#### **RESEARCH ARTICLE**



# Modelling Internet of things (IoT)-driven global sustainability in multi-tier agri-food supply chain under natural epidemic outbreaks

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#### **Abstract**

Epidemic outbreak (COVID-19, SARS-CoV-2) is an exceptional scenario of agri-food supply chain (AFSC) risk at the globalised level which is characterised by logistics' network breakdown (ripple effects), demand mismatch (uncertainty), and sustainable issues. Thus, the aim of this research is the modelling of the sustainable based multi-tier system for AFSC, which is managed through the different emerging application of Internet of things (IoT) technology. Different IoT technologies, viz., Blockchain, robotics, Big data analysis, and cloud computing, have developed a competitive AFSC at the global level. Competitive AFSC needs cautious incorporation of multi-tiers suppliers, specifically during dealing with globalised sustainability issues. Firms have been advancing towards their multi suppliers for driving social, environments and economical practices. This paper also studies the interrelationship of 14 enablers and their cause and effect magnitude as contributing to IoT-based food secure model. The methodology used in the paper is interpretative structural modelling (ISM) for establishing interrelationship among the enablers and Fuzzy-Decision-Making Trial and Evaluation Laboratory (F-DEMATEL) to provide the magnitude of the cause-effect strength of the hierarchical framework. This paper also provides some theoretical contribution supported by information processing theory (IPT) and dynamic capability theory (DCT). This paper may guide the organisation's managers in their strategic planning based on enabler's classification into cause and effect groups. This paper may also encourage the mangers for implementing IoT technologies in AFSC.

**Keywords** Agri-food supply chain (AFSC)  $\cdot$  COVID-19  $\cdot$  Global sustainability  $\cdot$  Internet of things (IoT)  $\cdot$  Food security  $\cdot$  Multi-tier  $\cdot$  Supply chain disruption

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#### Introduction

By the increased growth of global SCM, disruptions are continuously taking place in agri-food supply chain (AFSC) (Kamalahmadi and Parast 2016; Hosseini et al. 2019). AFSC risks are complex; and may be classified into functional and disrupting risks (Choi et al. 2019; Xu et al. 2020). The functional risks are connected by daily disorders in the AFSC functions like lead time of agri products production, processing and demand's fluctuating, the disrupting risks associated as low-frequency highly impacting actions (Kinra et al. 2019; Ivanov 2020). Disrupting actions (COVID-19) have instant impacts on AFSC and its networking system, results in a shortage of retailers, distribution centres and transportation facilities, etc. Consequentially, insufficient agri-food product shortages and delaying of services propagated towards



AFSC's downstream lead to the rippling effect and competitive disadvantages in the form of performance degradation (Dolgui et al. 2020). Araz et al. (2020) noticed that the COVID-19 outbreak was "breaking many global supply chains" as the World Health Organisation (WHO) declared COVID-19 as a pandemic. In this natural epidemic condition, it is prerequisite to considered multi-tier sustainable issues of AFSC.

A lacked contractual interrelationship between the focal firm (FF) of AFSC and sub-suppliers does not support the direct control of FF on multi-tier stakeholders due to improper information sharing (Mena et al. 2013; Tran et al. 2013). Although an AFSC often consists of a relative simpler bill of material (agri products), a multi-tier system consists of various stakeholders related to retailing, processing, production (farming), storage (warehouse) and other suppliers, which have increased the complexities and reduce the transparency (Atzori et al. 2010; Yakovleva et al. 2012). Furthermore, a multi-tier AFSC involves processing and commoditisation of the primary agri-grains as a bulk cargo which also reduces the traceability of a multi-tier system. Lastly, some issues are related to the variability of the qualities and quantities in the farming yield which does not provide the accurately forecasted demand pattern of consumers in a dynamic situation (COVID-19) (Aryal et al. 2020).

Although, industries' interrelationships in AFSC are mostly dynamic, globalised sustainable issues related to certification provided by different globalised standards and traceability demanding for the interaction of FF across different countries by integrating with their subsuppliers in a multi-tier system (Overstreet et al. 2013; Dolgui et al. 2018). As per the report of the economic and social department (United Nations), the worldwide population may increase to 8.5 billion by 2030 (ESA UN 2019). So, globalised agri-production must be increased for matching the consumer's demands, which may increase the global sustainability issues. For this, sustainable initiatives have been taken like "Paris Agreement" on reducing greenhouse gases (GHG) emissions during various agri practices and common agriculture policies (CAP) for improving AFSC practices as a multi-tier system (Achabou et al. 2017; Bustos and Moors 2018). Multi-tier-based sustainability of AFSC may help in the reduction of loses at different phases with minimising of deterioration of the agri-food qualities and thus contributed to AFSC sustainability (Clarke and Boersma 2017). Without considering sustainable factors, agri-food secure system may not be achieved.

Thus, the term sustainable-based agri-food secure system is getting much more focused from the area of research, academics and policymaking. Sustainability approach in AFSC may provide sufficient agri-food by adopting sustainable actions of AFSC by effective designing of SCM (Allaoui et al.

2018). The traditional AFSC in India is facing different problems in procuring, storing and distributing agri-food losses and deteriorations. To overcome above problems, IoT technologies like Blockchain, artificial intelligence (AI), robotics and RFID (Hartmann and Moeller 2014; Aboah et al. 2019) must be employed for ensuring transparent, traceable and accountable system at different levels of AFSC (Kauppi and Hannibal 2017; Cohen 2020). The following research objectives may be set:

- Identification of the enablers in driving IoT-driven multitier sustainability for AFSC;
- To establish the interaction among identified enablers for IoT-based sustainability for a food secure mechanism;
- To established a contextual interrelationship between the enablers by classifying into caused and influenced clusters; and
- Recommending managerial implications of the proposed research.

This research will also try to respond to the given research questions:

 What may be the needs of IoT has driven a multi-tier food security system in any natural epidemics (COVID-19)?

In the current scenario, tracking of processes in AFSC is critical by providing a basic idea of the agri products' past background, operational as well as processes throughout the SCM; however, traditional AFSC has not been tackling this kind of tracking mechanism. Furthermore, monitoring of food regulatory standards leads to standardisation in practices of food processing, packaging, distribution and retailing (Dev et al. 2020). Thus, there is a need for an IoT-driven food security system for ensuring sustainability at the globalised level.

 What are the criteria for the selection of enablers in IoT driven multi-tier food security system for ensuring global sustainability?

Different enablers involve in the IoT-driven multi-tier food security system based on the three decision model, i.e., strategic (making long-term planning), tactical (put strategies into action) and operational level practices (actual action implementation) (Busse et al. 2016). Thus, three decision-based models have been taken care for enabler identification to address the different issues related to IoT-driven food security system to ensure global sustainability.

 What type of methodologies may be employed for establishing interrelationship between the enablers and analyse cause and effect extent?



In this paper, an integrated (ISM and F-DEMATEL) approach is helping in transforming the vague and unorganised structural into a systematic structure and establishment of interdependency between the enablers by formulating causal and influenced group clusters (Chauhan et al. 2018). Furthermore, sensitivity analysis needs to be performed to check the results' robustness.

 How this study can be employed in practical implications for managers and practitioners?

An integrated analysis of the identified enablers will help managers and practitioners in making their longer-termed basis-resilient strategies. This research can guide the managers in adopting the most feasible IoT-based technologies in AFSC with economical-based customer's satisfaction with new horizons of productivity (Wilhelm et al. 2016; Harbour 2020).

Furthermore, the organisation of the proposed research is as follows: The "Literature review" section elaborates the literature review. The "Research methodology" section elaborates research methodology. The "Case illustration" section provides practical applications of this study with a numerical illustration. The "Discussion of findings" section discusses findings with its implications. Finally, the "Conclusion" section contributes to the conclusion of this study.

#### Literature review

In the following sub-sections, review of literature has been made for theoretical foundation, the identification of enablers and to identify research gaps.

#### **Theoretical foundation**

The two basic theories which act as a pillar for the entire literature review and enablers' identification are explained below.

Information processing theory Information processing theory (IPT) supports the impact of SC dynamics on effective information sharing and SC basic practices. Zhou and Benton Jr. (2007) identified that information sharing as a way of capturing the SC dynamics and reducing uncertainty within SC. Thus, IPT may recognise the enablers as accounting for information's processing in SC, viz., information sharing (IS), SC visibility, uncertainty minimisation and technology-based capabilities (Kante et al. 2019).

**Dynamic capabilities theory** Dynamic capabilities theory (DCT) defined the firm's competitiveness as "the firm's abilities for integrating, building, and reconfiguring the internal or external SC for addressing the continuously changing

environments" (Bouranta et al. 2019; Junior et al. 2019). Since DCT considered the firm's organisations and strategies' practices, it may be taken as bundles of capabilities instead of individual practices (Beske et al. 2014).

## The requirement of global sustainability under COVID-19 outbreak

Concerning COVID-19, food industries have been noted that primary agri production may not be largely declined as most of the farmlands are way distant from urbanised. But, the pandemic may affect agri-harvesting, processing, logistics and distributing and thus, poses globalised issues of sustainability (Ben-Daya et al. 2019; Dun and Bradstreet 2020). Thus, food organisations are required to implement sustainable practices at different multi-tier stages related to processing, transporting, retailing, packing, handling, cold storage and loading.

Therefore, there is a need of IoT-based dynamic system for processing information of agri-food safety standards in an effective way to different sub-suppliers of AFSC (Annosi et al. 2019; Aydin and Aydin 2020). Furthermore, in this global pandemic situation, there is a growth of opportunities which exist for the industries to provide quick response/online purchasing (e-commerce) or local/short SC-based and thus achieving sustainable competitiveness (Long et al. 2019; Farahani et al. 2020).

# Impact of IoT-based multi-tier system on sustainable AFSC at global level

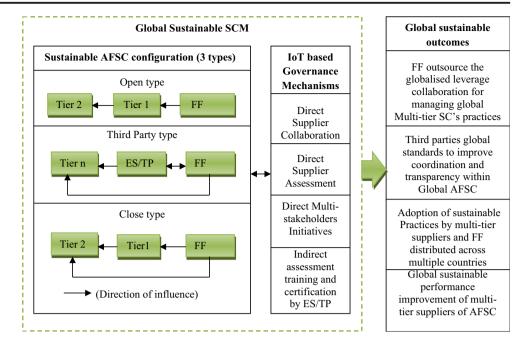
Multi-tier configuration type and IoT-based governance mechanisms are the key elements for sustainable development in global AFSC. Global AFSC encompassed the IoT-based involvement of multi-tier sustainable practices with initiatives driven by FF (external supports (ES) supported by government and NGOs, third parties (TP) and some other stakeholders for information processing) (Nirino et al. 2019; Cane and Parra 2020). Direct governing mechanisms need FF to provide time and capital for effectively establishing the associations with multi-suppliers, and indirect governing mechanisms depend on third parties' standards and regulation without any direct influence of FF (Formentini and Taticchi 2016). This governance system provides diverse implications for sustainable outcomes in dynamically active global AFSC during the fluctuating condition (COVID-19) (Zhu et al. 2017; Sarker et al. 2020) as shown in Fig. 1.

# Identification of enablers for IoT-based multi-tier sustainable food security system

Depending on the literature survey, fourteen enablers have been identified for developing IoT-based



**Fig. 1** Framework of sustainable AFSC and global AFSC



sustainable multi-tier agri-food secure model in a natural disruption of AFSC. The research databases used in this research are Emerald (www.emeraldinsight.com), Taylor and Francis (https://taylorandfrancis.com), Elsevier (www.sciencedirect.com), Springer (https://www.springer.com), Wiley (www.wiley.com) and IEEE journals (ieeexplore.ieee.org) (Chadegani et al. 2013). The main searched criteria consisting of published articles range from the year 2005 to 2020. Majority of the reviewed papers have been taken above the databases. The below-given keyword's strings have been entered as in title:

- 1. ("Global agriculture food supply chain" OR "global value chain" OR "global supply chain management") AND ("sustainable" OR "resilience" OR "disruptions").
- 2. ("agri-supply chain management" OR "resilience supply chain management" OR "sustainable supply chain management") AND ("Internet of Things" OR "global").
- 3. ("IoT driven sustainable agri-food supply chain management" OR "green supply chain "management" OR "global supply chain disruptions") AND ("modeling" OR "multi-tier" OR "governance" OR "configuration" OR "natural outbreak").

Thus, this provides the first level all searched database (n = 150 papers) having links between various scope of global sustainability, IoT-based multi-tier system of AFSC and natural epidemics outbreak. The complete process of paper selection and exclusion is shown in Fig. 2.

Brief description of the identified enablers has been explained in Table 1.

## Research gaps

The research gaps identified by extensive literature review are given below.

 In previous literature work, most of the work has focused only on the increasing agri-production or agri-based yield. There are less work that has been made on minimisation of AFSC losses or agri-food security issues like crop insurance, simulation of demand, route optimisation, blockchain cold chain based and smart contact (Naik and Suresh 2018; Murugesan and Sudarsanam 2020).

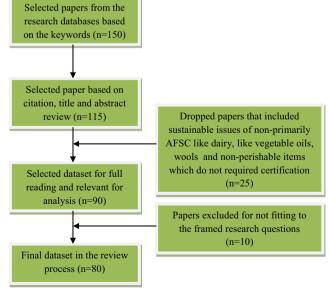


Fig. 2 Article searching, selection and exclusion process



 Table 1
 Identification of enablers for IoT-based multi-tier sustainable food security system of AFSC

Enablers	Brief description	References
E-governance and policy (C1)	This provides effective controlling and tracking of the sustainable AFSC practices by sharing efforts of government organisation, NGOs, CAP, food processing organisations (FF) and farmers by the means of third party-type multi-tier (multi-supplier) and indirect governing mechanism.	Wolfert et al. 2017; Armanda et al. 2019; Aryal et al. 2020
Education and training (C2)	Technical training includes awareness of multi-tier sub-suppliers about IoT technology, food regulation standards like hazard analysis and critical control point (HACCP), good hygiene practices (GHP), International Organisation of Standardisation (ISO) for food product handling by maintaining social distancing and aware farmer to implement IoT-based farming practices (organic farming, irrigation control)	Sharma and Vrat 2018; Kulikov et al. 2020
Top management support (C3)	It ensures funds, proper training, award/reward sharing and awareness programme about technical (IoT technology) knowledge, food products handling practices and effective information sharing. It also provides PPE, gloves and a mask for the workers. Thus, it ingrates sustainable initiatives to global SCM.	Linton and Vakil 2020; Irani and Sharif 2016; Gupta and Ivanov 2020
IoT-based infrastructure (C4)	IoT-based infrastructure is the availability and collaboration of each IoT-based technology throughout the multi-tier AFSC. Different IoT technologies such as RFID tags and readers, sensors, Blockchain, AI, BDA, robotics, cloud computing and Zigbee.	Li et al. 2014; Saberi et al. 2019
Setting of food quality standards (C5)	Imposing the third parties' food regulation standards by the means of implementing various standardised practices or information within the food SC during the execution of various SC activities.	Fanzo 2015; Ben-Daya et al. 2019
Information sharing (C6)	Information sharing is prerequisite for exchanging ideas between different sub-suppliers of a multi-tier system. Furthermore, information sharing improves food product recycling by proper information sharing between retailer, supplier and consumers.	Fuglie 2016; Saberi et al. 2019
Coordination and collaboration (C7)	Global standards-based effective coordination and collaboration between food regulation authorities, food processing organisation, supplier, warehouse and consumers. It supports the identification of human and organisational risks related to agri-food safety, security and scandals which ensures dynamic capabilities and traceability with global sustainability.	Luvisi 2016; Nakandala et al. 2017; Long et al. 2019
Quality control of agri products (C8)	It mainly depends on the 3D images of food grains and packed product based on the IoT-based sensor technology. 3D images of food items with the study of their pattern recognised the quality control processes for better quality controlling of agri products.	Bosona and Gebresenbet 2013; Van Hulst et al. 2020
E-farm marketing (C9)	E-farm marketing has been using the online portal for connecting farmer/food processing organisation to the big retailers connected to FF across different countries. Improved information sharing based on RFID tags/readers and barcodes technologies also supports to E-farm marketing.	Masiero 2015; Manavalan and Jayakrishna 2019
Route optimisation (C10)	It provides the optimum route to consumers by using cloud computing technology. It also helps in dynamic-based external information sharing dynamically which is utilised for the optimisation of a distributed network of different countries.	Validi et al. 2014; Irani and Sharif 2016; Ben-Daya et al. 2019
Simulating the consumption pattern (C11)	It provides simulation-based big data analysis for matching the demand of consumers globally located. Thus, it may predict the planning of agri-food distribution to ensure agri-food security, safety and availability in a disruptive event (COVID-19).	Badami and Ramankutty 2015; Vanderroost et al. 2017; Cane and Parra 2020
Smart packaging of agri products (C12)	Smart packaging is achieved by the AI-based intelligent packing of agri products, so that a best before date may be decided to simulate the barcode having an expiry date of agri products based on considering ambient, environmental or climate condition and long distributing chain of multi-tier system across different countries.	Ahmad and Mondal 2019; Saberi et al. 2019
Cold chain for perishable products (C13)	Cold chain for perishable products is the development of IoT and blockchain-interfaced refrigerant facility. The refrigerant or cold chain intensity may be adjusted depending on the type of global climate in different countries, quantities and perishable nature of agri products.	Talavera et al. 2017; Benis and Ferrão 2018; Allaoui et al. 2019
Sustainable-based competitive AFSC (C14)	This system focused on AFSC processed by safe distributing, safe storage and reduction of food loss during the natural epidemic outbreak (COVID-19) for ensuring competitiveness with multi-tier sustainability at a global level across different countries. The competitive AFSC is ensured by effective information processing in a fluctuating (dynamic) environment.	Gwynn-Jones et al. 2018; Gupta and Ivanov 2020; Li and Zobel 2020; Kamble et al. 2020

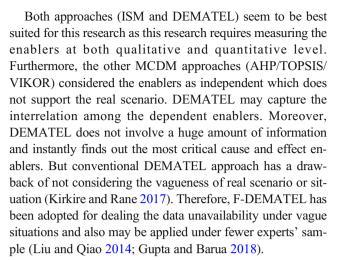


- A few types of research have supported the environmental, economical and social sustainable aspects at a globalised level while reviewing the SC disruption (COVID-19) issues. There is a requirement of sustainable-based quick processes transaction during both tier 1 and lower tier by considering producing stage, procuring stage, transporting stage, warehouse and distributing stage to attain sustainable-based multi-tier food secure system (Govindan 2018; Baumer-Cardoso et al. 2020).
- Most of the previous literature has only given attention to the specific applications of a single IoT technology. But in the developing of an IoT-dependent sustainable agri-food secures structure, there is a requirement of integration among different IoT technologies. However, less literature has been supported for the integration of IoT technologies (blockchain and cloud computing), which may interact on a real-time basis to develop resilience and effective system for mitigating the disruption risks (Papadopoulos et al. 2017; Ivanov and Dolgui 2019; Kamble et al. 2020).
- Most of the previous work has only oriented in one direction, either worked as qualitatively or quantitatively approach. Only a few studies have taken case studies along with numerical analysis of enablers and barriers with their individual effects of sub-suppliers on the entire system of AFSC for an IoT-driven global sustainable AFSC's security system (Ho et al. 2015; Moazzam et al. 2018; Singh et al. 2019).

#### Research methodology

The research methodology employed a two steps study as shown in Fig. 3.

For the evaluation of the enablers for IoT-based sustainability in AFSC, in the first phase, identification of enablers is based on reviewed literature and expert's suggestions. By this procedure, fourteen important enablers have been identified and verified by experts' suggestions. In the second phase, identified enablers have been evaluated by using combined ISM and F-DEMATEL. There are different techniques available such as ISM, total ISM, DEMATEL and analytical hierarchical process (AHP) for providing a structure-based relationship of the enablers but could not provide the quantified view of the inter-relationships (Dos Muchangos et al. 2015; Luthra et al. 2016). Hence, for the quantification of the interrelationships for any sophisticated system, integrated ISM-DEMATEL approach may be applied (Chauhan et al. 2018). But standard DEMATEL technique has a drawback as it does not have capabilities for dealing with any uncertainty of real case (Kirkire and Rane 2017). To avoid this drawback, there is a need for integrating DEMATEL with the fuzzy set theory proposed by Zadeh (1965).



Therefore, this research methodology is adopted in two phase. In the first phase, the ISM approach has been used for decomposing the complex structure of enablers into a systematic hierarchical structure of enablers. In the second phase, F-DEMATEL-based macro-oriented approach has been utilised for calculating the strength of linked enables which are connected either directly or indirectly in an ISM-based hierarchical structure for interpolating cause and effect digraph.

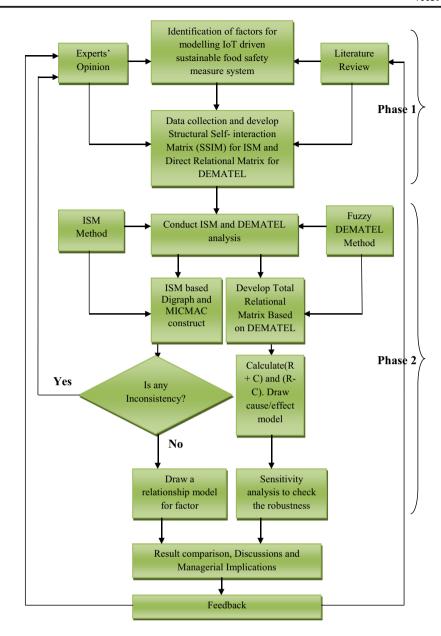
#### ISM methodology

ISM was initially introduced in 1970s by Warfield (1974). ISM may be adopted to establish the inter-relationships among the enablers by converting the unorganised system into a systemically organised system (Kapse et al. 2017; Chaple et al. 2018). ISM is commonly chosen among other modelling methods as it elaborates the type of interrelationships between enablers (Luthra et al. 2016; Shen et al. 2016). ISM has different steps as explained below.

- (1) Identification of the enablers. In the current research, enablers are connected to develop IoT-based multi-tier sustainable food security system.
- (2) Development of the contextual inter-relationships between enablers given by the expert's suggestions.
- (3) Constructing an SSIM. The advice of different experts has been utilised.
- (4) Development of final reachable matrix. SSIM is utilised for the development of the initial reachable matrix; this matrix is then changed to a final reachable matrix by finding out any transitivity links between the identified enablers.
- (5) Formation of the partition levels based on a final reachable matrix.
- (6) Conducting the MICMAC analysis for the identified enablers.
- (7) Constructing the digraph.



**Fig. 3** Framework of the proposed research



(8) Formation of the ISM model by removing transitivity links.

#### **Fuzzy-DEMATEL**

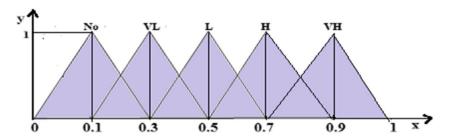
DEMATEL approach was first introduced by the Geneva Research Centre. The DEMATEL is a numerical technique, which may be utilised for analysing the cause and effect strength between interrelated variables of a complicated system (Tzeng et al. 2007). DEMATEL technique established the relation between enablers by classifying them in causal and effects and thus provides possible outcome based on an organised and systematic system (Lin 2013; Wu 2008; Hsu et al. 2013). Thus, F-DEMATEL methodology has been

adopted to deal with expert's biasing and imprecise real scenario (Seçme et al. 2009; Gupta and Barua 2018). The F-DEMATEL technique has the following steps as explained below.

1. Generation of a fuzzy initial direct relational matrix (D). For calculating the level of interaction between the enablers, a TFN scale has followed. As given in Fig. 4, the membership function  $\mu_a(x)$  is represented by y axis and TFN may be represented by x axis. Thus, TFN is represented by the triplet (l, m, r) for denoting association level between enablers, i.e., (0,0.1,0.3) representing (no), (0.1,0.3,0.5) (very low), (0.3,0.5,0.7) (low), (0.5,0.7,0.9) (high) and (0.7,0.9,1) (very high), respectively.



Fig. 4 Triangular fuzzy number



$$\mu_a(x) = \left\{ \begin{array}{ll} 0, & \text{if } x < l \\ (x-l)/(m-l) & \text{if } l \leq x \leq m, \\ (r-x)/(r-m) & \text{if } m \leq x \leq r, \\ 0, & \text{otherwise} \end{array} \right.$$

Thus, an initial direct relational matrix has been developed as D. In this enabler, i interacts with the enabler j as  $D = [d_{ij}]_{n \times}$ 

2. Normalisation of direct relation matrix "S" by using five steps as explained below (Opricovic and Tzeng 2003). A five-steps approach is shown below:

Step 1. Normalisation

$$\begin{array}{ccc} xr_{ij}^n & = & \left(r_{ij}^n & -\text{min}l_{ij}^n \end{array}\right)/\Delta_{\min}^{\max} \\ xm_{ij}^n & = & \left(m_{ij}^n & -\text{min}l_{ij}^n \end{array}\right)/\Delta_{\min}^{\max} \\ xl_{ij}^n & = & \left(l_{ij}^n & -\text{min}l_{ij}^n \end{array}\right)/\Delta_{\min}^{\max}$$

Step 2. Determine right (rs) and left (ls) normalised values:

$$xrs_{ij}^{n} = xr_{ij}^{n} / \left(1 + xr_{ij}^{n} - xm_{ij}^{n}\right)$$
$$xls_{ij}^{n} = xm_{ij}^{n} / \left(1 + xm_{ij}^{n} - xl_{ij}^{n}\right)$$

Step 3. Compute total normalised crisp values:

$$x_{ij}^{n} = \left[xls_{ij}^{n} - \left(xls_{ij}^{n} \times xls_{ij}^{n}\right) + \left(xrs_{ij}^{n} \times xrs_{ij}^{n}\right)\right]$$

$$/\left(1 + xrs_{ij}^{n} - xls_{ij}^{n}\right)$$

Step 4. Compute crisp values:

$$z_{ij}^n = \min l_{ij}^n + x_{ij}^n \times \Delta_{\min}^{\max}$$

Step 5. Integrate crisp values:

$$z_{ij} = \left(z_{ij}^1 + z_{ij}^2 + \dots + z_{ij}^p\right)$$
  $p = \text{Experts'number}$ 

 $S = k \times D$ 

where  $k = 1/\max_{1 \le i \le n} \sum_{i=1}^{n} d_{ij}$ 



- 3. Construct a total relation matrix T as  $T = S[I S]^{-1}$ , where "I" is the identity matrix
- 4. Drawing a causal (R+C) and effect's (R-C) maps as given:

$$T = \begin{bmatrix} t_{ij} \end{bmatrix}_{n \times n} \quad i, j = 1, 2, \dots, n$$
$$[R_i]_{n \times 1} = \left( \sum_{j=1}^n t_{ij} \right)_{n \times 1}$$
$$[C_j]_{1 \times n} = \left( \sum_{i=1}^n t_{ij} \right)_{1 \times n}$$

#### **Case illustration**

This section describes a case company, data collection and finally numerical illustration. These three sub-sections are explained below.

#### **Description of the firm**

The XYZ firm has adopted IoT-based infrastructure like developing technical manpower, IoT-based cold chain, adopting various quality standards of food quality and safety in FF, finally supplying the packed and raw agri products to consumers. This case study of FF has needed to deal with any kind of natural disruption in agri-food SC. Furthermore, the FF has to meet the specific challenge of food SC for maintaining high perishable nature of fresh vegetables, meeting random demands from a specific area of high risk by disruption (COVID-19), meeting high standards of food safety and quality as per government regulations and standards (HACCP, ISO, GHP) with IoT-based multi-tier sustainable development of entire AFSC. The complete framework of the proposed case study for XYZ firm is shown in Fig. 5.

The multi-tier view of AFSC is shown in Fig. 6.

#### Questionnaire formulation for collecting data

The questionnaire was designed for rating and analysing the identified enablers as given in Appendix 1. Initially, 25 experts were contacted working in different firms. Out of 25 experts, only 5 experts have filled their responses either through online or offline mode. Afterwards, the demographics' profiles of the participating panel were analysed. Two experts were qualified at the graduate's level, 02 were postgraduate's level and 01 having a doctoral degree. Most of the decisions-makers (experts) were highly experienced

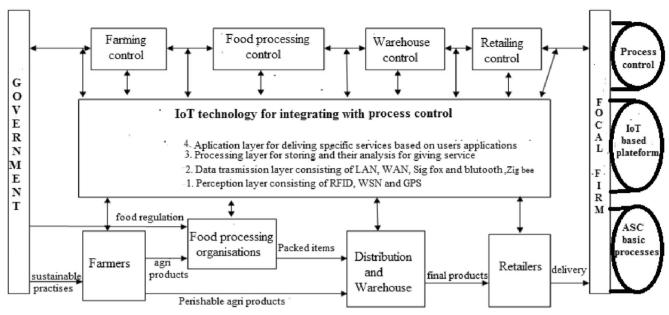


Fig. 5 Complete framework of the proposed case study for XYZ firm

ranging from 5 to 25 years. As per collected data, the decisions-makers involved in this research were the logistics' supervisor (E1); the food and worker safety's supervisor (E2); the chief executive officer (E3) for setting different standards (HACCP, GHP) for IoT-based agri products production, processing, packing and handling; the agri-food procurement manager (E4) for managing strategies about placing an order to farmers/suppliers for primary agri products like fresh vegetable and food grain; and research and development (R&D) specialist (E5) having environmental (ISO 14001 standards) and disaster management (ISO 37120 standards) expertise.

#### **Numerical illustration**

This section consisting of further three subsections, viz., ISM approach, F-DEMATEL approach and sensitivity analysis as explained in subsequent sections.

Fig. 6 Multi-tier view of AFSC

#### ISM application

This subsection elaborates different calculating steps of ISM approach. The complete procedure is given as under:

**Structural self-interaction matrix** To establishing the interaction between the enablers which are enabling the IoT-dependent agrifood sustainable development, four notations are used for expressing the relationships between the enablers i and j as:

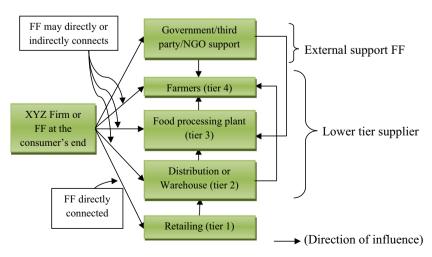
V: Enabler i facilitating enabler j.

A: Enabler i facilitating enabler i.

X: Enabler i and j facilitating one another.

O: There is no interaction between enabler i and j.

Experts are requested for providing their agreements in the framing of initial SSIM with the help of four notations as





explained earlier. Based on the experts' response, initial SSIM for enablers is given in Table 8 of Appendix 2.

**Initial and final reachability matrix** The SSIM needs to be transformed into an initial reachability matrix by replacing notations with binary digits (0, 1) as explained in Table 2.

The final reachability matrix is constructed based on the transitivity links as given in Table 3.

**Levelling-based partitions** By using Table 3, intersecting point of antecedent's sets (depending power) and reachability's sets (driving power) is determined. The iterating procedure will carry on for identifying each level as shown in Table 4.

Classification of enablers (MICMAC analysis) Cluster or sector formation of enablers is mainly based on the value of driving and depending on power as indicated in Fig. 7.

This cluster formation is similar as given by Kamble et al. (2018). The first cluster or quadrant belongs to "autonomous variables" with weak-driven and dependence powers. It is weakly linked with other enablers or negligible impact on the entire system developed by the ISM approach. In this study, the autonomous sector is empty suggesting that every enabler is weakly or strongly associated in the model. The second group belongs to the dependent category with strong dependence and weak-driven power. These variables require special focus. Enablers C9, C10, C11 and C14 are the part of this sector.

The third sector belongs to linkage category with strong-driven and dependence's powers. It is not stable and having closed looping effect on other variables. Enablers C7, C8, C12 and C13 are the part of this category. The fourth sector belongs to the independent category with strong-driven and weak dependence's power. Enablers C1, C2, C3, C4, C5 and C6 belong to this region. These variables require special planning of policy maker.

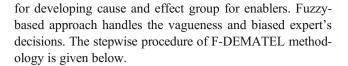
**ISM model** Based on Tables 3 and 4, an ISM hierarchical model of enablers for IoT-driven multi-tier sustainable food security system has been developed as depicted in Fig. 8.

#### **Fuzzy-DEMATEL** application

After the formulation of a systematic structure by using ISM technique, the F-DEMATEL methodology has been applied

Table 2 Notations and conversion of binary digits

Notations in SSIM	Entry $(i, j)$ in SSIM	Entry (j, i) in reachable matrix
V	1	0
A	0	1
X	1	1
O	0	0



Constructing a direct relational matrix The experts given in the "Questionnaire formulation for collecting data" section have given suggestions for the evaluation of the enablers in the pairwise matrix or direct relational matrix based on fuzzy linguistic variables.

**Developing a direct relational normalised matrix** The normalisation of the aggregated direct relational matrix of experts' TFN numbers by using step 2 as explained in F-DEMATEL methodology is given in Table 9 of Appendix 2.

**Developing a total relational matrix** Total relational matrix has been developed based on the normalised matrix using step 3. Determine (R+C) and (R-C) as given in Table 5.

Constructing causal model Construct a causal and effect model for the enablers by using (R+C) and (R-C) values in Fig. 9. From Fig. 9, it may be concluded that enablers C5, C8, C7, C11, C9, C10 and C14 are categorised into effect group. Similarly, enablers C1, C3, C4, C13, C2, C6 and C12 are categorised into cause group.

#### Sensitivity analysis

Sensitivity analysis is used for checking the validity and robustness of the results obtained based upon experts' opinions (Raja Ambedkar et al. 2018). Sensitivity checking also helps in the determination of any biasing by a specific expert, which may alter the final results of the research. Therefore, this paper has applied the above analysis by changing the weights given by the experts for a particular case to analyse the overall impact on the results. The sensitivity analysis has been made by providing higher weightage to one expert and giving the equally divided weightage to rest of four experts. In the same manner, five different runs have been performed as shown in Table 6.

For each run, different total relational ([T]) matrix has been constructed by using a direct relational matrix ([D]) based on the expert's weightage. In all of the five scenarios, C1, C3, C4, C13, C2 and C6 are categorised into cause group. Similarly, C5, C8, C7, C11, C9, C10 and C14 are categorised into effect group. Nevertheless, C12 is categorised into effect group in scenario 2 and scenario 5. Similarly, C12 is categorised into a caused group for another scenario. Thus, C12 is highly sensitive. The complete sensitivity results are shown in Table 7.

The R-C graphs are shown in Fig. 10.



Table 3	Eino1	reachable	motrix	for	anablara
Lable 3	rınaı	reachable	mairix	tor	enablers

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	DR.P
C1	1	1*	1	1	1	1	1	1	1	1	1	1*	1	1	14
C2	0	1	0	1	1	1	1	1	1	1	1	1	1	1	12
C3	0	1*	1	1	1	1	1	1	1*	1*	1*	1*	1*	1	13
C4	0	1*	0	1	0	1	1	1*	1	1*	1*	1	1	1	11
C5	0	1*	0	1*	1	1	1	0	1	1	1*	1*	1*	1	11
C6	0	1	0	1	1*	1	1*	1*	1	1	1	1	1*	1	12
C7	0	0	0	0	0	0	1	1*	1	1	1	1	1	1	8
C8	0	0	0	0	0	0	1	1	1*	1	1	1	1*	1*	8
C9	0	0	0	0	0	0	0	0	1	1	1	0	0	1	4
C10	0	0	0	0	0	0	0	0	0	1	0	0	0	1	2
C11	0	0	0	0	0	0	0	0	1	1*	1	0	0	1*	4
C12	0	0	0	0	0	0	1*	1*	1	1*	1*	1	1	1*	8
C13	0	0	0	0	0	0	1	1	1	1*	1*	1*	1	1*	8
C14	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
DP.P	1	6	2	6	5	6	10	9	12	13	12	10	10	14	116/116

This symbol is representing trasformations (0 to 1\*) based on transivity rule

### **Discussion of findings**

Globalised-based fragmenting of AFSC sustainability (COVID-19), along with increased stakeholder's demands for increased transparency and food security, has increased the involvement of lower-tier or sub-supplier for ensuring sustainability (Miemczyk et al. 2012; Lakshmi and Bahli 2020). Nevertheless, the majority of severe sustainable issues in the AFSC are frequently regenerated by lower-tier suppliers positioned in the second tier or further upstream (Grimm et al. 2014; Gunasekaran et al. 2014). This paper identified the important enablers of IoT-based sustainable multi-tier food security system in AFSC and linking it to global sustainable

outcomes. Finally, interdependent enablers were analysed based on ISM and DEMATEL technique.

E-governance and policy (C1) is the most significant caused group by using (R-C) value and classified into independent variable based on driving and dependence power. In developing countries, sustainability's issues of AFSC are mainly ensured by governments' authorities. These authorities controlled the various stages of AFSC for assuring sustainable progress of SCM by avoiding procuring delays and food frauds resulting agri-food secure system, especially when dealing with the global distribution of multi-tier system (Ganasegeran and Abdulrahman 2020). Top management support (C3) is

**Table 4** Initial iteration matrix for enablers

	Reachability set	Antecedent set	Intersecting set	Levels
1	1,2,3,4,5,6,7,8,9,10,11,12,13,14	1	1	Level VIII
2	2,4,5,6,7,8,9,10,11,12,13,14	1,2,3,4,5,6	2,4,5,6	Level V
3	2,3,4,5,6,7,8,9,10,11,12,13,14	1,3	3	Level VII
4	2,4,5,6,7,8,9,10,11,12,13,14	1,2,3,4,5,6	2,4,5,6	Level V
5	2,4,5,6,7,9,10,11,12,13,14	1,2,3,5,6	5	Level VI
6	2,4,5,6,7,8,9,10,11,12,13,14	1,2,3,4,5,6	2,4,5,6	Level V
7	7,8,9,10,11,12,13,14	1,2,3,4,5,6,7,8,12,13	7,8,12,13	Level IV
8	7,8,9,10,11,12,13,14	1,2,3,4,6,7,8,12,13	7,8,12,13	Level IV
9	9,10,11,14	1,2,3,4,5,6,7,8,9,11,12,13	9,11	Level III
10	10,14	1,2,3,4,5,6,7,8,9,10,11,12,13	10	Level II
11	9,10,11,14	1,2,3,4,5,6,7,8,9,11,12,13	9,11	Level III
12	7,8,9,10,11,12,13,14	1,2,3,4,5,6,7,8,12,13	7,8,12,13	Level IV
13	7,8,9,10,11,12,13,14	1,2,3,4,5,6,7,8,12,13	7,8,12,13	Level IV
14	14	1,2,3,4,5,6,7,8,9.10,11,12,13,14	14	Level I



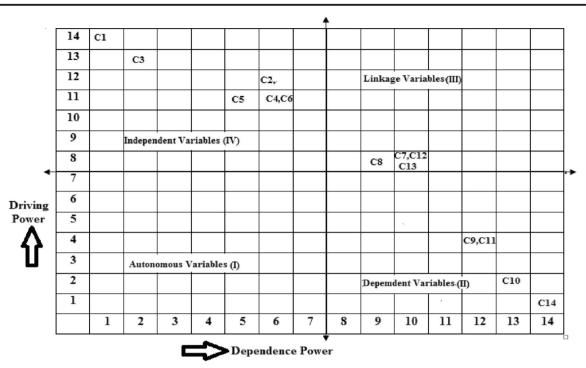
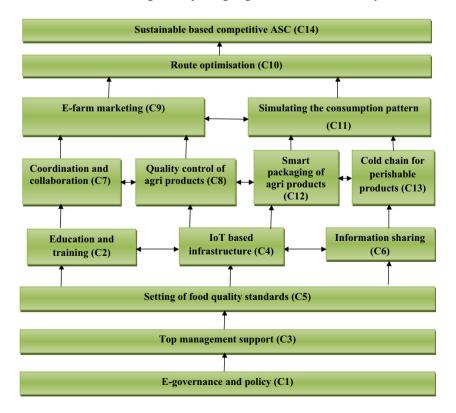


Fig. 7 ISM-based MICMAC analysis

the second important caused group and classified into an independent variable. It may provide proper training to lower supplier, mainly responsible for sustainable issues about awareness on global environmental regulations and standards, pollutants reducing by following ISO14000 series (Jayasinghe et al. 2019).

Fig. 8 ISM hierarchical model

IoT-based infrastructure (C4) is the third important cause group and clustered in the independent variable. IoT-based infrastructure systems provide important data of government and organisational data for decision-making by the FF about global demand fluctuation, regulating quality standards, monitoring for adjusting logistics action before any accidents





- 0.34306 0.29860 - 0.48284 -1.40280-0.693730.78625 0.23693 2.66483 14.00983 2.51861 3.97580 4.25985 4.98632 3.77128 2.07292 2.16171 6.09472 6.73680 6.66030 5.79176 5.18576 5.83944 0.62190 0.55530 0.60600 0.62157 0.47302 0.601190.64843 0.55891 0.32548 0.36798 0.36809 0.38264 0.32171 0.44420 0.52407 0.47802 0.44141 0.53155 ).564150.474360.460710.518300.54101C11 0.51715 0.54147 0.59836 0.53790).541140.639460.59319 0.49269 0.50301 0.541963.46995 ).56044 0.38989 0.433973.49412.4771 ).491400.42563 0.46679 0.36190 0.464390.428240.458410.36512 0.38718 0.44174 0.42933 0.45579 0.43012 5.88716 0.35725 0.43017 0.45354 0.49379 0.50852 0.47581 0.53809 0.47385 0.54668 0.38917 0.42409 0.44998 0.38140 0.38230 0.394502 Total direct relational matrix 0.380200.40424 ).402230.46867).391240.42077 0.43913 0.482990.423440.446930.461660.40416 0.33190 0.35076 0.35505 0.40263 0.38881 0.42273 0.37047 0.3991 C1**Fable 5** 

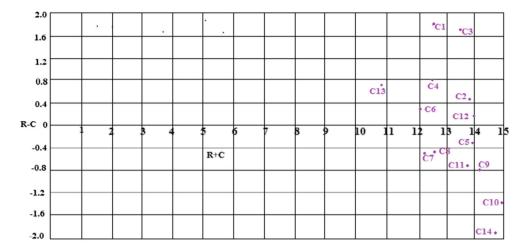
(Daneshvar Kakhki and Gargeya 2019). Cold chain for perishable products (C13) is the fourth important cause group and categorised under linkage variable. This finding may be validated as India needs cold storage round of 61.13 million metric tons but it has capacity only 32 million metric tons (The Economic Times 2017). Thus, it has a shortage of 50% cold capacity. Cold storage is required for controlling the quality of AFSC by reducing the degrading of agri-food and less contaminating of processes. Jose and Shanmugam (2019) noticed that degrading of agri-food from post-harvested stage to consumers' hand mostly occurs due to low cold storage system.

Education and training (C2) is the fifth important cause group and categorised into independent variables. This finding may be validated as it empowers the farmers and other workers of food organisation about the new emerging technologies and other global sustainable practices provided by third parties' collaboration (Mangla et al. 2017). Information sharing (C6) is the sixth important cause group and categorised into the independent variable. Effective information leads to proper communication among the multi-tier suppliers located globally in the SCM that has reduced response time to any disrupting event in SC (Ivanov and Dolgui 2020; Dun and Bradstreet 2020). Smart packaging of agri products (C12) is the seventh important cause group and act as a linkage variable. Agri-based perishable products need extra protection during handling and palletising; this may be possible sensor-based smart packing (Mangla et al. 2018; Corkery and Gelles 2020). It may further protect packed agri products against food lost due to thermal degradation during transportation in a humid climate condition of different countries (Shukla et al. 2014).

Sustainable-based competitive ASC (C14) is the most important influenced group based on (R-C) value and classified into a dependent variable based on the driving and dependent power. Sustainable-based competitiveness for AFSC means considering sustainable practices at operational, tactical and strategies level for yielding both socio-economic and environmental-build competitiveness (Singh et al. 2019; Krishnan et al. 2020). Similarly, route optimisation (C10) is the second important influenced group and classified into a dependent variable. Route optimisation enhances the competence of appropriately meeting the order which included avoiding the delays of orders, effectively managing lead times, reliable delivering. Furthermore, route optimisation may reduce GHG emissions which may lead to environmental-based global sustainable practices specifically in any epidemic outbreak (Farahani et al. 2020; Mishra et al. 2018). E-farm marketing (C9) is a third important effect group and comes under the dependent variable category. This finding may be justified as the wastage in the AFSC mostly occurs due to the large numbers of intermediates stakeholders as the number of intermediates increased; switching of agri-food reserve will be increased from one stakeholder to another, and results in degrading losses of agri-food (Schanes et al. 2018).



Figure 9 The cause and effect diagram of enablers



Simulating the consumption pattern (C11) is the fourth important effect group and classified into a dependent variable. It may help in improving the distribution channels for route optimisation at the global level for improving social and environmental sustainability. It may also regulate the prices based on the daily demands of agri-food and logistics facilities. Coordination and collaboration (C7) are the fifth important effect group and classified into linkage variable. Coordination enclosed the channels of union and secure inter-relationship together with joint decision-making and collaborating for ensuring common sustainable goals by integrating local SCM and global SCM (Agyemang et al. 2018). Quality control of agri products (C8) is the sixth important effect group and classified into linkage variable. It may segregate the agri-food products based on their origination, procuring dates, processing's lots, etc. (Tan et al. 2010; Shih and Wang 2016). Setting of food quality standards (C5) is the seventh important effect group and categorised into the independent variable. Even though food regulatory bodies like Food Safety Standards Authority of India (FSSAI) have provided standards, not every stakeholder of AFSC is fully aware of the standardised procedure of food processing and packaging (Joshi et al. 2009).

Finally, sensitivity analysis has allowed the experts to consider the robustness of their decisions. Smart packaging of agriproducts (C12) is the most sensitive enabler. C12 is categorised into effect group in scenario 2 and scenario 5. Similarly, C12 is categorised into a caused group for another scenario. Thus, C12 is highly sensitive.

#### **Theoretical contributions**

This research has highlighted the role of information exchanging among the various stakeholders of the multi-tier system in AFSC. This study supports the information processing theory (IPT) and dynamic capability theory (DCT). IPT considered the impact of information sharing on capturing the SC

dynamics and reducing uncertainty within SC. Therefore, this research connects both IPT and DCT as it involves IoT-based information sharing in a dynamic environment of fluctuating demands in the recent outbreak (COVID-19). This study has identified the enablers (information sharing, coordination and collaborations and IoT-based infrastructure, setting of food quality standards) which are accountable for information processing within a multi-tier system of AFSC to avoid the bullwhip effect. Also, this research has identified the enablers (route optimisation, E-farm marketing, smart packaging of agri products, cold chain for perishable products and simulating the consumption pattern) which are accountable for firm's dynamic capabilities of integrating, building and reconfiguring the internal and external adaptability to sustain in rapidly changing environment (COVID-19). Thus, this research has contributed to both IPT and DCT in the context of theoretical contributions.

#### Managerial and practitioners implications

Instead of the current going outbreak (COVID-19), this work seeks for identification of enablers for modelling of an IoT-based AFSC sustainability. The finding suggests some managerial implications in effectively managing IoT-based AFSC for achieving sustainable-based food security. This research may develop dynamic capabilities within a multi-tier system

Table 6 Weightage assigned to the experts during sensitivity analysis

Sensitivity run	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
Run 1	0.40	0.15	0.15	0.15	0.15
Run 2	0.15	0.40	0.15	0.15	0.15
Run 3	0.15	0.15	0.40	0.15	0.15
Run 4	0.15	0.15	0.15	0.40	0.15
Run 5	0.15	0.15	0.15	0.15	0.40
Current case	0.20	0.20	0.20	0.20	0.20



**Table 7** (R-C) results given by different experts during sensitivity analysis

Enablers	Current	Scenerio1	Scenerio2	Scenerio3	Scenerio4	Scenerio5
C1	1.80008	1.712181	2.156665	1.599417	2.497553	2.675488
C2	0.52815	0.378821	0.572488	0.502497	1.011352	0.774436
C3	1.73310	1.65859	2.188308	1.980074	1.577325	1.458863
C4	0.80199	0.805325	1.079415	0.558955	0.982139	1.184376
C5	-0.34306	-0.42728	-0.47154	-0.15221	-0.61596	-0.31443
C6	0.29860	0.349853	0.602748	0.345508	0.809607	1.442452
C7	-0.48284	-0.32971	-0.29271	-0.12641	-1.27413	-1.04767
C8	-0.47539	-0.42918	-0.51209	-0.66055	-0.4806	-0.80603
C9	-0.78625	-0.86447	-1.4014	-0.63638	-0.98969	-0.53108
C10	-1.40280	-1.00089	-2.19216	-1.80199	-1.7247	- 3.31767
C11	-0.69373	-0.86032	-0.76005	-0.8316	-1.18357	-0.4487
C12	0.23693	0.258529	-0.04325	0.521446	0.79652	-0.06022
C13	0.69688	0.310889	1.137867	0.573901	1.772701	2.185324
C14	- 1.91168	- 1.56234	- 2.06429	- 1.87265	- 3.17855	- 3.19513

of AFSC which may be utilised by the managers in both internal (top management support, education and training, smart packaging of agri products, quality control of agri products) and external information (E-farm marketing, simulating the consumption pattern, route optimisation) sharing in a turbulent environment (COVID-19) of system.

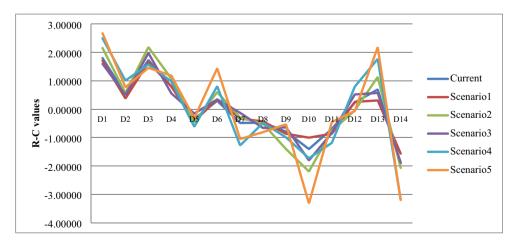
This research may also guide the managers of FF to decide the managing strategies of the lower and upper tier suppliers, e.g., either to adopt direct evaluation (casual inspection or auditing) or collaboration (worker's training and implementing sustainable practices). Furthermore, inter- and intra-organisational information sharing develops transparency and traceability in AFSC operations for responding to the agri-food scandals and risks so that subsequently action may be taken by managers of the focal companies.

It may help the managers to consider IoT for the multi-tier system in effectively information's sharing among food regulatory bodies and other multi-tier suppliers. IoT infrastructure may guide the managers in the transportation of grains and perishable vegetables from excess cultivation regions to deficient regions. Furthermore, the use of IoT-based online procurement (efarming) may facilitate efficient distribution by reducing the mediators or small retailers during the whole AFSC.

**Fig. 10** Sensitivity analysis of (R-C) values

This study may guide the managers for effective training of employee in adapting technologies involved in the cold chain, food handling for maintaining the quality of products. This research will further guide the managers for improving the packaging standards of agri products to enhance the qualities of agri products and waste reduction during the transporting and warehousing stages. Improved packaging may help the managers in the branding of their product for better product management at the globalised level. The initiatives such as RFID and BDA technology will help managers in the prediction of crop yield and demand pattern. Forecasting of crop yield may help the managers in policy-making for storage, processing, packaging, etc.

Similarly, forecasting of demand pattern may guide the managers for their logistics planning. Thus, by investing in the IoT implementation for the multi-tier system, managers have built up their firm's effectiveness for serving the upstream practices (farming, food processing and storage) and downstream (retailers, consumers) in a better manner. Furthermore, managers may get collaborated with non-profits NGOs and other third parties for facilitating the achievement of their global sustainable outcomes. It may





guide the managers for the planning of feasible IoT technology in managing food security and safety under current ongoing epidemics (COVID-19) instead of customer satisfaction and new horizons of profitability.

Finally, the classifications based on the cause and effect group of enablers may guide the managers in differentiating the autonomous and reliant variables which will guide the managers in strategic planning based on enablers' mutual inter-relationships. Managers might be capable of identifying the processes which have been previously implemented for grouping the same and thus develop dynamic capabilities within AFSC.

#### **Unique contribution**

The research develops an IoT-based multi-tier sustainable food security model for integrating sustainable and global AFSC. In any natural epidemic outbreaks (COVID-19), this research has focused both on agri-food production and optimised distributing system by going beyond tier 1 supplier. Thus, this research may help in the reduction of GHG emission from lower-tier/upstream and food wastage for attaining environmental- and socioeconomic-based global sustainability within AFSC.

This research may act as a very initial step for providing sufficient food grains/products to growing populations with improved technology-based farming practices and reduced farmlands. Furthermore, this paper proposed a quantitative view for developing the hierarchical inter-relationships between enablers of IoT-based agri-food security system based on ISM-DEMATEL approach.

#### Conclusion

In the phase of recent epidemic outbreaks (COVID-19), the world has been paused in the centre of disruptive risk at the global level. Currently, AFSC needs to be more flexible and sustainable which have risk-mitigating capabilities. This research focused on ensuring sustainable collaboration of multi-tier system by using different configurations and governing mechanisms based on several IoT technologies. Thus, the current study focused on information processing of the multi-tier system (IPT) to develop dynamic's capabilities (DCT) within AFSC. To tackle the risks of food security and food scandals, this research proposed an ISM-based systematically arranged hierarchal structure of the enablers involved in IoT-driven multi-tier system. Furthermore, F-DEMATEL approach is employed for showing the strength of cause and effect groups of enablers. The findings of the research show that E-governance and policy (C1) are the most important cause group, and sustainable-based competitive ASC (C14) is the most important influenced group. The enablers under caused or influenced are critical and tend to affect the entire system. On the other side, enablers under dependence group are critical and tending influenced by the entire system. Finally, sensitivity analysis has been made for checking the robustness of the result or experts accuracy. Based on sensitivity analysis, it has been noticed that in all five scenarios, C13 enablers have got first rank and C14 has ranked fourteen. Furthermore, enablers C11 and C10 are the most sensitive enablers. Lastly, the research framework presented in this paper is validated by taking a case company (XYZ) of perishable agri products.

Though the present has given some important results, the present paper still has some limitations. Although an extensive literature review has been made, still, there is a possibility of not considering some enablers for developing IoT-based sustainable AFSC system. Another limitation of this study is the response biasing associated with the subjective weight provided by the experts. Any biasing may affect the results of the enablers' analysis. Furthermore, the proposed research is entirely based on IPT and DCT approach. Still, there is a scope of some other theoretical approach like stakeholder theory or any other. Furthermore, in the future, more enablers may be taken by using some validation model like structural equation modelling. In the future, this research analysis may extend to some other theories like stakeholder theory (ST) and resource-based theory (RBT) for understanding the role of multi-tier suppliers. In the future, the results may be validated by case studies of any other dynamic supply chain like pharmaceutical industries and health care supply chain.

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**Authors' contributions** Sanjeev Kumar: ideas, conceptualisation, writing- original draft preparation, data collection and curation, methodology, formal analysis

Sunil Luthra: ideas, writing- original draft preparation, conceptualisation, formal analysis, project administration, critical review, commentary and revision

Dixit Garg: data collection and curation, formal analysis, supervision, reviewing and editing

Data Availability All the data has been provided in the manuscript.

#### Compliance with ethical standards

**Ethics approval and consent to participate** All authors follow the ethics in the research and provide consent to participate in the research.

**Consent for publication** All authors provide consent for publication.

**Competing interests** The authors declare that they have no competing interests.

#### **Appendix 1. Sample questionnaire**

Dear respondents

Greetings.

This research has been made for identification and analysis of enablers of an IoT-based AFSC sustainability in any



disruption of SC caused by natural epidemics (COVID-19). For developing an IoT-based sustainable food secure system. This sample is also a part of the present research work. Your response to the questions will not be shared to any organisation. Your response may guide to analyse the identified enablers provided by the literature. We would be grateful and highly obliged if you respond to some of the questions in section I and filling up the response sheet in section II. All the personal information will not be shared to anyone.

Sincerely Authors

Section I

General information about experts

Please click only one option

- 1. What is your basic qualification level?
- Graduate
- Postgraduate
- Doctorate
- Any other, please specify ......
- 2. What is your work experience?
- Less than 10 years
- 10–15 years
- 15-20 years
- Greater than 20 years
- 3. What is the area of your expertise related to IoT-based food security system?

- Logistics department
- Food and worker safety
- · Government regulatory bodies
- Environmental and disaster management
- · Agri-food procurement strategies
- · Any other, please specify......
- 4. What is the designation of the selected decision-makers in a particular organisation?
- Manager
- Supervisor
- Chief executive officer
- · R&D team member
- Any other, please specify.......

Section II

Decision-maker's preference for the identified enablers

Response sheet: Study the interaction among identified enablers for ISM approach

ISM approach has been employed to study the interaction among identified enablers. According to the procedure of ISM, we need your judgement in the development of SSIM, following four denotations used for correlating among two-variable "i" and "j".

V: i drive the j.

A: j drives the i.

X: i and j each other.

O: i and j are unrelated

Please give your response (only blank spaces) for SSIM development of enablers.

S. no.	Enablers for IoT-dependent sustainable agri-food secure model														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	E-governance and policy(C1)	-													
2	Education and training (C2)	-	-												
3	Top management support (C3)	-	-	-											
4	IoT-based infrastructure (C4)	-	-	-	-										
5	Setting of food quality standards (C5)	-	-	-	-	-									
6	Information sharing (C6)	-	-	-	-	-	-								
7	Coordination and collaboration (C7)	-	-	-	-	-	-	-							
8	Quality control of agri products (C8)	-	-	-	-	-	-	-	-						
9	Smart packaging of agri products (C9)	-	-	-	-	-	-	-	-	-					
10	Route optimisation (C10)	-	-	-	-	-	-	-	-	-	-				
11	Simulating the consumption pattern(C11)	-	-	-	-	-	-	-	-	-	-	-			
12	E-farm marketing (C12)	-	-	-	-	-	-	-	-	-	-	-	-		
13	Cold chain for perishable products (C13)	-	-	-	-	-	-	-	-	-	-	-	-	-	
14	Sustainable-based competitive ASC (C14)	-	-	-	-	-	-	-	-	-	-	-	-	-	-



Response sheet: Analysing the identified enablers to understand their causal relations

Please provide the rating to the following enablers on 5-point Likert scale for developing a direct relational matrix. For measuring the strength of interaction/association between variables, a TFN (triangular fuzzy number) scale as given, i.e.,

(0,0.1,0.3) for (no interaction), (0.1,0.3,0.5) for (very low interaction), (0.3,0.5,0.7) (low interaction), (0.5,0.7,0.9) (high interaction) and (0.7,0.9,1) (very high interaction), respectively. Furthermore, based on your expertise, you may add/delete any other variable.

S. no.	Enablers for IoT dependent sustainable agri-food secure model														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	E-Governance and policy(C1)	-													
2	Education and training (C2)		-												
3	Top management support (C3)			-											
4	IoT-based infrastructure (C4)				-										
5	Setting of food quality standards (C5)					-									
6	Information sharing (C6)						-								
7	Coordination and collaboration (C7)							-							
8	Quality control of agri products (C8)								-						
9	Smart packaging of agri products (C9)									-					
10	Route optimisation (C10)										-				
11	Simulating the consumption pattern (C11)											-			
12	E-Farm marketing (C12)												-		
13	Cold chain for perishable products (C13)													-	
14	Sustainable-based competitive ASC (C14)														-
Autho Depar	of experttrip	T	hank	you	ı ver	y mi	uch :	for g	ivin	g val		resp	onse. he bo	x.	



#### **Appendix 2**

 Table 8
 Initial SSIM for enablers based on experts

	C1	C2	С3	C4	C5	C6	C7	C8	С9	C10	C11	C12	C13	C14
C1	-	О	V	V	V	V	V	V	V	V	V	0	V	V
C2		-	O	V	V	X	V	V	V	V	V	V	V	V
C3			-	V	V	V	V	V	O	O	O	O	O	V
C4				-	O	X	V	O	V	O	O	V	V	V
C5					-	V	V	O	V	V	O	O	O	V
C6						-	O	O	V	V	V	V	O	V
C7							-	A	V	V	V	V	X	V
C8								-	O	V	V	V	A	O
C9									-	V	X	A	A	V
C10										-	O	O	O	V
C11											-	O	O	O
C12												-	V	O
C13													-	O
C14														-

 Table 9
 Normalised direct relational matrix based on an aggregate rating of experts

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	0.0137	0.0798	0.0674	0.0464	0.0755	0.0591	0.0920	0.0796	0.0758	0.0798	0.0836	0.0591	0.0547	0.0879
C2	0.0507	0.0137	0.0836	0.0631	0.0960	0.0630	0.0672	0.0549	0.0342	0.0960	0.0839	0.0960	0.0507	0.0879
C3	0.0672	0.0960	0.0137	0.0588	0.0920	0.0562	0.0836	0.0796	0.0712	0.0631	0.0836	0.0879	0.0562	0.0920
C4	0.0340	0.0712	0.0547	0.0137	0.0713	0.0758	0.0879	0.0672	0.0712	0.0755	0.0302	0.0549	0.0758	0.0960
C5	0.0507	0.0960	0.0588	0.0588	0.0137	0.0674	0.0712	0.0591	0.0960	0.0836	0.0712	0.0137	0.0591	0.0960
C6	0.0549	0.0712	0.0506	0.0549	0.0591	0.0137	0.0630	0.0591	0.0836	0.0672	0.0549	0.0758	0.0137	0.0796
C7	0.0591	0.0588	0.0588	0.0631	0.0630	0.0423	0.0137	0.0758	0.0588	0.0712	0.0672	0.0672	0.0423	0.0137
C8	0.0178	0.0592	0.0716	0.0547	0.0674	0.0507	0.0672	0.0137	0.0758	0.0758	0.0712	0.0507	0.0340	0.0839
C9	0.0589	0.0220	0.0507	0.0547	0.0920	0.0588	0.0712	0.0631	0.0137	0.0836	0.0879	0.0960	0.0465	0.0839
C10	0.0589	0.0589	0.0259	0.0796	0.0960	0.0549	0.0575	0.0796	0.0836	0.0137	0.0588	0.0839	0.0438	0.0960
C11	0.0547	0.0547	0.0547	0.0342	0.0549	0.0716	0.0507	0.0713	0.0836	0.0879	0.0137	0.0549	0.0758	0.0960
C12	0.0591	0.0879	0.0796	0.0672	0.0260	0.0634	0.0423	0.0673	0.0960	0.0960	0.0836	0.0137	0.0507	0.0960
C13	0.0547	0.0423	0.0588	0.0465	0.0549	0.0218	0.0340	0.0423	0.0712	0.0878	0.0713	0.0758	0.0137	0.0713
C14	0.0674	0.0672	0.0464	0.0588	0.0712	0.0589	0.0340	0.0465	0.0712	0.0960	0.0836	0.0713	0.0423	0.0137

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