health and safety have been identified as the most strongly correlated factor to social sustainability (Stanikienė & Stankevičiūtė, 2018).

The positive correlation between safety and sustainability has been endorsed in several research works (McQuaid, 2000; Camuffo et al., 2017; Jilcha & Kitaw, 2017; Wang & Wu, 2020). The outbreak of COVID-19 is another factor to boost the concern about human health and safety. It has impacted the definition of sustainability. The importance of the health and safety aspect has been emphasized by Hakovirta and Denuwara (2020), who call for considering human health as the fourth pillar of sustainability. As is evident in the current case study, most operational decisions (e.g., shop-floor operations planning and quality control planning) have been driven by health and safety aspects (Table 1), which would add more reasons to consider health as the fourth pillar of sustainability as suggested by Hakovirta and Denuwara (2020).

6.1.2. Resilience

The pandemic has been considered a new driver for production systems and supply chains to implement resilience practices, including being more flexible and robust (Han et al., 2020; Ivanov, 2020a; Singh et al., 2020; Zhu & Krikke, 2020). In light of the profound disruptions and rapid changes that have stemmed from the virus outbreak, robustness is essential to maintain planned performance, while flexibility is vital to respond to changes and adjust plans and policies accordingly. In this regard, the case study reveals that new requirements have emerged, including guidelines, standards, and legislation related to COVID-19, which add a new dimension of robustness. Production systems and supply chains must comply with these emerging requirements to ensure their ability to maintain planned performance in addition to adjusting and coordinating their decision-making and risk management processes. Likewise, the continuous development of flexibility is much needed to manage production systems and supply chains. This has been manifested in the case study by adopting the PDCA cycle for risk management to ensure the continuity of the risk management process, thus leading to a higher resilience production system by increasing preparedness for future risks.

6.1.3. Sustainability-resilience relationship

Previous analysis of the pandemic’s influence on sustainability and resilience has shown some intersection points between both concepts (Renn, 2020; Zhu & Krikke, 2020). As one of the main elements of social sustainability, safety measures support business continuity and economic growth, significantly related to resilience (Cai & Luo, 2020). Additionally, as shown in the case study, ensuring the safety of both facilities and employees helps production systems and supply chains be robust, which is a main element of resilience. Hence, safety-related initiatives may have a positive impact on resilience as well as on sustainability.

This case study has demonstrated the use of a monitoring and mitigation plan for COVID-19 virus transmission within the production system. This is a safety-related measure that directly affects the social sustainability aspect as well as supporting business continuity and economic growth, which are resilience-related measures. In this regard, this study provides an essential step towards a better understanding of the relationship between sustainability and resilience concepts in supply chains, which is not well established in the literature as demonstrated by the different reported views by Marchese et al. (2019); Roostaei et al. (2019); Roostaei et al. (2018); and Renn (2020). The presented monitoring and mitigation plan offers a structured approach to be easily implemented in the industry. Additionally, the quantification of the benefits of applying this plan, such as the number of infected workers, the number of subject 1 cases and further virus transmission, and the number of shutdowns may be used to enhance the understanding of the relationship between resilience and sustainability. Moreover, the findings of this case study partially support the second view, i.e., sustainability is a basis for resilience, in line with Balugani et al. (2020) argument. More specifically, social sustainability has proven key for resilience-building as well as sustainability development during pandemics.

On the other side, higher flexibility and robustness, which are considered the main pivots of resilience, support the continuous flow of quality products through the supply chain, which is also in the interest of social sustainability. Therefore, flexibility and robustness may have a positive impact on sustainability as well as resilience. This lies in line with (Ivanov, 2018b; Balugani et al., 2020) findings, confirming that the concepts of sustainability and resilience are interconnected through many intersections, and thus the research on their integration as well as the assessment of their integration is much needed (Roostaei et al., 2018; Mohammed, 2019).

6.2. Performance measurement

Based on literature analysis, various KPIs have been used to assess sustainability and resilience in supply chains. However, no unified measure can be found to assess their integration (Roostaei et al., 2018; Zavala-Alicarver et al., 2020). Therefore, the need for new combined KPIs is growing to assess the integration of sustainability and resilience (Roostaei et al., 2018; Balugani et al., 2020). On the other hand, analysis of the case study does not lead to better findings. The case study has shown several measures to quantify the changes introduced by the different tactical and operational decisions. In the case study, the relation of these measures to the sustainability and resilience pillars represents the principal informant’s subjective opinion. A quantitative assessment of the impact of the different decisions on sustainability and resilience requires considerable time to study changes and identify trends. For resilience measures, the performance is monitored during the disruption until the recovery (Li et al., 2017). Since under the current circumstances industries have not yet recovered from COVID-19 such an assessment is currently not possible.

As illustrated in Table 1, the management of the studied case uses a set of measures, which are well known in the industry, to monitor the
changes based on the decisions made. These measures include the number of SKUs sold, number of weeks of the horizon, percentage of the changeover loss in the OEE loss tree, days on hand, and percentage of reduced errors and cost reduction. Such measures are commonly and strongly related to economic sustainability and robustness, while some may reflect environmental and social sustainability and flexibility. Also, newly introduced measures (number of workers per line per zone, the social distance between workers, percentage of virtual teams, number of subject 1 cases, and further virus transmission) are used to monitor the production system performance during the pandemic given the significant changes made across the different planning levels. Such measures are mainly related to social sustainability and robustness. These measures may be used as components in a newly devised KPI to integrate sustainability and resilience assessment and help fill the gap identified in the literature by Roostaei et al. (2018) and Zavala-Alcivar et al. (2020).

6.3. Learning from COVID-19

As illustrated in case findings (Section 5.3.2), the production system has made several efforts during the pandemic to utilize digital solutions that can help to reduce the possibility of virus transmission among employees and society. For example, the COVID-19 outbreak has helped the case production system advance and develop in some areas such as process automation and factory digitalization, leading to the transformation of the crisis into an opportunity. Utilizing computer vision to solve the problem of implementing and controlling social distancing has forced the case team to learn and develop new computer vision applications to solve other pandemic-related challenges.

On the other hand, computer vision applications helped the team detect and control employees and equipment (e.g., forklift) from accessing unauthorized areas leading to better control of undesired movements within the production system. This may also positively impact different pillars of sustainability and resilience (e.g., reducing time waste and providing a safer production system). The team was also able to improve the efficiency of some operations, such as reducing time, cost, and errors. It is worth noting that technology adoption can support resilience-building (Vishnu et al., 2019; Zhang et al., 2020). The production system under study has had several steps towards digitalization before the outbreak of the pandemic. These have paved the way for using digital solutions to ensure a resilient, sustainable production system. The efforts made in deploying digital solutions within the production system may lay the foundations for leveraging Industry 4.0 related technologies on the supply chain level. These technologies are recognized for their capability to achieve efficiency, resilience, and sustainability by mitigating risks and providing business continuity (Zhang et al., 2020). It further provides preparedness for similar future risks; thus, enhancing production system resilience.

Quality inspection is one of the areas where the case production system has managed to transform the crisis into an opportunity and improve its efficiency by reducing operating costs and inspection errors using computer vision. Furthermore, the team managed to avoid the costs of digitalizing such operational activities internally instead of hiring a specialized company. Another area is shoulder-to-shoulder activities. These practices have enabled maintaining operations while increasing efficiency, reducing waste, and identifying areas for improvement, which led to improving the sustainability and resilience of the production system.

Efficiency improvement and waste reduction can help in developing the economic and environmental pillars of sustainability, respectively. Although process automation usually replaces workers and negatively impacts social sustainability, it is needed to avoid virus transmission among workers and society in today’s vulnerable environment under COVID-19. Hence, it may have a relatively positive impact on social sustainability. On the other hand, learning key insights from disruptions and seizing opportunities emanated from the COVID-19 pandemic by developing and advancing process automation would be an effective lever for recovery following disruptive events. Thus, it ensures the continuity of operations and enhances the resilience of production systems and supply chains. Therefore, in light of the frequent and severe disruption risks associated with the COVID-19 outbreak, sustainability development and resilience-building need to be ready for the next disruption and are considered a top priority for business continuity.

6.4. COVID-19 implications: The new normal

The case company has introduced new demand planning practices for their production system by shortening the S&OP cycle to respond to the dynamic market and uncertain environment emanated from COVID-19. This decision was made to improve system responsiveness. Responsiveness of production systems and supply chains used to be measured by their quick response to unexpected changes in the market (Franco et al., 2020; Kim, 2018). Although market changes include market fluctuations that lead to disruptions in demand, further disruptions have emerged due to the outbreak of COVID-19. These disruptions are more severe, exist for longer times, are highly uncertain, and propagate among the whole supply chain (Ivanov, 2020a, 2020b; Ivanov & Dolgui, 2020; Queiroz et al., 2020), affecting every stage of it (i.e., supply, transportation, production, distribution, and demand disruptions).

As evident from the case findings, the COVID-19 pandemic has enforced some changes in the tactical and operational planning decisions within the production system and the supply chain, which would lead to a new normal. One of the main drivers behind such changes is the real need for integrating and improving sustainability and resilience. New rules for job assignment and staff scheduling based on zoning and the PCR test results have been introduced. Furthermore, the developed framework and its operationalization have helped in implementing the regulations. Manufacturers have been faced with plentiful guidelines for resuming operations and mitigating risks; translating these into an implementable flowchart is vital to ensure efficient implementation of regulations.

Shorter time horizon planning decisions are favored because of the considerable uncertainty and highly dynamic environment caused by the COVID-19 pandemic and the constant changes in the guidelines and legislation issued by international, regional, and national institutions. Thus, the traditional boundary between tactical and operational planning decisions, as revealed by the case study, has become increasingly blurred. It is currently unknown whether these decisions will be permanent and last for an extended time or temporary where practices will return to normal after the pandemic. Also, in the case of temporary changes, it is still unknown when it will return to the previous state. In this respect, simulation modeling may help decision-makers arrive at informed decisions to mitigate, be prepared to and recover from pandemics (Currie et al., 2020).

7. Conclusions, limitations, and future work

This work has developed a decision-making framework integrating sustainability and resilience for managing production systems within supply chains because of the outbreak of COVID-19. A case study has served as the illustration of the operationalization of adopting sustainability and resilience concepts in the decision-making process during the pandemic. The food sector has been selected due to the utmost criticality of food safety and security. Business continuity achieved via resilience and sustainability of the production system and the supply chain for this sector under pandemic circumstances is indispensable. Emphasis has been laid on the tactical and operational decisions made within the production system to maintain its sustainability and resilience, leading to the mitigation of operational and sustainability-related risks emerging from the outbreak of COVID-19.

The presented case study contributes to achieving numerous benefits on research and practical levels. The following may be concluded. First,
the managerial implication of this work is offering a means of building up knowledge and understanding complex relationships in managing production systems and supply chains during the pandemic. The current work has shed light on lessons learned from the implementation of planning and operational decisions to mitigate the effect of the disruptions and ensure business continuity. The case study has shown that the technology and efforts of digitalization are the cornerstones for mitigating risks and ensuring a resilient and sustainable production system during the pandemic. Production systems and supply chains should examine their sustainability and resilience to understand the extent to which their supply chain can continue to run with minimal cost in the face of such high-impact disruptions.

Second, the proposed decision-making framework allows for operationalizing new and advanced safety standards, new logics of functioning and organization, and new shift planning methods within production systems to prevent virus transmission. It further ensures the continuity of the risk management process, increasing, thus, system preparedness for future risks. Third, coordination and alignment within supply chain actors are vital to manage risks and ensure the different actors’ resilience and sustainability and hence the supply chain. Fourth, although the case under study represents a specific industry, analogies may be drawn to other similar industries or products that continue to have high demand during the pandemic, such as pharmaceuticals, medical supplies, and PPE. Due to the unprecedented nature of the pandemic and its enormous effect globally, case-based research may play a vital role in documenting lessons learned, making comparisons among industries, regions, decision levels, and supply chain actors. A thorough analysis of the different practices and assessing their impact may help draw conclusions, establish new theories, and redefine existing concepts.

Fifth, this work has highlighted areas where more research is needed to support decision-making for risk mitigation to achieve a resilient, sustainable production system and supply chain. Resilience-building efforts at the firm level minimize disruption propagation and, in turn, enhance the resilience of the whole supply chain (Ivanov et al., 2014; Dolgui et al., 2018). The need for integrated performance measures of sustainability and resilience and the quantification of the mutual effect between the two dimensions and their constituting components are examples of areas needing more investigation.

One limitation of this work is the lack of quantification for the proposed metrics for resilience and sustainability. While the current research has confirmed the relation and interaction between sustainability and resilience through observation and discussion, the quantification of resilience and sustainability requires more analysis. Furthermore, a single case study has a limitation of the generalizability of the drawn conclusions (Voss et al., 2002). Hence, multiple industrial cases may be further conducted in similar and different industries and in different geographical locations to allow for the generalization of conclusions and testing and refinement of the proposed decision-making framework.

Recommendations for future work may include the need to model the production system’s operations to support decision-making under the dynamic conditions of risks. Simulation modeling would be a valuable tool for analysis and decision aid for making informed decisions in a highly dynamic environment. Furthermore, the design of performance measurement frameworks that can simultaneously address sustainability and resilience is recommended. These frameworks need to include a dynamic measure to cope with resilience requirements while covering the sustainability triple bottom line. Since the integration of sustainability and resilience is in infancy, there is a need to delineate the intersection of both dimensions and quantify the relationship between them and their components.

CRediT authorship contribution statement

Aly Owida: Conceptualization, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. Noha M. Galal: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. Ayman Elrafie: Validation, Formal analysis, Investigation, Resources.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

The following questions are used to direct the discussion. They may be followed up with other questions for clarification and more detailed information collection.

- What is the nature of the production facility?
- Did the management take steps towards digitalization before the pandemic?
- Before the pandemic, what strategies and practices were followed by the production facility to support sustainability and resilience?
- How did COVID-19 impact the production facility?
- What types of risks were you confronted with during the pandemic?
- Did the company have a contingency plan that could be applied?
- What guidelines did the company follow in managing the operations during COVID-19?
- Was there a specific and transparent approach to manage risks emanated from COVID-19?
- How did was the COVID-19 transmission monitored and controlled in the production facility?
- What are the tactical and operational decisions that were made during the pandemic?
- How did the decisions made affect the production facility performance?
- How was the technology used for risk mitigation purposes?

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