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

Sanjeev Yadav
Research Scholar, Department of Mechanical Engineering, National Institute of Technology, Kurukshetra-136119, Haryana, India
Dr. Sunil Luthra (sunilluthra1977@gmail.com)
Assistant Professor, Department of Mechanical Engineering, Ch. Ranbir Singh State Institute of Engineering and Technology, Jhajjar-124103, Haryana, India https://orcid.org/0000-0001-7571-1331
Dixit Garg
Professor, Department of Mechanical Engineering, National Institute of Technology, Kurukshetra-136119, Haryana, India

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Method Article

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Sanjeev Yadav
Research Scholar, Department of Mechanical Engineering,
National Institute of Technology, Kurukshetra-136119, Haryana, India
E-mail: ysanjeev949@gmail.com

Dr. Sunil Luthra*
Assistant Professor, Department of Mechanical Engineering,
Ch. Ranbir Singh State Institute of Engineering and Technology, Jhajjar-124103, Haryana, India
E-mail: sunilluthra1977@gmail.com
Phone-91-9466594853

Dr. Dixit Garg
Professor, Department of Mechanical Engineering,
National Institute of Technology, Kurukshetra-136119, Haryana, India
E-mail: dixitgarg@yahoo.co.in

*Corresponding author

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Abstract: The resilience of Agri-Food Supply Chain (AFSC) due to recent epidemics outbreak (COVID-19, SARS-CoV-2) has not been matching with, globalisation of AFSC, and complicated networking system of AFSC and thus poses huge global sustainable issues. Thus, the aim of this research is the modelling of the sustainable AFSC secure mechanism managed through different emerging application of Internet of Things (IoT) technology (Blockchain, Robotics, Big data analysis and Cloud computing). Competitive Supply Chain Management (SCM) 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 and environments and economical practices. This paper also studies the interrelationship and their cause and effect magnitude among various enablers contributing to IoT based food secure model. The methodology used in the paper is Interpretative Structural Modelling (ISM) for establishing interrelationship among the variables and Fuzzy-Decision-Making Trial and Evaluation Laboratory (F-DEMATEL) to provide the magnitude of the cause–effect strength of the hierarchical framework. Finally, this paper has limitation of taking only factors related to food security system by considering present natural epidemics of COVID-19. In future, other dimensions of AFSC may be considered based on COVID-19 epidemics effect on AFSC.

Keywords: Agri-Food Supply Chain (AFSC); COVID-19; Global Sustainability; Internet of Things (IoT); Food security; Multi-tier; Supply Chain Disruption.

1. 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 shortage of retailers, distribution centres and transportation facilities. Consequentially, insufficient agri-food products shortages and delaying of services propagated towards AFSC's downstream, leads to the rippling effect and competitive disadvantages in the form of performance degradation (Dolgui et al., 2018; Dolgui et al., 2020; Li and Zobel, 2020). Araz et al. (2020) noticed that the COVID-19 outbreak "breaking many global supply chains" as the World Health Organisation (WHO) declared COVID-19 as pandemic. In this natural epidemics condition, it is prerequisite to considered multi-tier sustainable issues of AFSC.

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 Focal Firm (FF) across different countries by integrating with their sub-suppliers in a multi-tier system (Overstreet et al., 2013). As per the report of economic and social department (United Nations), the world wide population may increase to 8.5 billion by 2030. So, globalised agri-production must be increase 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 Green House 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).

Multi-tier based sustainability of AFSC may help in reduction of loses at different phases with minimising of deterioration of the agri-food qualities, and thus contributed 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 area of research, academics and policy making. 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 (Misangyi et al., 2016). To overcome above problems, IoT based SCM must be employed for ensuring transparent, traceable and accountable system at different levels of AFSC (Kauppi and Hannibal, 2017). This paper explores different IoT technologies like Blockchain, Artificial Intelligence (AI), Robotics, RFID, etc. (Hartmann and Moeller, 2014; Aboah et al., 2019). The following research objectives may be set:

- Identification of the factors in driving IoT driven multi-tier 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 the given research questions:

- What may be needs of IoT driven multi-tier food security system in any natural epidemics (COVID19)?

In current scenario, tracking of processes in AFSC is critical by providing a basic idea of agri-product's past background, operational as well as processes throughout the SCM; however traditional AFSC has not been tackling this kind of tracking mechanism. Further, 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 of IoT driven food security system for ensuring sustainability at globalised level.

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

Different enablers involves 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 model have been opted 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-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). Further, sensitivity analysis needs to be performed to check the result robustness.

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

ISM- DEMATEL based analysis of the identified enablers was used by managers in making their longer termed basis resilient strategies. This research has the capability to guide the managers in adoption the most feasible IoT based technologies in AFSC with economical based customer's satisfaction with new horizons of productivity (Wilhelm et al., 2016b). Further, organisation of proposed research: Section 2 elaborates the Literature Review. Section 3 elaborates research methodology. Section 4 provides practical applications of this study with numerical illustration. Section 5 discussed findings with its implications. Finally, Section 6 contributes to conclusions with limitations and future scope of this research.

2. Literature Review

In the given sub-sections, literature work has been made for the identification of enablers and to identify research gaps.

2.1 Requirement of Global Sustainability under COVID 19 Outbreak

With respect to 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 Bradsteet, 2020). Thus, food organisations required to implement sustainable practices at different multitier stages related to processing, transporting, retailing, packing, handling, cold storage and loading. Therefore, there is a need of IoT based system for communicating information of agri-food safety standards in an effective way to different suppliers of AFSC (Luvisi, 2016; Talavera et al., 2017). Further, in this global pandemic situation, there is a growth opportunities exist for the industries to provide quick response/online purchasing (e-commerce) or local/short SC based supplying the requirements of consumers and thus achieving sustainability (Farahani et al., 2020; Li and Zobel, 2020).

2.2 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 and initiatives driven by FF, ES (External Supports) provides by government and NGOs, Third Parties (TP) and some other stakeholders. Direct governing mechanisms needs FF to provide time and capital for effectively establishing the associations with multi-suppliers and indirect governing mechanisms depends on third parties standards and regulation without any direct influence of FF. This governance system provides diverse implications for sustainable outcomes in Global AFSC (Formentini and Taticchi, 2016; Zhu et al., 2017) as shown in Figure 1.

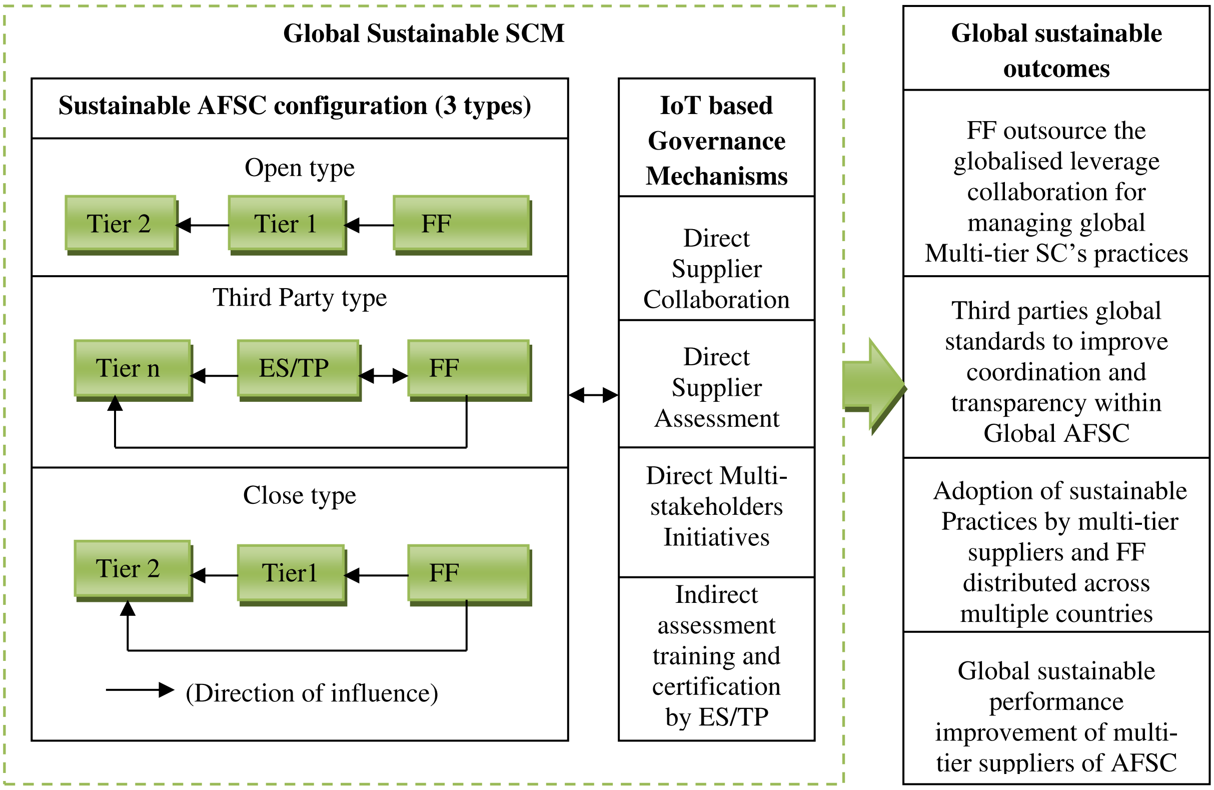


Figure 1: Research framework of Sustainable AFSC and Global AFSC

2.3 Identification of Factors for IoT based Multi-tier Sustainable Food Security System

Depending on literature survey, fourteen factors have been identified for developing IoT based sustainable multi-tier food security system 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 (www.springerlink.com), Wiley (www.wiley.com) and IEEE journals (Chadegani et al., 2013). The main searched criteria consisting of published articles ranging from year 2005 to 2020. Majority of the reviewed papers have been taken from the International Journal of Production Economics, Journal of Cleaner Production and International Journal of Production Research etc. 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 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 Figure 2.

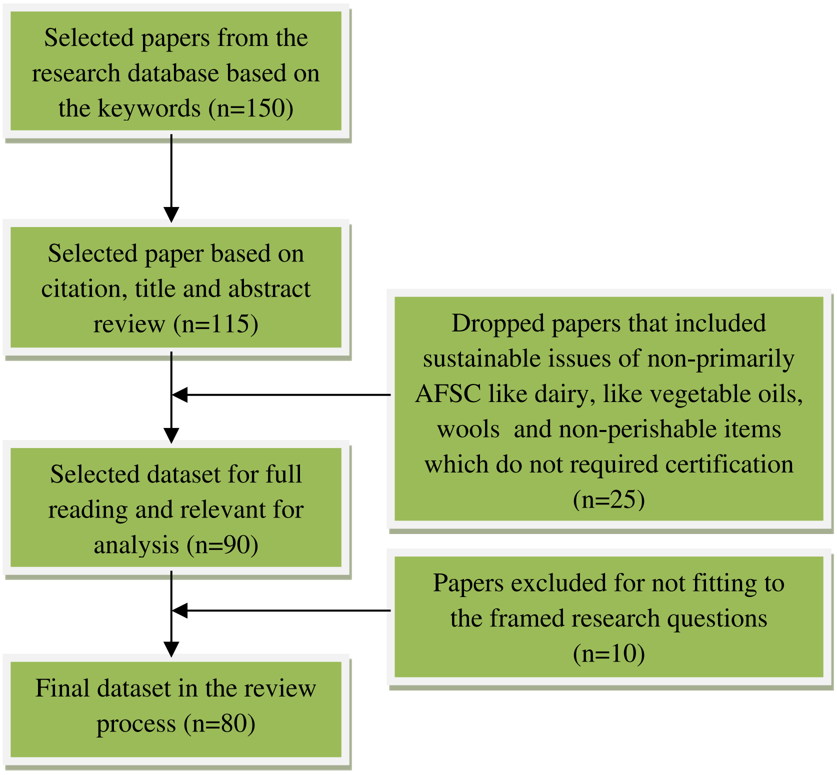


Figure 2: Article searching, selection and exclusion process

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

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 practises by sharing efforts of government organisation, NGOs, CAP, food processing organisations and farmers by the means of third party type multi-tier and indirect governing mechanism.	Wolvert et al., 2017; Armanda et al., 2019
Education and training (C2)	Technical training includes awareness of multi-tier sub suppliers about IoT technology, food	Sharma and Vrat, 2018

	regulation standards like Hazard Analysis and Critical Control Point (HACCP), Good Hygiene Practices (GHP),International Organisation for Standardisation (ISO) for food product handling by maintaining social distancing and farmer to implement IoT based farming practices.	
Top management support (C3)	It insures funds, proper training, award/reward sharing and awareness program about technical (IoT technology) knowledge, food products handling practices, effective information sharing. It also provides PPE, gloves, mask for the workers. Thus, it ingrates sustainable initiatives to global SCM.	Linton and Vakil, 2014; 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 Zig bee etc.	Li et al., 2014; Saberi et al., 2019
Setting of food quality standards (C5)	Imposing the third parties' food regulation standards by the means 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 multi-tier system. Further, 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 supports the identification of human and organisational risks related to agri food safety and security to ensure global sustainability.	Luvisi, 2016; Nakandala et al., 2017
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 study of their pattern recognised the quality control processes for better controlling of quality of agri products.	Bosona and Gebresenbet, 2013
E-farm marketing (C9)	E farm marketing is the using of on-line portal for connecting farmer/food processing organisation to the big retailers connected to focal firms across the different countries. Improved information sharing based on RFID tags/readers and barcodes technologies also lead to E-farm marketing.	Masiero, 2015;Manavalan and Jayakrishna, 2019

Route optimisation (C10)	It provides the optimum route to the consumers by using cloud computational technology which is for the optimisation of distributing network of different countries.	Validi et al., 2014; Irani and Sharif, 2016
Simulating the consumption pattern (C11)	It provides simulation based big data analysis for matching the demand of consumers of globally located. Thus, it may predict for the planning of agri-food distribution to ensure agri-food security and safety.	Badami and Ramankutty, 2015; Vanderroost et al., 2017
Smart packaging of agri products (C12)	It is AI based intelligent packing of agri products, so that a best before date may be decide to simulate the barcode with expiring date of agri products by 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 interfaced refrigerant facility. The refrigerant or cold chain intensity may be adjusted depending on the type of global climate in different countries, quantities of agri products e.g. food grains or perishable vegetables.	Talavera et al., 2017; Benis and Ferrão, 2018
Sustainable based competitive AFSC (C14)	This system focused on AFSC processes by safe distributing, safe storage and reduction of food loss during natural epidemic outbreak (COVID 19) for ensuring competiveness with multi-tier sustainability at global level across different countries.	Gupta and Ivanov, 2020; Li and Zobel, 2020; Gwynn-Jones et al., 2018

2.4 Research Gaps

The following research gaps have been reported based upon the review of literature:

- In previous literature work, most of the work has focused only on the increasing agri-production or agri based yield and less literature work has been done on minimisation of AFSC losses or agri food security issues like crop insurance, simulation of demand and smart contact etc. (Naik and Suresh, 2018).
- A few researches have supported the environmental, economical and social sustainable aspects at globalised level while reviewing the SC disruption (COVID 19) issues. There is a requirement of sustainable based quick processes transaction during the 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 on 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, which may interact on real time basis to develop a resilience and effective system for mitigating the disruption risks (Papadopoulos et al., 2017; Ivanov et al., 2019).
- Most of the previous work has only oriented in one direction, either worked as qualitatively or quantitatively approach. Only few studies have taken case studies along with numerical analysis of enablers with their individual effects on the entire system of AFSC for an IoT driven global sustainable AFSC's security system (Ho et al., 2015; Moazzam et al., 2018).

3. Research Methodology

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

[Figure 3 about here]

For the evaluation of the factors for IoT based sustainability in AFSC. In the first phase, identification of enablers based on reviewed literature and expert's suggestions. By this procedure, fourteen important factors have been identified and verified by experts' suggestions. In the second phase, identified factors have been evaluated by using combined ISM and fuzzy DEMATEL. There are different techniques available such as ISM, Total ISM, DEMATEL and Analytical Hierarchical Process (AHP) for providing a structure based relationships of the enablers but could not provide the quantified view of the inter-relationships (Dos Muchangos et al., 2015; Luthra et al., 2016; Chauhan et al., 2018). Hence, for the quantification of the inter-relationships for any sophisticated system, integrated ISM-DEMATEL approach may be applied. 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 of integrating DEMATEL with the fuzzy set theory proposed by Zadeh (1965).

3.1 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).

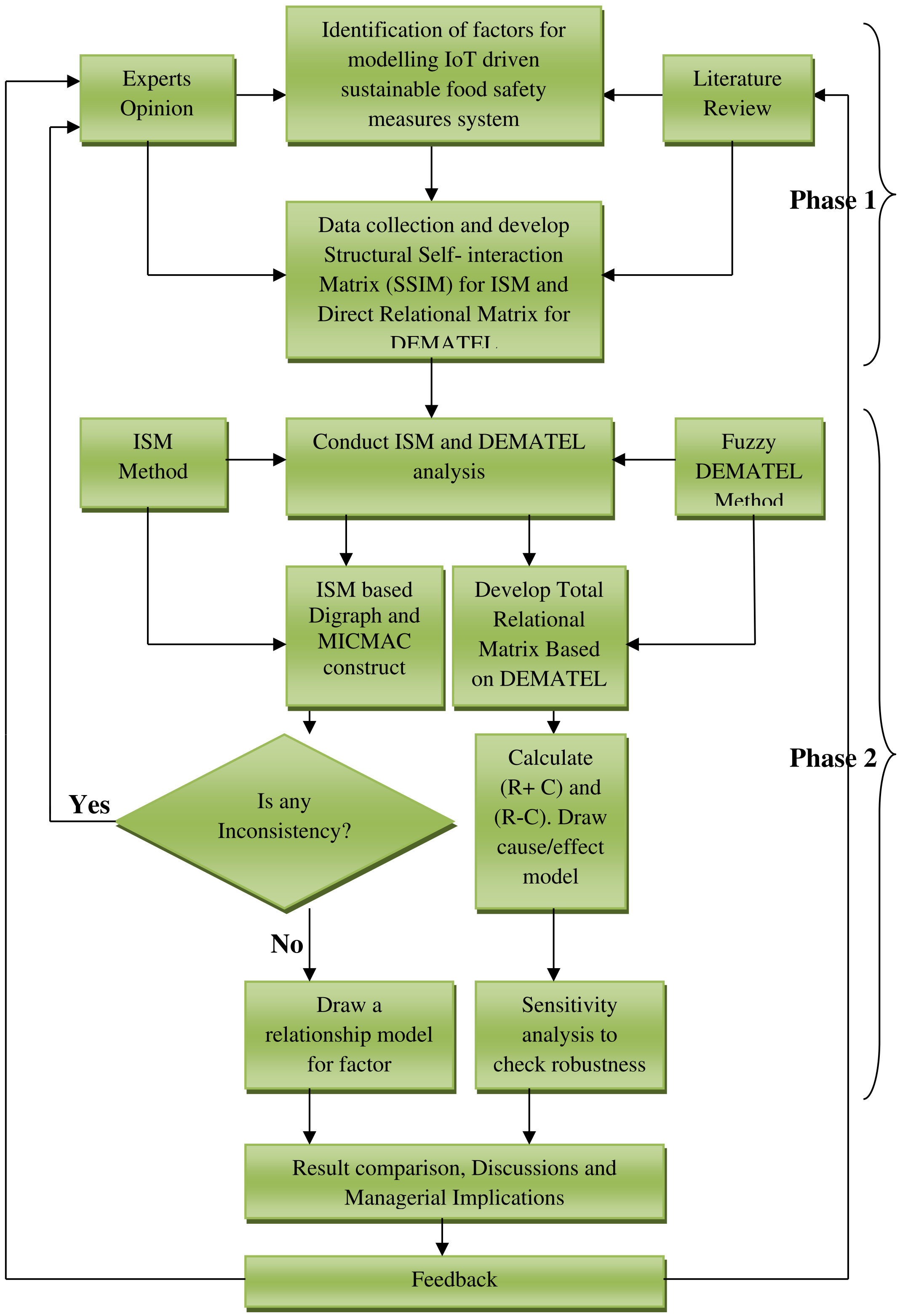


Figure 3: Framework of the proposed research

ISM is commonly chosen among other modelling methods as it elaborates the type of inter-relationships type between enablers (Luthra et al., 2016; Shen et al., 2016). The stepwise explanation of this methodology is given in research framework as shown Figure 3. 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 the contextual inter-relationships between enablers given by the expert's suggestions.

(3) Constructing a 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 final reachable matrix by finding out any transitivity links between the identified enablers.

(5) Formation of the partition levels based on final reachable matrix.

(6) Conducting the MICMAC analysis for the identified enablers.

(7) Constructing the digraph.

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

3.2 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, Fuzzy based 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 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 Figure 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), i.e. (0,0.1,0.3) for (No relation) for , (0.1,0.3,0.5) (Very Low relation), (0.3,0.5,0.7) (Low relation), (0.5,0.7,0.9) (High relation) and (0.7,0.9,1) (Very High relation) respectively.

$$\mu_a(x) = \begin{cases} 0, & \text{if } x < l \\ (x-l)/(m-l) & \text{if } l \le x \le m, \\ (r-x)/(r-m) & \text{if } m \le x \le r, \\ 0, & \text{otherwise} \end{cases}$$

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

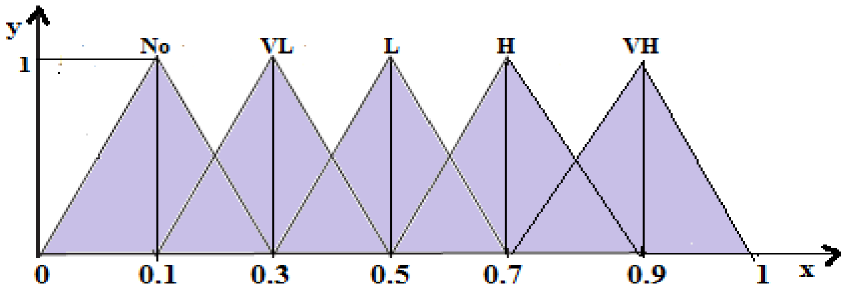


Figure 4: Triangular fuzzy numbers

2. Normalisation of direct relational table into normalised direct relational matrix S by using five steps as explained below (Opricovic and Tzeng, 2003). A five-step algorithm as follows for a particular fuzzy number (l, m, r):

Step1. Normalisation

$xr_{ij}^{n} = (r_{ij}^{n} - minl_{ij}^{n}) / \Delta_{min}^{max}$

$xm_{ij}^{n} = (m_{ij}^{n} - minl_{ij}^{n}) / \Delta_{min}^{max}$

$xl_{ij}^{n} = (l_{ij}^{n} - minl_{ij}^{n}) / \Delta_{min}^{max}$

Step2. Compute right (rs) and left (ls) normalisation values:

$$xrs_{ij}^{n} = xr_{ij}^{n} / (1 + xr_{ij}^{n} - xm_{ij}^{n})$$

$$xls_{ij}^{n} = xm_{ij}^{n} / (1 + xm_{ij}^{n} - xl_{ij}^{n})$$

Step3. Compute total normalised crisp values:

$$x_{ij}^{n} = [xls_{ij}^{n} - (xls_{ij}^{n} \times xls_{ij}^{n}) + (xrs_{ij}^{n} \times xrs_{ij}^{n})] / (1 + xrs_{ij}^{n} - xls_{ij}^{n})$$

Step4. Compute crisp values:

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

Step5. Integrate crisp values:

$z_{ij} = (z_{ij}^{1} + z_{ij}^{2} + ... z_{ij}^{p})/ p$, where p is numbers of decision makers

S= k × D

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

3. Construct a total relation matrix T as: T= S $[I - S]^{-1}$, where I matrix is identity matrix
4. Drawing a cause and effect diagram. In this x axis (R+ C) denotes the cause axis and y axis (R- C) denotes causal based effects axis as shown below:

T= $[t_{ij}]_{n\times n}$, i, j= 1, 2…..n

$[R_i]_{n\times 1} = (\sum_{j=1}^{n} t_{ij})_{n\times 1}$

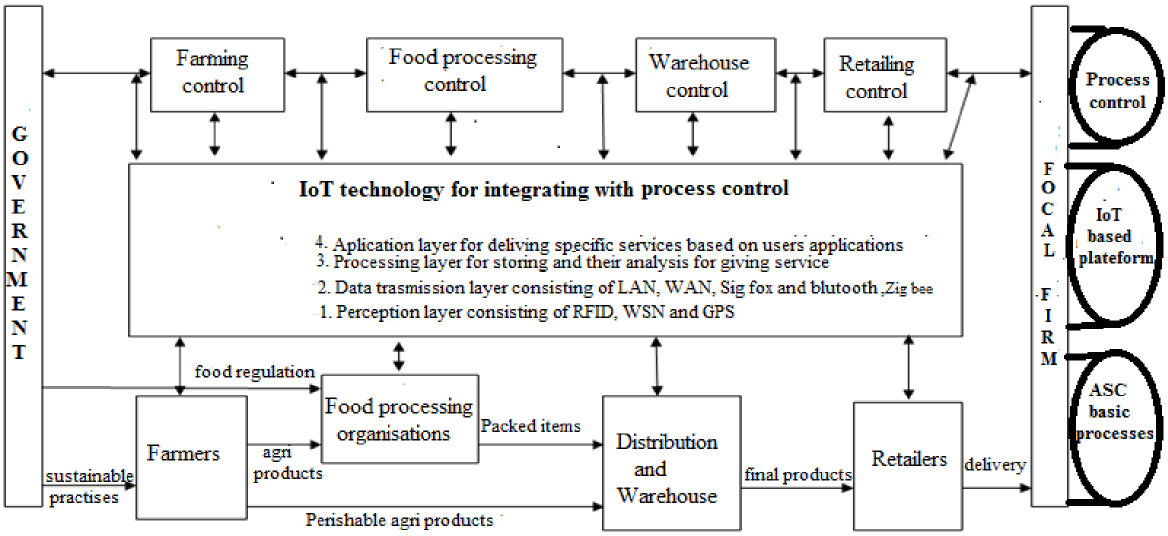
$[C_j]_{1\times n} = (\sum_{i=1}^{n} t_{ij})_{1\times n}$

4. Case Illustration

This section includes a case study, questioner's development and finally numerical illustration. The case illustration consists of three sub-sections. These sub-sections are explained below in subsequent sections.

4.1 Description of the Firm

XYZ (fictitious name) act as a Focal Firm (FF) in a multitier system of AFSC which is located in India for delivering the perishable packed vegetables to most of the districts. Currently firm's processes consists of vegetables harvesting, food grains processing, packing and commercialisation of agri- product items consists of large varieties of cold storage based perishable products. Depending on consumer's requirement in different demographic regions, the packed products range from 5Kg to 40Kg. Vegetables normally used as raw products are potatoes, fresh cabbages, peas, groundnuts, mushrooms and carrots. Most of the Food Processing Plants (FPP) of XYZ is situated at small distance from farmlands, which are dedicated for cultivating, cutting, packaging fresh vegetables by keeping in a cold ambient condition. Each processing plant has special facilities to a particular crop cultivations and cold storage of Work in Process Inventory (WIPI) to avoid spoilage. FF has one Main Processing Plant (MPP) for handling final packed agri products and distributions to retailers and end consumers. The whole multi-tier system of FF initiated from the planning of consumer's demands and ends by delivering of agri products to FF at the consumer's end. Based on IoT infrastructure, FF intended to directly approach tier 1 (Big retailers) and may directly/indirect controlled the lower tier (food processing, distribution and farmers) by itself and collaborating with external supports. This entire process is given in Figure 5 and Figure 6.



(Information flow) ⟷ (Product flow) ⟶

Figure 5: Complete framework of the proposed case study for XYZ firm

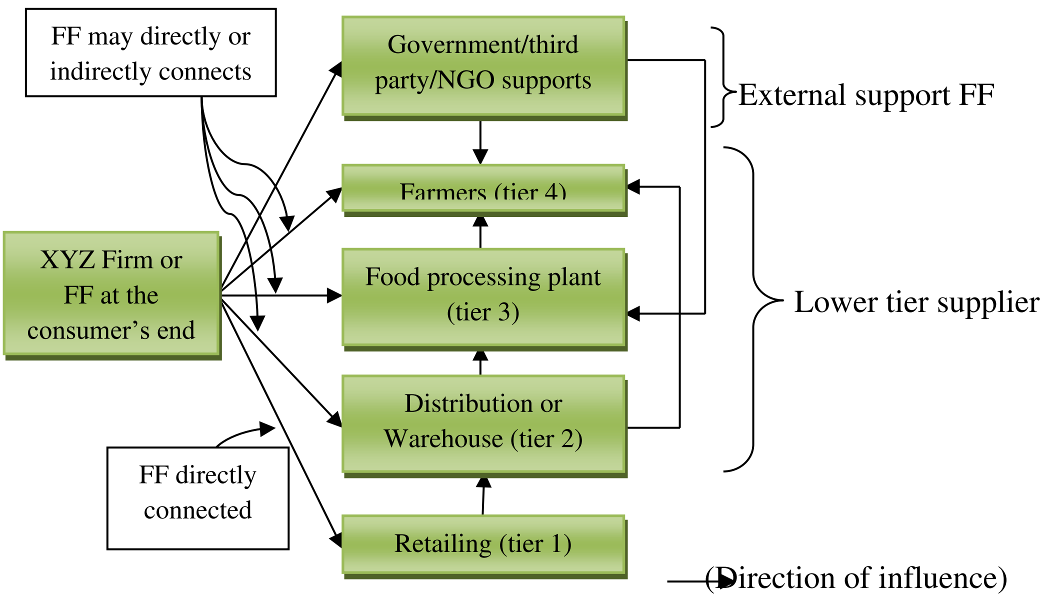


Figure 6: Multi-tier view of AFSC

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. Further, 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.

4.2 Questionnaire Development and Data Collection

The framing of questions takes place based on the research panel of five experts to rate and analysis of the identified factors as shown in Appendix A. A total of 25 experts were approached from several case companies. In this context, a questionnaire was framed by considering all enablers in the literature and collect the response either through mail or postal. Out of 25 experts only 5 experts have filled their responses either through online or offline. Thus, 20 percent response rate has been used in this study. These participated 05 experts were categorised as their demographic characteristics. As per professional qualification level of experts, 02 experts were graduates, 02 were post graduate and 01 was doctorate. Most of the decisions makers (experts) were highly experienced ranging from5 to 25 years. Based on the filled questionnaire, the decisions makers involved in this research were the Logistics' Supervisors (E1), the Food and Worker Safety's Supervisors (E2), the Chief Executive Officers (E3) of government regulatory bodies 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 order to farmers/suppliers for primary agri products like fresh vegetable and food grain , Research and Development (R&D) team member (E5) having environmental (ISO 14001 standards) expertise and disaster management (ISO 37120 standards)expertise.

4.3 Numerical Illustration

This section explains the numerical illustration of the study. It consists of three sub section namely ISM application, DEAMATEL application and sensitivity analysis as explained below.

4.3.1 ISM application

This section elaborates different steps of ISM by the means of numerical illustration. The complete sequence of procedure is given below.

4.3.1.1 Structural self-interaction matrix

For the establishment of the relationships among the enablers for developing IoT based sustainable security system, four notations have been applied for expressing the relationships among the enablers i and j as explained below.

V: Enabler i facilitating the Enabler j.
A: Enabler j facilitating the Enabler i.
X: Enabler i and j facilitating each other.
O: Enabler i and j are not related.

Experts given in sub-section 4.2 were requested to provide their agreement for 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 B1 of Annexure B.

4.3.1.2 Initial and Final reachability matrix

The SSIM has been transformed to an initial reachability matrix by placing the binary digits (0, 1) at the position of V, A, X and O for (i, j) as explained in below Table 2.

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

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

Table 3: Final reachable matrix for 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

4.3.1.3 Levelling based partitions

By using final reachability matrix the intersecting point of antecedent set (depending power) and reachability set (driving power) has determined. Iterating procedure will carry on for identifying each level as shown in Table 4.

Table 4: Initial iteration matrix for enablers

	R.S	**A.S**	**I.S**	**Levels and Iterations**
1	1,2,3,4,5,6,7,8,9,10,11,12,13,14	1	1	LEVEL VII
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 VI
4	2,4,6,7,8,9,10,11,12,13,14	1,2,3,4,5,6	2,4,6	LEVEL V
5	2,4,5,6,7,9,10,11,12,13,14	1,2,3,5,6	2,5,6	LEVEL V
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

4.3.1.4 Classification of factors (MICMAC analysis)

Cluster or sector formation of enablers mainly based on the value of driving and depending power as indicates in Figure 7.

[Figure 7 about here]

This cluster formation is similar as given by Kamble et al. (2018b). The first cluster or quadrant is belongs to “autonomous variables” having weak driving and depending values. These variables are weakly linked with other enablers or negligible impact on the entire system developed by ISM approach. In this study, autonomous sector is empty suggesting that every enabler is weakly or strongly associated in the model. Second sector belongs to depending variables having high depending and low driving values. These variables require special focused. Enablers C9, C10, C11 and C14 are the part of this sector.

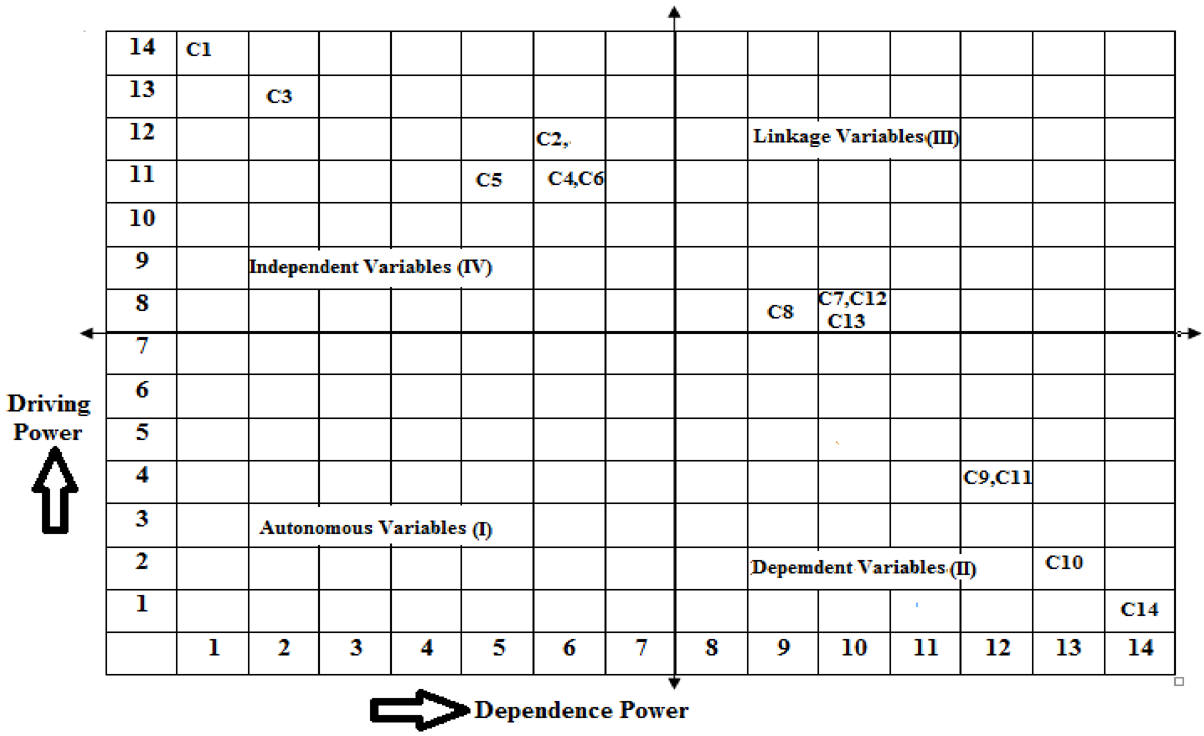


Figure 7: ISM based MICMAC analysis

Third sector belongs to linkage variables with high driving and depending values. These variables are unstable and having closed looping effect on other variables. Enablers C7, C8, C12 and C13 are the part of this sector. Fourth sector belongs to independent variables with high driving and low dependence power. Enablers C1, C2, C3, C4, C5 and C6 belong to this region. These variables require special planning of policies maker.

4.3.1.5 ISM based hierarchical structure

Based on the final reachability matrix (Table 3) and level partitioning (Table 4), an ISM based hierarchical model of enablers for IoT driven multitier sustainable food security system has been developed as depicted in Figure 8.

[Figure 8 about here]

4.3.2 Fuzzy DEMATEL application

After formulation of systematic structure by using ISM technique, the fuzzy DEMATEL methodology has been applied for developing cause and effect group for enablers. Fuzzy based approach handles the vagueness and biased expert's decisions. Step wise procedure of Fuzzy DEMATEL methodology is given below.

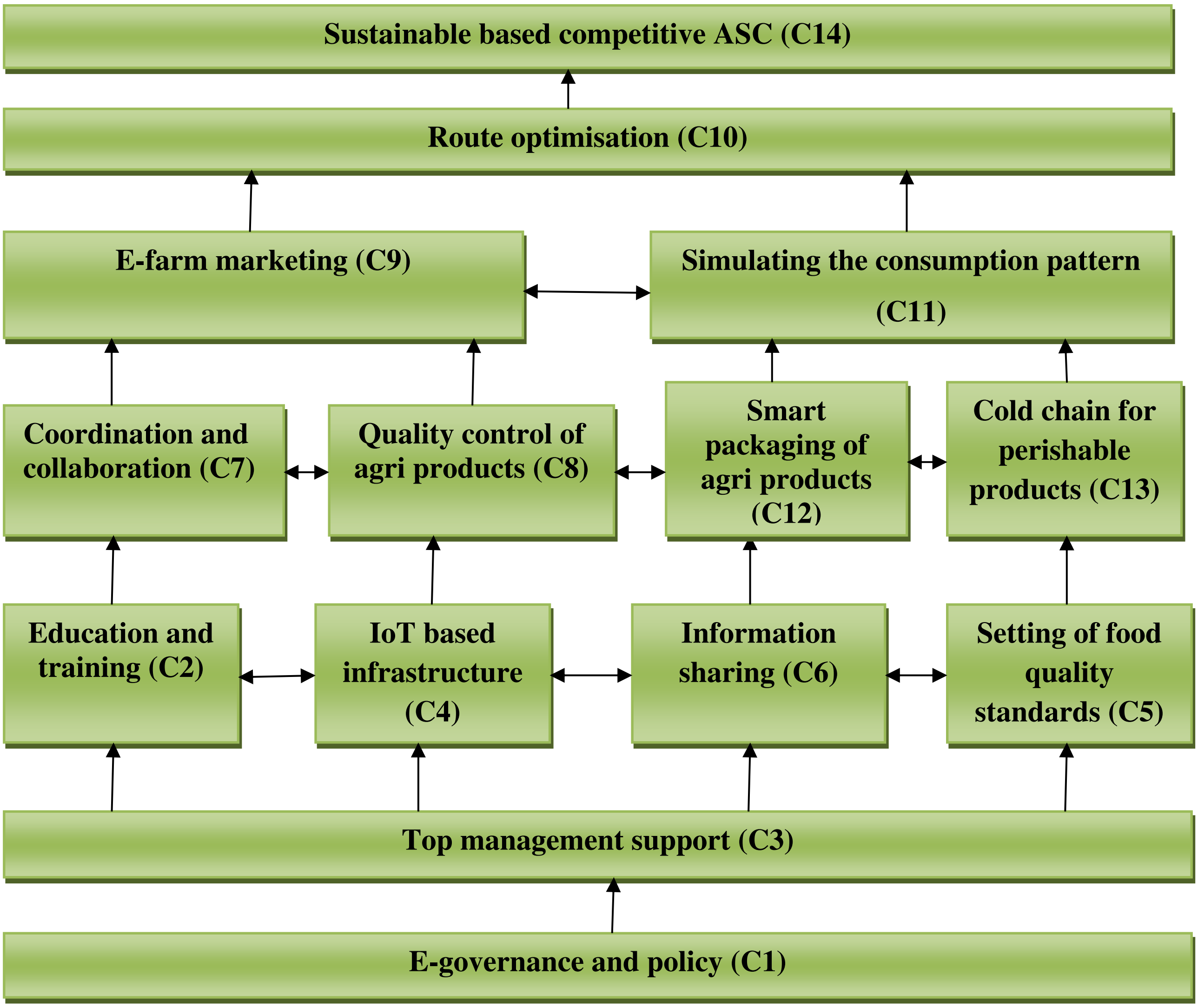


Figure 8: ISM based hierarchical structure for showing dependencies

4.3.2.1 Construct a direct relational matrix

The experts given in sub section in 4.2 have given suggestions for the evaluation of the enablers in the pair wise matrix or direct relational matrix based on fuzzy linguistic variables.

4.3.2.2 Construct a normalised direct relational matrix

Normalisation of the aggregated direct relation matrix of TFN values suggested by the experts, by applying sub steps 1 to 5 of main step 2 explained in F- DEMATEL methodology as given in Table B2 of Annexure B.

4.3.2.3 Construct a total relational matrix

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

Table 5: Total direct relational matrix

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	R	R+C	R-C
C1	0.38577	0.53066	0.46559	0.44495	0.56086	0.45831	0.51733	0.52375	0.58458	0.63474	0.57326	0.52656	0.39986	0.64847	7.25471	12.70934	1.80008
C2	0.41964	0.46881	0.47744	0.45840	0.57468	0.46030	0.49140	0.49867	0.54576	0.64578	0.56929	0.55560	0.39484	0.64725	7.20787	13.88759	0.52815
C3	0.45503	0.56945	0.43613	0.47638	0.59920	0.47656	0.53129	0.54580	0.60642	0.64870	0.59837	0.57550	0.41932	0.68163	7.61979	13.50647	1.73310
C4	0.37556	0.48524	0.42057	0.38140	0.51682	0.43968	0.47756	0.47437	0.53814	0.58486	0.48333	0.48498	0.38937	0.60842	6.66030	12.51861	0.80199
C5	0.39915	0.51598	0.43224	0.43210	0.47549	0.44174	0.47280	0.47715	0.57046	0.60431	0.53155	0.45887	0.38264	0.62190	6.81637	13.97580	-0.34306
C6	0.37047	0.45634	0.39124	0.39450	0.47385	0.35725	0.42824	0.43928	0.51647	0.54114	0.47436	0.47311	0.31059	0.55891	6.18576	12.07292	0.29860
C7	0.35505	0.42344	0.38020	0.38230	0.45354	0.36512	0.36190	0.43397	0.46995	0.51715	0.46071	0.44141	0.32171	0.47302	5.83944	12.16171	-0.48284
C8	0.33190	0.43913	0.40424	0.38917	0.47581	0.38718	0.42563	0.38989	0.50301	0.54147	0.48231	0.44420	0.32548	0.55530	6.09472	12.66483	-0.47539
C9	0.40263	0.44693	0.42077	0.42409	0.53809	0.43017	0.46679	0.47711	0.49269	0.59836	0.54101	0.52407	0.36809	0.60600	6.73680	14.25985	-0.78625
C10	0.40416	0.48299	0.40223	0.44998	0.54668	0.43012	0.45841	0.49412	0.56044	0.53790	0.51830	0.51688	0.36798	0.62157	6.79176	14.98632	-1.40280
C11	0.38881	0.46166	0.41321	0.39441	0.49379	0.42933	0.43583	0.47104	0.54196	0.58706	0.45905	0.47767	0.38377	0.60119	6.53878	13.77128	-0.69373
C12	0.42273	0.52864	0.46867	0.45686	0.50852	0.45579	0.46439	0.50442	0.59319	0.63946	0.56415	0.47802	0.39011	0.64843	7.12338	14.00983	0.23693
C13	0.35076	0.40459	0.37587	0.36451	0.44297	0.34343	0.37667	0.39947	0.47855	0.52983	0.46268	0.44742	0.29195	0.52230	5.79099	10.88510	0.69688
C14	0.39297	0.46587	0.39832	0.40925	0.49912	0.41218	0.41405	0.44105	0.52143	0.58377	0.51415	0.48215	0.34840	0.51602	6.39873	14.70913	-1.91168
C	5.45463	6.67972	5.88669	5.85831	7.15943	5.88716	6.32228	6.57011	7.52305	8.19456	7.23251	6.88645	5.09411	8.31040			

4.3.2.4 Cause and effect diagram

Construct a cause and effect diagram of the enablers by using (R+C) and (R-C) values. By using Figure 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 categorised into cause group.

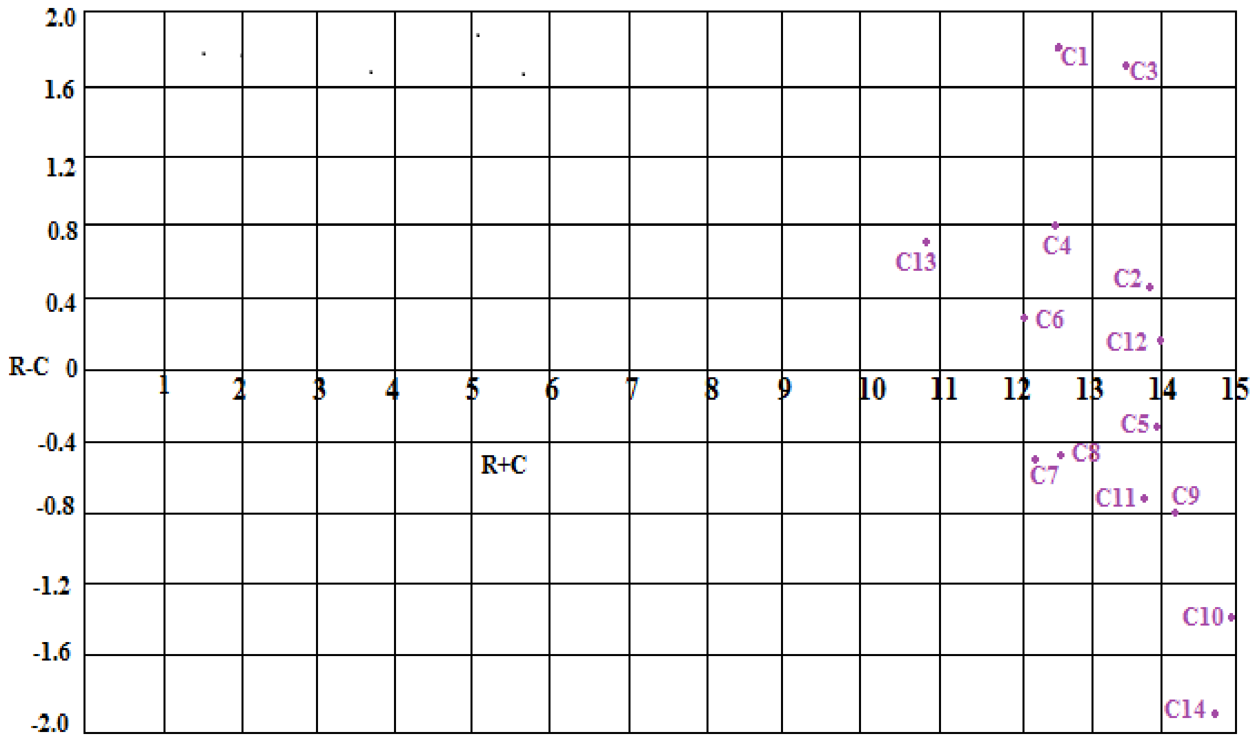


Figure 9: The cause and effect diagram of enablers

4.3.3 Sensitivity analysis

Sensitivity analysis has been done for checking the validity and robustness of the results obtained based on experts opinions (Raja Ambedkar et al., 2018). Sensitivity checking also helps in 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 analysis the overall impact on the results. The sensitivity analysis has been done 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.

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

For each run, different total relational ([T]) matrix has been constructed by using 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 caused group for other scenario. Thus, C12 is highly sensitive. The complete sensitivity results have shown in Table 7.

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

Factors	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

The R-C graphs have shown in Figure 10.

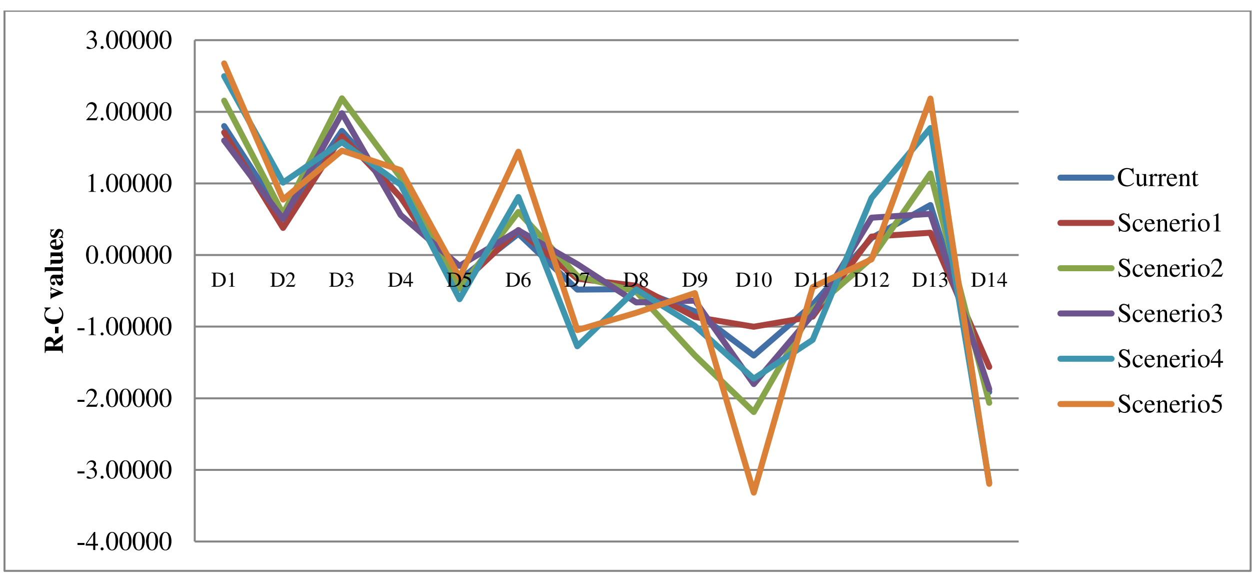


Figure 10: Sensitivity analysis of (R –C) values

5. Discussion of Findings

Globalised based fragmenting of AFSC sustainability, along with increased stakeholder's demands for increasing transparency and food security, have increased the involvement of lower tier or sub-supplier for ensuring sustainability (Miemczyket al., 2012). 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., 2011; 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 important cause group based on (R-C) value and classified into independent variable based on driving and dependence power. In the 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 global distribution of multi-tier system (Ganasegeran and Abdulrahman, 2020). Top management support (C3) is the second important caused group and classified into 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).

IoT based infrastructure (C4) is the third important cause group and clustered in independent variable. IoT based infrastructure systems provide important data of government and organisational data for decision taking by the FF about global demand fluctuation, regulating quality standards, monitoring for adjusting logistics action before any accidents (DaneshvarKakhki 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 (Times of India, 2014). Thus it has 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 occur 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 independent variable. Effective information leads to proper communication among the multi-tier suppliers located globally in the SCM has reduced responsive 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 linkage variable. Agri based perishable-products needs extra protection during handling and palletising, this may be possible sensor based smart packing (Corkery and Gelles, 2020). It may further provide protection of packed agri products against food loose due to thermal degradation during transportation in 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 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 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. Further, 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 at third important effect group and comes under dependent variable category. This finding may be justified as the wastage in the AFSC mostly occurs due 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, results in degrading losses of agri food (Schanes et al., 2018).

Simulating the consumption pattern (C11) is the fourth important effect group and classified into dependent variable. It may help in improving the distribution channels for route optimisation at global level for improving social and environmental sustainability. It may also regulate the prices based on daily demands of agri food and logistics facilities. Coordination and collaboration (C7) is the fifth important effect group and classified into linkage variable. Coordination enclosed the channels of union and secure inter-relationship together with jointly decision taking 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 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. (Shih and Wang, 2016). Setting of food quality standards (C5) is the seventh important effect group and categorised into independent variable. Even though, food regulatory bodies like Food Safety Standards Authority of India (FSSAI) have provides standards, not every stakeholders of AFSC are fully aware about 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 agri products (C12) is the most sensitive enabler. C12 is categorised into effect group in scenario 2 and scenario 5. Similarly, C12 is categorised into caused group for other scenario. Thus, C12 is highly sensitive.

5.1 Managerial and Practitioners Implications

In lieu of current going outbreak (COVID 19), this work seeks for identification of variables for modelling of an IoT based AFSC sustainability. This research attempts to establish the interrelationships and cause and effect analysis of the identified, which may help managers in reducing the wastage and improved the quality of agri food products throughout the AFSC for ensuring multitier sustainable based competiveness as well as to other agri-food organisations. The finding suggests some managerial implications in effectively managing IoT based AFSC for achieving sustainable based food security. First, this research may 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).

It may help the managers to consider IoT for 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. Further, the use of IoT based online procurement (e-farming) may facilitate the efficient distribution by reducing the mediators or small retailers during the whole AFSC.

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 their products branding for better product management at the globalised level. The initiatives such as RFID and BDA technology will help managers in 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 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. Further, 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 on-going epidemics (COVID 19) in lieu with customer satisfaction and new horizons of profitability.

5.2 Unique Contribution

The research develops an IoT based multi-tier sustainable food security model for integrating sustainable and global AFSC. In any natural epidemics 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 reduction of GHG emission from lower tier/upstream and food wastage for attaining environmental and socio-economic based global sustainability within AFSC.

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

6. Conclusion

The world has been paused in the central of globalised disruptive risk (COVID 19). Currently, AFSC has facing the global risk of food security and sustainability due to high flexibility in consumer demand and breaking off SC links. To tackle the above issues, this research proposed a systematically arranged structure with cause and effect strength for the variables involved in IoT-driven AFSC sustainability. Thus, the objective of this paper is ensuring globalised sustainability based on the collaboration of multi-tier system by using different configurations of multi-tier system and governing mechanisms based on several IoT technologies. In this sense, this paper has identified fourteen enablers through literature. These enablers were evaluated by using ISM and Fuzzy- DEMATEL.

Finally, sensitivity analysis has been done for checking the robustness of the result or experts accuracy. Based on sensitivity analysis, it has been noticed that in all five scenario, C13 enablers have got first rank and C14 has ranked fourteen. Further, enablers C11 and C10 are the most sensitive enablers. The research framework presented in this paper has 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. In the present paper, the combined ISM-DEMATEL approach has taken only fourteen enablers for IoT driven food security system or AFSC sustainability. The developed model in this paper is highly dependent on the experts' opinions. Further, the proposed framework in this research is not a generalised view for dairy items, meat and pulses, which are in demands at global level. Further, in future more enablers may be taken by using some validation model like structural equation modelling. In future, this research model may extend to some other SC of dairy items by taking deeper tier or suppliers.

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Appendices

Appendix-A

Sample Questionnaire

Dear Respondents

Greetings...

This research has been done for identification and analysis of factors of an IoT based AFSC sustainability in any disruption of SC caused by natural epidemics (COVID 19). For developing an IoT based sustainable food security system. This sample is also a part of the present research work. Your response to questions will not be share to any organisation. Your response may guide to analyse the identified factors provided by literature. We would be grateful and highly obliged if you response to some of the questions in section I, section II and filling up the response sheet in Section III. 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
- Post Graduate
- 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 particular organisation?

- Manager
- Supervisor
- Chief Executive Officer
- R&D team member
- Any other, please specify..........

Section II

General Information about the firm

Please click only one option

1. What is the area of the cultivated farmlands attached to your firm?

- Under 5 acres
- 5 to 10 acres
- 10 to 15 acres
- Over 15 acres

2. What is your firm sales volume?

- Under 30 million
- 30 to 40 million
- 40 to 50 million
- Over 50 million

3. How many employers have been worked in your firm?

- Under 100
- 100 to 500
- 500 to 1000
- Over 1000

4. What is the experience of your firm in implementing IoT related technology?

- Less than 6 months
- 6 to 12 months
- More than a year
- Any other, please specify..........

Section III

Decision maker's preference to the identified factors

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

ISM approach has been employed to study the interaction among identified factors. According to procedure of ISM, we need your judgment in 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 in below table for SSIM development of enablers.

S. No.	**Factors for IoT based sustainable food security system**	**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 factors to understand their causal relations

Please rate the following enablers on 5 point Likert scale for constructing a direct relational matrix. For measuring the extent of relation established between two factors a TFN (Triangular Fuzzy Number) scale has followed i.e. (0,0.1,0.3) for (no relation) for , (0.1,0.3,0.5) (very low relation), (0.3,0.5,0.7) (low relation),(0.5,0.7,0.9) (high relation) and (0.7,0.9,1) (very high relation) respectively. Further, based on your expertise, you may add/delete any other variable.

S. No.	**Factors for IoT based sustainable food security system**	**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)**														

Name of Expert ……………………….

Authority …………………………………

Department ………………………………..

Email………………………………………..

Date and place……………………………...

Thank you very much for giving valuable response

If any other suggestion, specify in box

Appendix-B

Table B1: Initial SSIM for enablers based on experts

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	-	O	V	V	V	V	V	V	V	V	V	O	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 B2: Normalised direct relational matrix based on 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

Declarations

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.

Availability of data and material: All the data has been provided in manuscript

Competing interests: 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.

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Sunil Luthra: *Ideas, Writing– Original draft preparation, Conceptualization, Formal analysis, Project administration, Critical review, Commentary and revision*
Dixit Garg*: Data collection and curation, Formal Analysis, Supervision, Reviewing and Editing*

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Figures

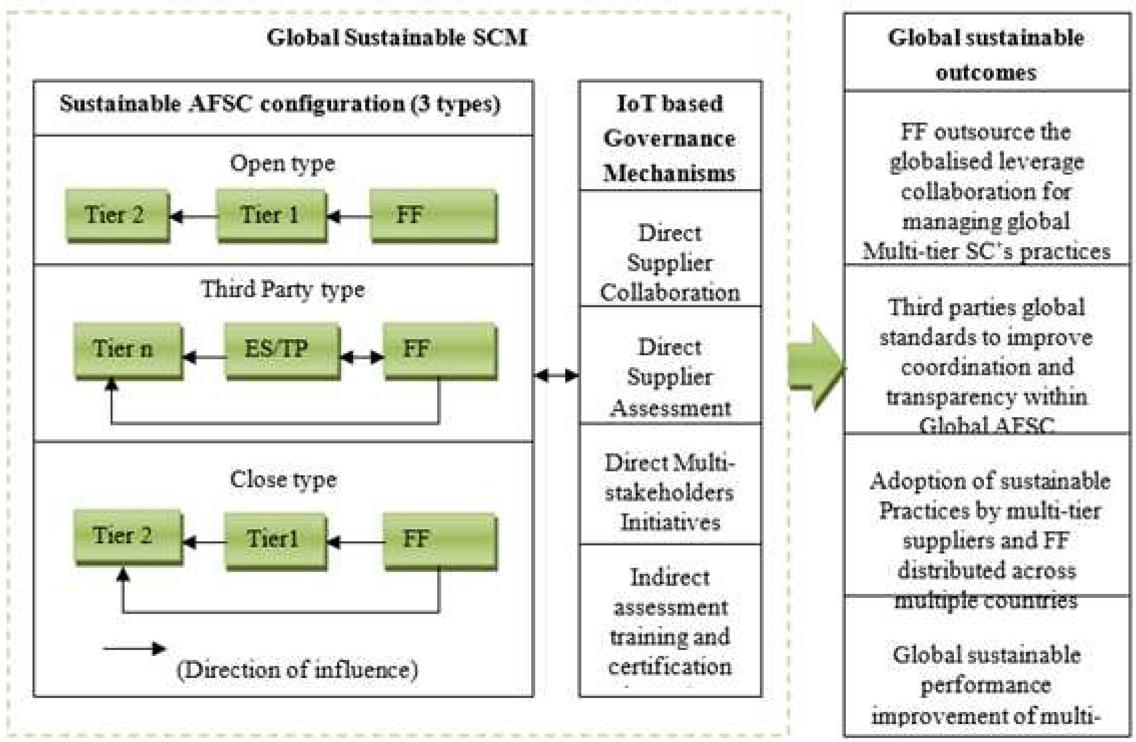

Figure 1

Research framework of Sustainable AFSC and Global AFSC

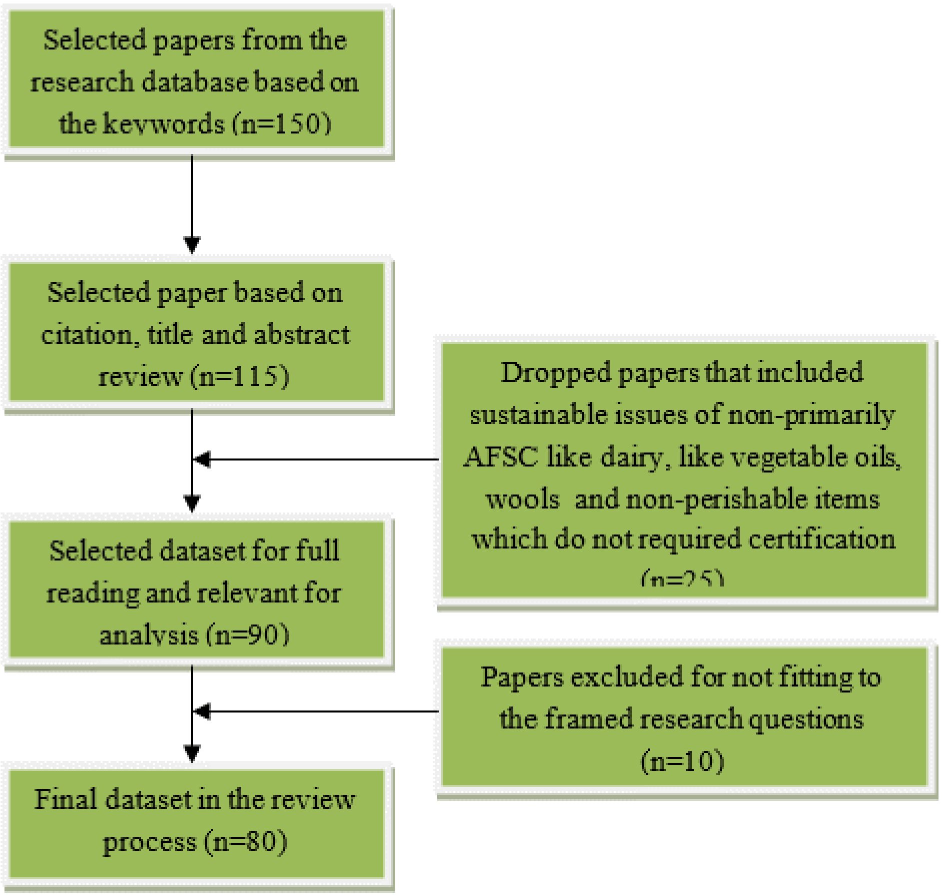

Figure 2

Article searching, selection and exclusion process

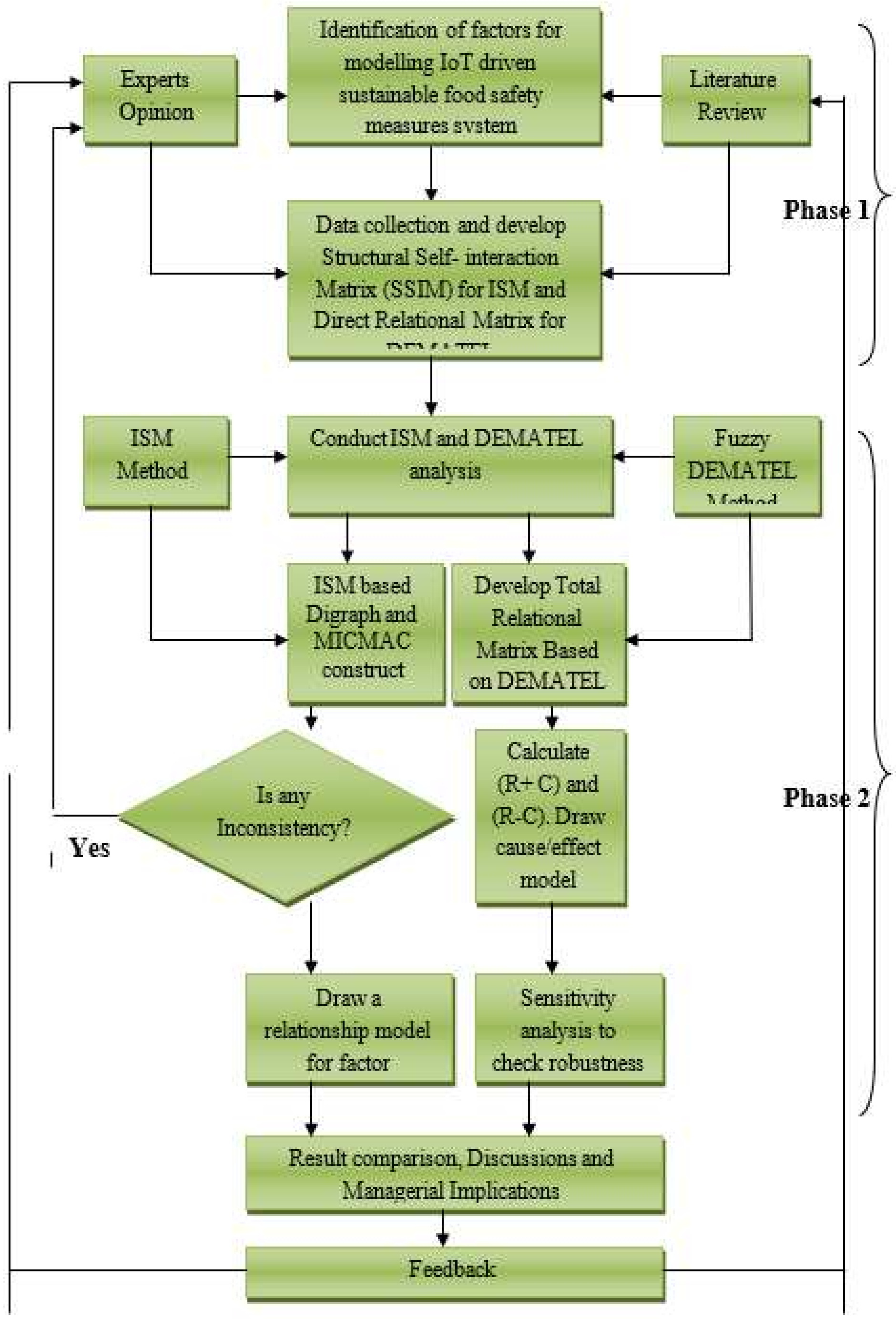

Figure 3

Framework of the proposed research

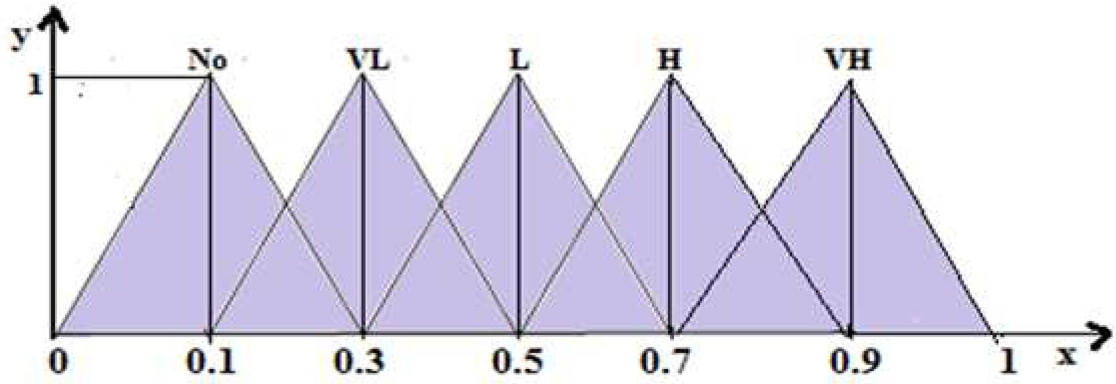

Figure 4

Triangular fuzzy numbers

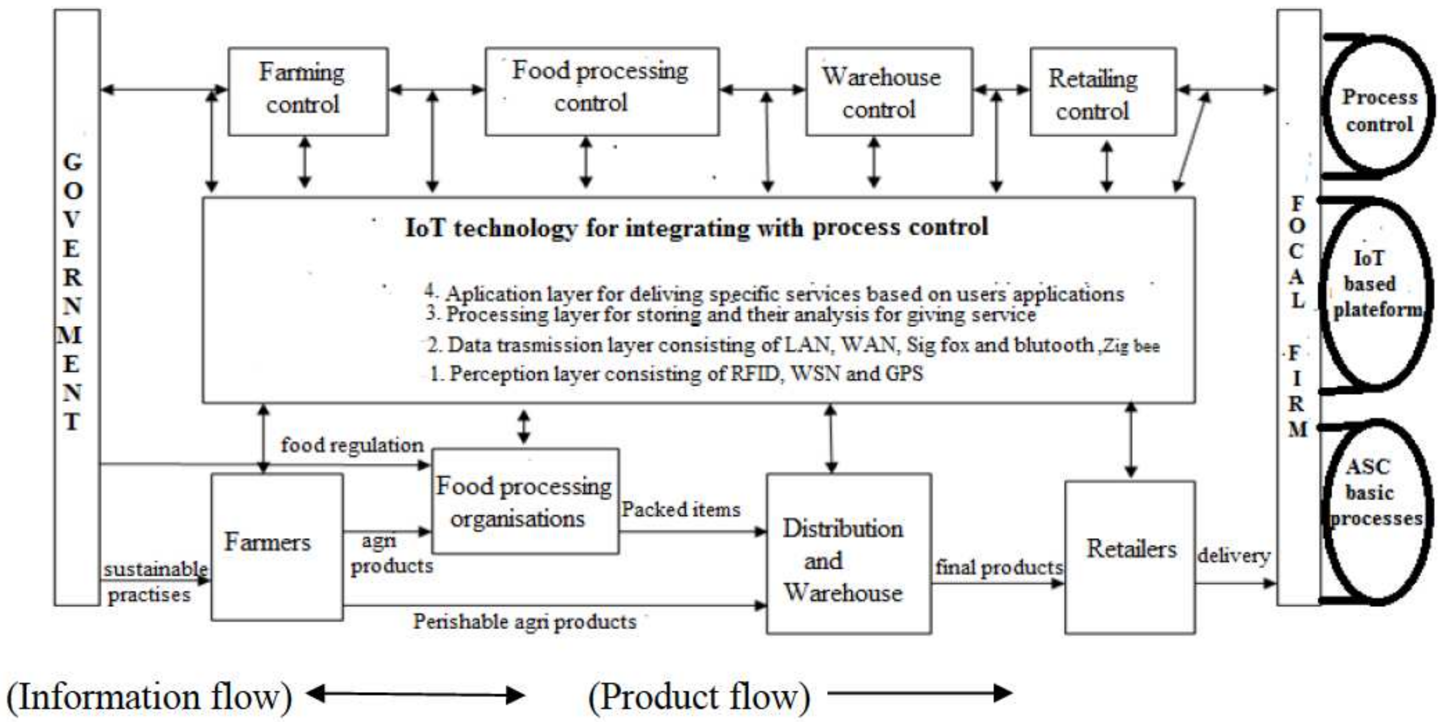

Figure 5

Complete framework of the proposed case study for XYZ firm

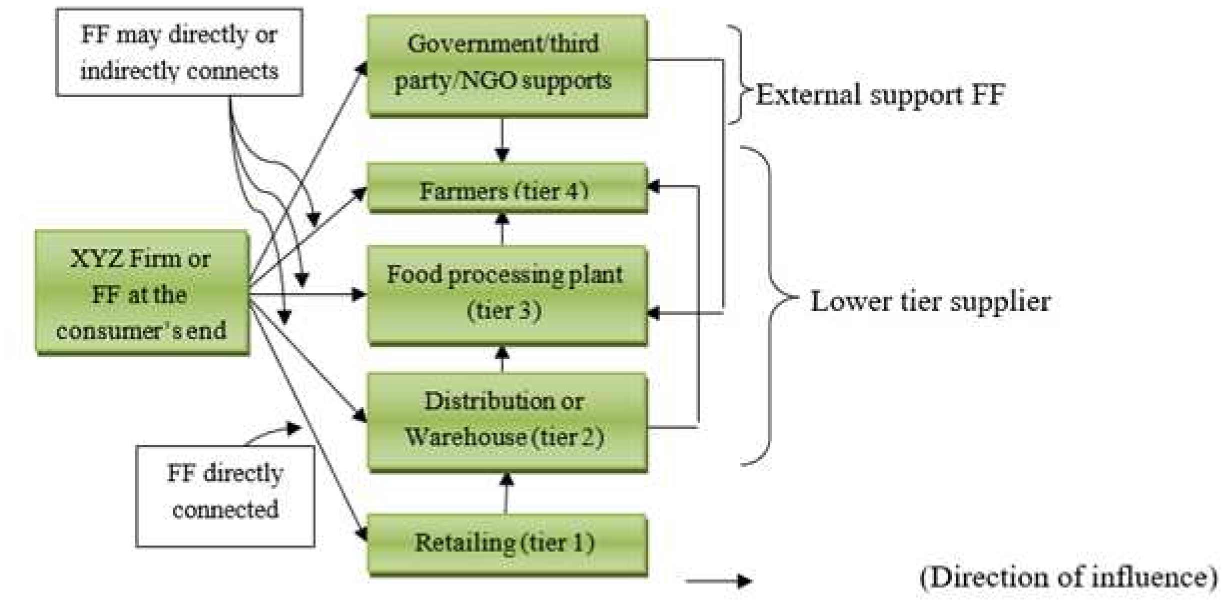

Figure 6

Multi-tier view of AFSC

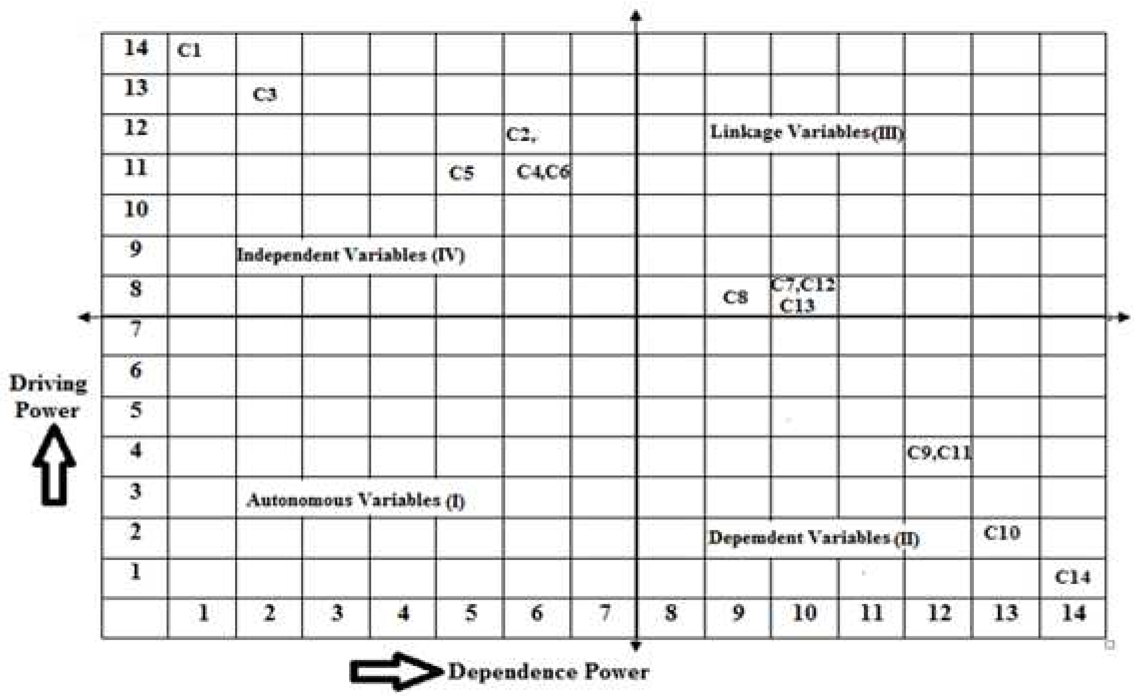

Figure 7

ISM based MICMAC analysis

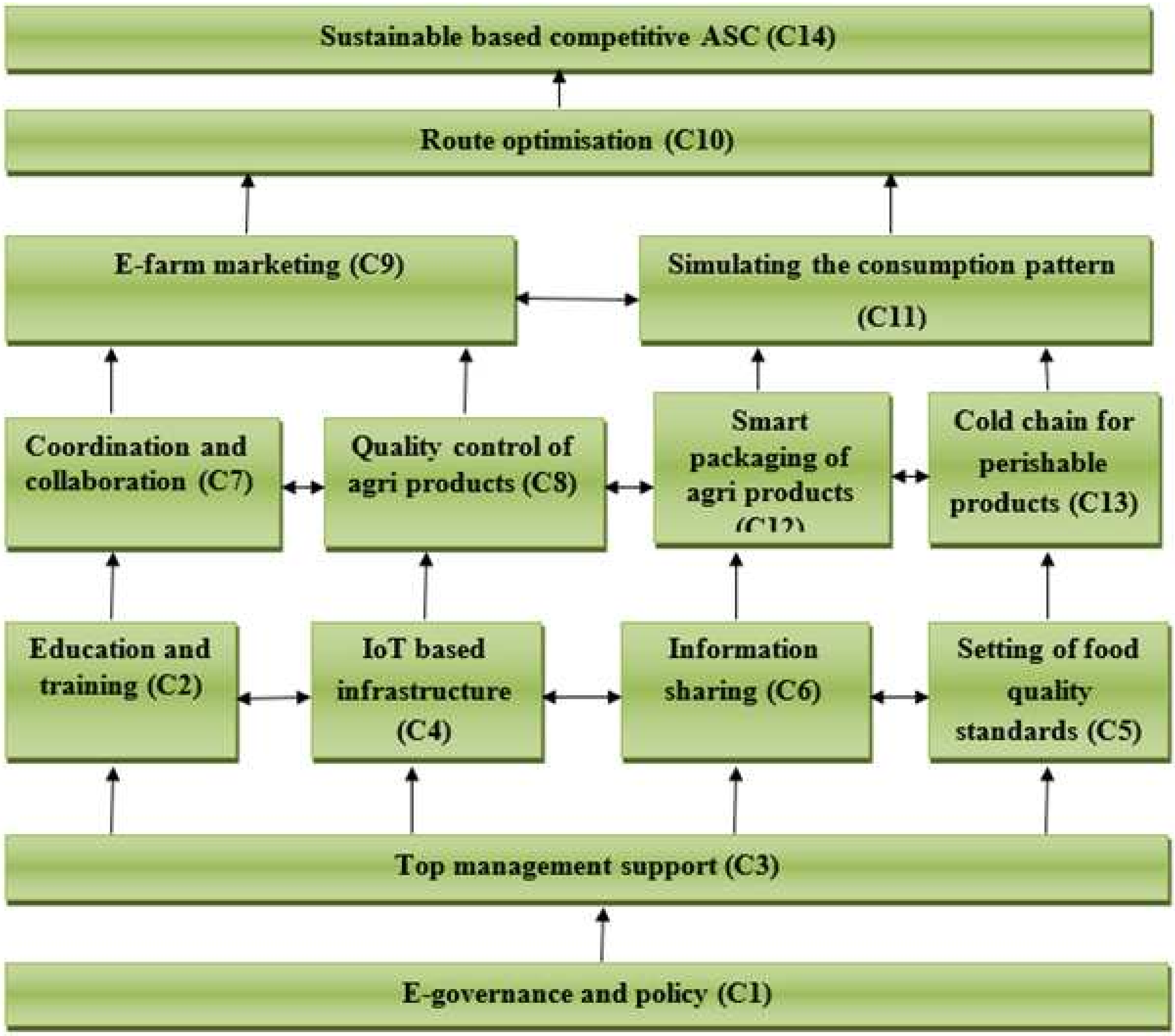

Figure 8

ISM based hierarchical structure for showing dependencies

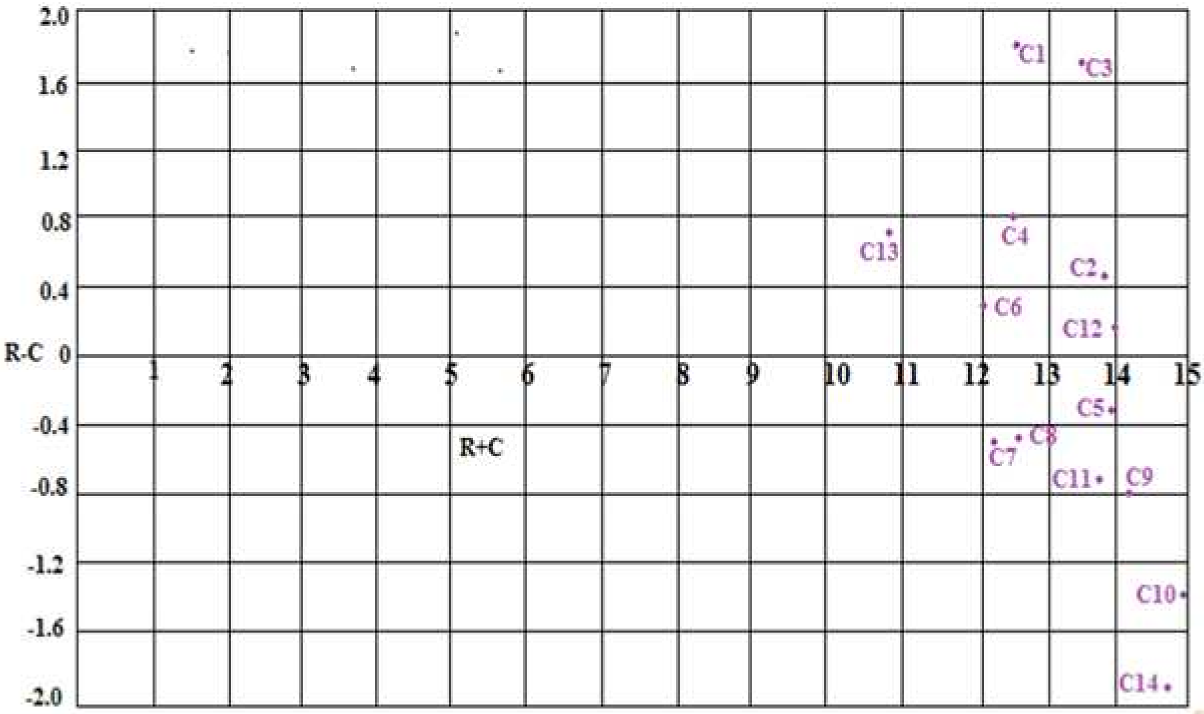

Figure 9

The cause and effect diagram of enablers

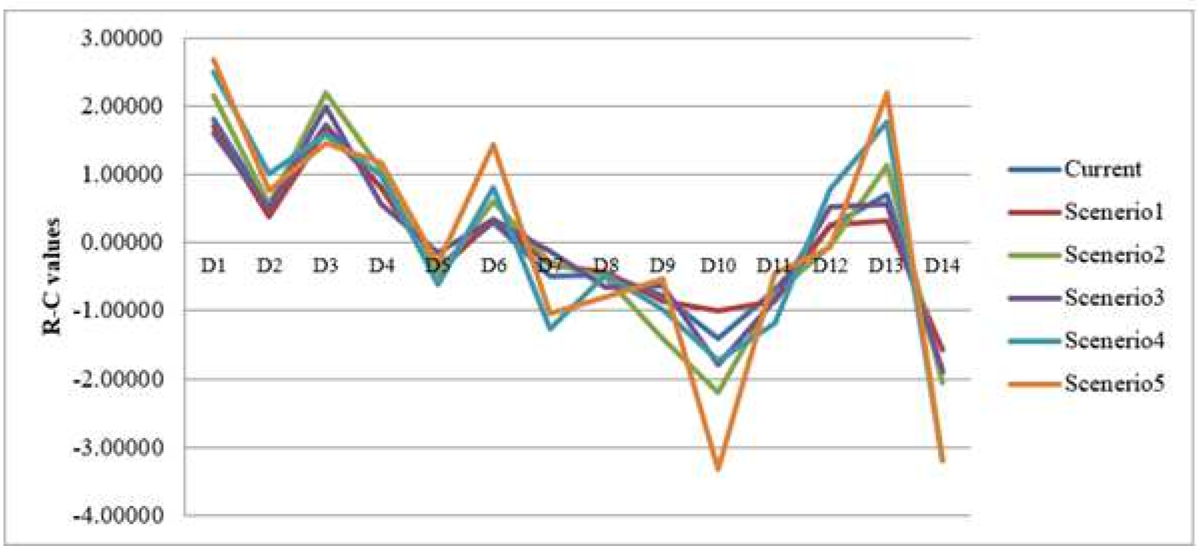

Figure 10

Sensitivity analysis of (R –C) values

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Appendices.docx