Logistics and distribution challenges to managing operations for corporate sustainability: Study on leading Indian diary organizations

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Abstract

In order to improve the corporate sustainability of agro-food value chains, business organizations need to rely on a higher performing and more reliable logistics system. Particularly, in case of dairy industry, organizations are facing some important challenges containing people management, short shelf life, high food losses and wastage, high greenhouse gas emissions. Based on "Confederation of Indian industry - Dairy Vision 2025", it is believed that the dairy sector in India has high potential if organizations can develop an effective logistics and supply chain system. This article attempts to analyze the interaction between distribution related challenges with a focus operational excellence and higher corporate green growth and sustainability viewpoints in food supply chains by considering the business example of four Indian dairy product based organizations using graph theory and matrix approach. Several key challenges were identified based on a literature survey and experts' views. Graph theory and matrix approach has been applied to select the most significant challenge. The results show that food organizations must work on cold chain to manage logistics and distribution challenges to reduce wastage, decrease financial losses and to take environmental issues into account. This paper ranks the challenges as well as develop an index for the dairy industry to achieve corporate sustainability in its supply chain and logistics network. The present study findings will provide useful knowledge for managers and policy makers managing interaction between people and process aspects and corporate sustainability management in the agro-based diary organizational logistics and supply chains. This is one of the unique studies in food supply chain that helps in improving the logistics and supply performance in diary industries of emerging economies.

Keywords: Agro-food supply chain, Corporate sustainability, Operational excellence, Cold chain technology, logistics and distribution management, Diary sector, Emerging economy - India

1. Introduction

The agro-food supply chain (A-FSC) is crucial for all production, as it follows a 'farm to fork' structure. In the food industry, higher quality and safer food is always a top priority. Overall, A-FSC has the capability to link millions of players such as farmers, industries, governments and other organizations to deal with political and economic issues whether in a local, national or global context (Beske, et al., 2014; Genovese, et al., 2017).

Some emerging economies are, on the one hand, suffering from insufficient safe food while, on the other hand, wasting food (Mangla et al., 2018a; Banaeian et al., 2018). In China, 190 kilocalories of food per person are lost every day. While, in India, approximately 40% of grains are wasted because of inefficient management of the food supply network yearly. Organizations are currently facing a series of challenges to supply sufficient food for increasing population globally, while dealing with environmental degradation and climate change, monitoring food safety and security and integrating the supply networks to reduce waste. Food safety related threats pose serious concerns to food supply chains (FSCs), undermining public confidence in the food sector.

It is therefore important to promote sustainable production and distribution in the food industry (Govindan, et al., 2014). Sustainability oriented food supply chains include all forward (procurement of materials, production and distribution) and reverse processes (collection and return of used products) to achieve the goals of higher social, economic and environmental performance (Bloemhof and Soysal, 2017; Sgarbossa and Russo, 2017; Sharma et al., 2018a).

FSC plays a vital role in the dairy sector to meet the population's food requirements, especially in a rapidly growing economy like India. Notably, India is known as the world largest milk producer. It is estimated that 66% of the total population of India depends on the dairy and agriculture sector. In rural areas, dairy farming is a prime source of income for communities (Rajendran and Mohanty, 2004; Li, et al., 2014). In order to design sustainability in food value chains, particularly in the dairy industry, logistics plays a central role. Many problems can arise during transportation and distribution of any dairy product including people management, product damage, leakage or spoilage (Jabbour et al., 2015; Mangla et al., 2018b). As a result, this can mean fewer retail outlets

selling dairy products and hence making a business loss for producers. Hence, it is required to develop a system that could minimize the dairy losses and improve their operational performance. Indeed, logistics and distribution is one of the most important factors in supplying dairy based food products (Jabbour and de Sousa Jabbour, 2016). Concurrently, logistics may also affect the environmental, social and economic sustainability of organizations in terms of increased carbon dioxide emissions, higher food insecurity and wastage (Rajeev et al., 2017). In this sense, managers must address the identified challenges linked to logistics and distribution for the development of sustainability in FSCs and logistics in the context of the dairy sector.

This research aims to analyze the logistics-focused challenges for the implementation of sustainability in food chains in the dairy sector. However, there can be different opinions in different industries when adopting sustainability initiatives (Zhu and Sarkis, 2006; Yadav et al., 2018; Sarkis, 2018). Managers must also recognize the impact of these factors on their work and learn how to prioritize them; they must explore the inter-relationships of these challenges to manage their effect on the food supply network. To achieve the aims already identified, this research sets out the following objectives:

i. To recognize the challenges to logistics and distribution with a view to implementing sustainability in food chains
ii. To model the challenges to establish their priority
iii. To provide the industry with information for effective management of potential challenges

In order to recognize the challenges related to logistics for sustainability in food value chains, several companies working in the northern region (Uttarakhand) of India were investigated. In the present study a graph theory and matrix approach (GTMA) is projected to solve multiple criteria decision-making (MCDM) problems (Muduli et al., 2013; Singh et al., 2017; Kumar et al., 2017). GTMA can transform the effect of each challenge on other challenges into single numerical values. In addition, GTMA can identify the inter-dependence between the challenges.

The paper is designed as follows. In Section 2, the review of the related literature is examined. Section 3 explains the solution methodology and the research methods. Section 4 presents the proposed research framework. Discussion of research outcomes and managerial implications of

the study are provided in Section 5. Finally, we present the conclusions along with the scope for future research in Section 6.

2. Literature Review

The literature review mainly focuses on the logistics and distribution driven challenges for the successful implementation of sustainability in food value chains in the dairy sector. According to the methods initially proposed by various researchers and academicians (Junior and Godinho Filho, 2010; Jabbou, 2013; Mariano, et al., 2015), a structural review was conducted to examine the published articles in the fields of food supply chain, transportation and sustainability. Firstly, important terms were defined to underpin the initial search criteria. The keywords used in the search were Supply Chain Management, Sustainability, Transportation, Dairy industry, Challenges, Issues. After completing this initial step, a combined search was conducted using key phrases Sustainability and Food Supply Chain; Challenges and Dairy Industry; Transportation and Challenges and Sustainability and Food Supply Chain; Transportation and Challenges and Ecological and Environmental and Social Sustainability and Food Supply Chain. In this exercise, Scopus, Science Direct and Google Scholar databases were used for the search using the default search field "title, abstract, keywords." In this way, based on the theme and scope of this research this work collects various relevant articles, as shown in reference list.

2.1 Sustainability in FSC

Sustainability involves a combination of ecological, social and financial responsibilities for future generations to satisfy their needs (WCED 1987; Amui et al., 2017; Ahmadi et al., 2017). Sustainability has become a significant concern among business organizations (Carter and Rogers, 2008; Jabbour et al., 2013; Vlajic et al., 2013; Luthra and Mangla, 2018). FSCs are at the forefront of this development due to the pressure being exerted from increased consumer demands on food quality and sustainability. In A-FSC, designing a chain network is a complex issue due to an intrinsic focus on the quality of product and demands for environmental sustainability (Allaoui et al., 2018; Goyal et al., 2018). In food distribution, quality, health and safety take central consideration due to the increase in cases of food scares. Sustainability in A-FSC includes fanatical-green aspects as well as a social dimension; employees' health and safety must be

ensured. In FSC, retailers and caterers can contribute to organizational sustainability through higher temperature controlled distribution, sustainable sourcing (Baldwin 2009), reducing waste in storage and providing high standard food service operations during preparation and service (Turenne 2009). To enhance sustainability in FSC, organizations are also focusing on labelling related to food miles, which allows food managers to access the carbon footprint and ecological impacts of the production and distribution activities (Saunders et al., 2006; Wilson, 2007). The concept of sustainability in FSC has gained significant attention from scholars in recent years (Elhedhli and Merrick, 2012; Govindan, et al., 2014; Rajeev et al., 2017). Some have proposed an eco-design of transportation in FSC. Bendul et al., (2017) developed a sustainable FSC model mainly focusing on the parameters of sustainability in developing countries to overcome the differences in distribution systems and framework conditions. Brent et al. (2018) suggested that the food industry should adopt connected and autonomous vehicles (CAVs) to deliver perishable products given the time constraints. They indicate that the use of automated transportation in FSC can ensure minimal business loss. Due to increased competition in the food industry, organizations may face difficulties in meeting consumer demand while maintaining the quality, quantity and price of their products. Many executives of food companies are conscious about the integration, coordination and management of food products, all essential elements for their business, while keeping their foot in the competitive market. Companies need to focus on the introduction of a sustainable process in the FSC in a holistic manner. There are many issues related to food production in India; however, wastage and transportation based factors must be addressed. Food companies need to focus on transforming their sustainable processes to decrease waste generation (Pagell and Wu, 2009; Bloemhof and Soysal, 2017). Consumer involvement and awareness is further driving organizations to adopt sustainability in FSCs. Customers are now expecting more from the food industry; they are interested in how food is produced and presented due to rising concerns of food safety and security in recent years (Beske et al; 2014). A sustainable FSC goal should be to cut down on waste within the industry (Diamond, 2002). Transportation and logistics plays a crucial role in improving the financial, public and green performance of FSCs (Hamprecht et al; 2005).

2.2 Logistics function and sustainability in FSC and the dairy industry

Sustainability has become an important topic in the business agendas of many food companies. Increased customer knowledge and government regulations are also forcing companies to include sustainability in their core systems such as operational, technical and welfare (Fredriksson and Liljestrand, 2015). Transportation and logistics aspects in FSCs have also been of concern among researchers in recent years (Villarreal, et al., 2017). Vehicle scheduling, routing, delivery, environmental issues, cost, social factors, truck availabilities and communication gaps between supplier and receiver are among the major areas addressed by researchers (Eliiyi et al., 2009; Zhang and Yun, 2009; Zhang et al., 2009; Yu et al., 2013; Zhang and Qiu, 2014; Zhang et al., 2015; Yu et al., 2015; Schiller and Kenworthy, 2017;).

In the dairy industry, owners and managers try to grow the majority of their produce in close proximity to their farms to minimize transportation costs (Douphrate, et al., 2013). Johnny et al., (2009) compared traditional and green supply chains after the recent introduction of environmental regulations that affect manufacturing operations and logistics systems from an industrial viewpoint. In the dairy sector, some companies are not using eco-friendly refrigerants in transportation vehicles or employing cold storages; this is a major issue for environment sustainability (Khan et. al 2019). In the dairy business, there is a general lack of collaboration between logistics, warehouses or cold storages; this tends to increase total carbon emissions. Organizations should use more combination modes of transportation (rail-road, road-ship and road-air) in the dairy sector (Kumar et. al 2019). Chilling centres sometimes keep chilled milk for four to five days because of transportation problems; this automatically raises the overall cost and decreases the profit margin (Mishra and Raja Shekhar, 2012). In the dairy industry, transportation of milk and their products need air conditioned or insulated vehicles to allow firms to expand their operational areas (Kumar et. al 2018b). Forecasting is another key concern for many diary based firms (Litman, 2017). In addition, increasing fuel prices add to current operational problems for transportation system. Sometimes due to logistics problems, the delivery of products is delayed and/or reached to customers' with a degraded quality.

The dairy sector has recognized logistics and distribution as a challenge; companies are looking at these challenges to minimize their effect in sustainable business development (Mor, et al., 2018). Several key challenges concerning transportation in the dairy industry are identified based on a literature review and stakeholders' opinions. Based on experts' inputs, 27 challenges were divided

into seven main areas. These are Environmental related (EC), Government/political related (GPC), Roads related (RC), Financial related (FC), Cold chain related (CCC), Technology related (TC) and Legal (LC). A brief description of these challenges is provided in Table 1.

Table 1: Challenges to logistics aspects for sustainability in FSC in dairy industry

S. No.	Challenges	Description	References
Environmental related challenges (EC)			
1	Floods in plains	Floods in plains stop the transportation of dairy products and increase the chance of spoilage.	Kaewunruen et al., (2016), Osti and Nakasu, (2016)
2	Landslides in hilly areas	Landslides occurring in hilly areas hinder transportation facilities in those areas, leading to company losses.	Klose et al., (2015); Redshaw et al., (2017)
3	CO_2 gas emission	Emission of CO_2 due to transportation of dairy products increases environmental pollution issues.	Coley et al., (2009); Aggarwal and Jain, (2016); Lee, et al., (2017)
4	Lack of weather forecasting	Improper information regarding weather conditions affects the delivery of products.	Dey et al., (2015); Yadav et al., (2016)
Government / political related challenges (GPC)			
5	Lack of policies	Lack of policies regarding health, environment and transportation is a big problem.	Marsden and Reardon, (2017)
6	Lack of security assurance	Transportation system integrated with GPS location, weather forecasting and traffic updates can lead to better public safety, emergency response and disaster recovery.	Roy and Sahu, (2017); Wang and Yue, (2017)
7	Failure of government	Lack in implementation of plans, policies and regulations in transportation of dairy products is a failure of government	Winston, (2000); Patankar et al., (2010)
8	Lack of monitoring	Lack of monitoring in transportation of dairy products increases the chances of contamination.	Gandhi and Zhou, (2014); Dandage, et al., (2017)
Roads related challenges (RC)			
9	Toll taxes	Tolls and check-posts slow down traffic speed, waste time and frustrate transporters. It is difficult to obtain	Sahu, (2017), Kayisu et al., (2018).

		road permits to travel from one state to another.	
10	Mixed traffic	In India, mixed traffic is found on the same road even on highways. This causes inconvenience for transporters as well as pollution, congestion and road accidents.	Castillo-Manzano et al., (2016);
11	Lack of infrastructure	Most Indian roads are un-surfaced and are not suitable for use of vehicular traffic during the rainy season.	Sahu, (2017); Roy and Sahu, (2017); Kayisu et al., (2018)
12	Lack of facilities	Lack of roadside facilities such as repair shops, telephones, first aid centres etc. Charging issues for electric vehicles is still a problem.	Khan et al., (2018)
Financial related challenges (FC)			
13	Increase in crude oil prices	Increasing price of crude oil in the global market directly affects the transportation sector and increases the price of dairy products.	Kaman et al., (2017)
14	Lack of proper investment	Lack of proper investment causes issues for transportation in dairy sector.	Khisty and Lall, (2017); Buranelli, F. C. (2018)
15	Lack of funds	Due to lack of funds the maintenance and infrastructure of roads is very poor with even less available in the five-year plan.	Sahu, (2017)
16	Currency variation	Fluctuations in currency affect trading. It increases overall cost of transportation.	Nkomo, (2017); Mtisi et al., (2017)
Cold Chain related challenges (CCC)			
17	Poor pest control	Pest control is a challenge during transportation of dairy products.	Saurav and Potti, (2016); Kamana et al., (2017)
18	Lack of temperature control	Lack of temperature control may spoil the whole batch of dairy product during transportation.	Tassou et al., (2009); Mercier et al., (2017); Ryan, (2017)
19	Lack of equipment	Lack of equipment in cold chain affects storage and transport of milk.	Ashok et al., (2017)
20	Lack of availability of services and resources	Lack of skilled technicians, lack of inconsistent procurement of spare parts, weak inter-departmental	Krishnadevarajan et al., (2015); Ashok et al., (2017)

		agreements and procedures lead to a lack of services and resources.	
Technology related challenges (TC)			
21	Lack of adoption	Adoption of new technologies in transportation is very slow and affects profits of organizations.	Misra, (2008); Nazir et al., (2017)
22	Lack of skilled labour	Lack of skilled labour in the organization affects production and profitability.	Shamsi et al., (2014).
23	Lack of information technology (IT) application	Adapting information technology with transportation are challenges facing organizations.	Negi and Anand, (2015)
Legal related challenges (LC)			
24	Disputes between partners	In transportation, ownership and high profit margins cause disputes between partners.	Venkatesh and Luthra, (2016)
25	Lack of safety	Organizations must ensure that goods arrive safely without any theft issues. Organizations must have proper information about their employees.	Simangunsong et al., (2016); Smith, (2017); Financial Express, (2018)
26	Lack of transparency	Lack of transparency at every level of administration is a challenge; it affects public service	Tortajada, (2016); Venkatesh and Luthra, (2016)
27	Lack of trust	Lack of trust and commitment between the supplier and firms is an obstacle in implementation of sustainability.	Hertel, et al., (2017)

2.3. Research gaps

From the literature review, several research gaps were identified, as given below:

1. Sustainable production and distribution is a relevant and time driven problem for food organizations. The FSC, especially in the Indian dairy industry, plays a vital role in economic progress. Based on "Confederation of Indian industry - Dairy Vision 2025", the dairy sector in India has high growth potential. Thus, sustainability in FSC for the dairy industry becomes a critical issue; it is still in its initial stages in many developed and developing countries (Li et al., 2014). Additionally, the adoption of sustainability in FSC initiatives is very tough for companies and underpins logistics challenges for dairy businesses. The dairy industry itself consumes high amounts of natural resources. Very limited studies are available on adoption of sustainability concepts considering

transportation, distribution and logistics issues from a knowledge based operations management perspective in the dairy sector (Beske et al., 2014; Meneghetti and Monti, 2015).

2. Work on recognizing and analyzing challenges to logistics for developing sustainability in FSCs in the dairy sector in emerging economies is limited. Various activities such as using lack of skilled workforce, less fuel-efficient vehicles, less efficient cold-chain systems and low technological updates may hamper the logistics mechanism in delivering food products to the consumer (Carter and Rogers, 2008; Sharma et al., 2018b).
3. The majority of existing studies focus on the understanding of production system, food availability and development of policies at a broad level (Zhang et al., 2018). Very limited studies have been made to evaluate priority ranking and inter-relationships among challenges to logistics for successful sustainability concepts in FSCs in a dairy industry in an emerging economy.
4. Due to a higher population, diversified geographical conditions and social inequality, the availability of safe and high quality food is a big concern in a developing economy like India. Focusing on logistics and distribution aspects such as the time taken and running costs may ensure smoother delivery of food products at a reasonable price (Leamer and Storper, 2014; Rodrigue et al., 2016). This provides motivation to conduct research on addressing logistics focused challenges in developing sustainability in FSCs in the dairy sector; this would help in meeting sustainable development goals that have been set (Van Donselaar and Broekmeulen, 2012; Kumar et al., 2015; Tostivint et al., 2017).

In the present study, a two-stage methodology has been used to fill the above-mentioned research gaps.

Stage 1: Identification of the most common challenges in distribution and logistics for the implementation of sustainability in FSCs in the dairy industry underpinned by current literature and expert views. Stage 2: Analysis of challenges to establish their priorities using GTMA.

3. Proposed research framework

Based on a critical analysis of relevant literature, the challenges related to distribution and logistics have been determined. These challenges were finalized after inputs from experts in the industry.

The identified challenges were analyzed further by using a GTMA method. GTMA technique helps to understand the behaviour of challenges by establishing their priority and inter-relationships. The projected framework is shown in Figure 1.

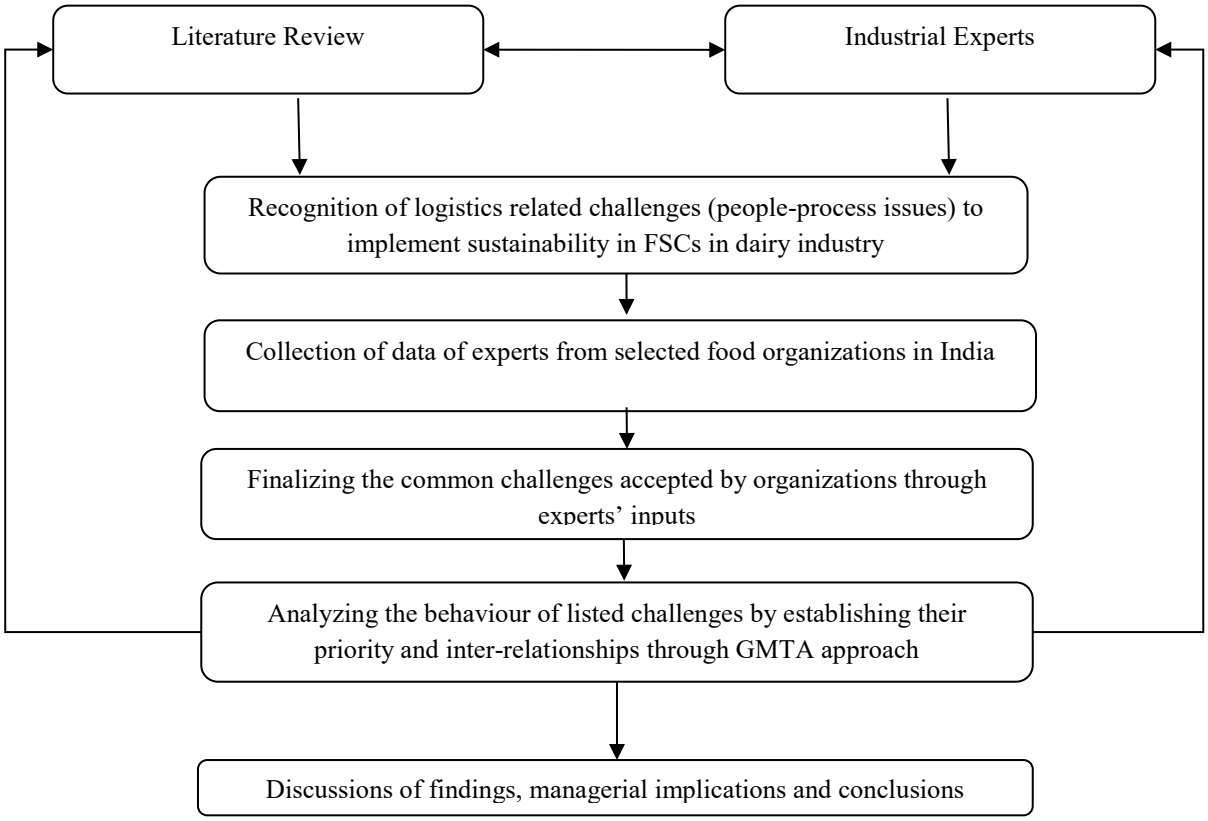

Figure1: Proposed research flowchart

4. Solution Methodology

To meet the aims of this study, GMTA technique is used as the solution methodology. GTMA approach is a systematic decision-making methodology used to find inter-relationships and interactions among the identified sub-challenges (Muduli et al., 2013; Shirinivas et al., 2010). In this work, GTMA is adopted to quantify the impact of challenges.

GTMA mainly focuses on estimating the inter-dependency of variables included within the problem structure (Wagner and Neshat, 2010). GTMA has been successfully implemented in areas such as supply chain coordination (Kaur et al., 2006), manufacturing (Jain and Raj, 2016) and

supplier selection (Khan, et al., 2018). There are several other techniques such as Interpretive Structural Modeling (ISM)(Kumar et al., 2017), Decision Making Trial and Evaluation Laboratory (DEMATEL) (Wang et al., 2016) or Fuzzy Cognitive Maps (FCM) that could be used. However, it is important to note that every method has its specified area of application and all of the above mentioned techniques primarily focus on developing the structural relationships instead of computing the weights. On one hand, GTMA helps to assess the inter-relationship among the included variables but it also assists in computing weights. While, on the other hand, it facilitates the practitioners to utilize the relationship results to develop execution strategies. Hence, for the present case, it is essential to use an approach that can utilize the inter-relationships and compute weights of the included factors rather than develop a structural hierarchy or identify the cause and effect factors. For this study, GTMA is considered as the most suitable choice (Grover et al., 2006).

The main steps followed in the methodology are:

Step 1. Recognition of the challenges

Step 2. Construction of the digraph; the diagraph of the challenges and sub-challenges was established by observing their inter-dependencies on each other

Step 3. Construction of the matrix; the digraphs are converted into matrices. The variables of the matrix are then replaced by the values given in Table 3 after expert input.

Table 3: Relative importance of challenge (dxy) (Muduli et al., 2013)

Definition	**Relative importance of attributes**	
	d_{xy}	**d_{yx}= 10-d_{xy}**
Comparing challenges are equally important	5	5
One challenge is moderately important over another	6	4
One challenge is strongly important over another	7	3
One challenge is very strongly important over another	8	2
One challenge is extremely important over another	9	1
One challenge is extraordinarily important over another	10	0

The details regarding the representation of permanent function is shown in Appendix D.

Step 4. Theoretical best and worst values: The theoretical best and worst value of the challenges are obtained next. This signifies the relative significance of challenges.

5. Problem context – case organizations

A-FSCs, especially in the Indian dairy industry, play a vital role in economic progress. In India, 70% of the total population reside in rural areas; many depend on agriculture and the dairy industry for their livings. India's dairy industry is worth rupees 5.4 trillion by value in 2010-2016 and it will attain value of 9.4 trillion in 2016-2020 on rising consumerism. In India near about 650 companies working in the dairy sector and they contribute 25 per cent of the Gross National Income. The National Dairy Development Board has stated that the dairy sector is important for rural poverty improvement in India. Thus, refining productivity and sustainability of the dairy sector would be very beneficial. There are more than 200 companies working in the dairy sector in northern India. In Uttarakhand region, a large population is engaged in dairy business, as currently, 50 dairy companies are operating and contributing to the state economy. Among those, 10 are large scale, 15 are medium scale and 25 are small scale companies. For this research, authors contacted 10 dairy product based food companies in the northern region of India particularly in Uttarakhand. In response, four companies showed interest in this research. Objectives were agreed and company inputs were shared with the research team. Hence, four Indian dairy business companies were involved in the case analysis. Details of their profiles are presented in Table 4 below:

Table 4: Brief information about companies

	Company 1	**Company 2**	**Company 3**	**Company 4**
Established	1961	1973	2009	1989
Annual Turnover	US$ 10 billion	US$ 4.5 billion	US$ 2.0 billion	US$ 5 billion
Employees	20,000	13,000	6,000	10,000

Products	Milk, ghee, butter, khoya and paneer.	Milk, butter, ghee, and paneer.	Milk, butter, panner and chocolate products.	Milk, cheese, butter, and paneer.
Mission and Vision	The company is active in organizing various workshops to make farmers and employees more aware of producing milk in a sustainable manner. The company is also conscious of the need to study the challenges in logistics to improve production capacity.	The company focuses on the use of circular economy concept i.e. reuse, recycle and repair. The company wishes to adopt renewable sources of energy during the manufacturing of their products.	Presently, the company is running ten manufacturing plants across the country. To reduce the impact of carbon dioxide emission (CO_2), the company uses electric vehicles for short journeys. The company is interested in analyzing the challenges in logistics for sustainable food supply chains.	The company is devoted to giving consumers the best quality dairy products in the food sector. The company has participated in this research with a view to improving their production and efficiency.

6. An application

6.1 Collection of data

For data collection, 30 experts were selected from 4 case companies. 26 are from the food industry comprising of 6 general managers, 5 distribution and logistics managers, 5 supply chain managers, 5 production and operations managers, 3 financial officers, 2 environmental engineers. Industrial experts have a minimum working experience of 5 years. While, 4 experts are from academia; these academics have 10 years' experience in their domain and are involved in various research projects related to supply chain and logistics and distribution system in food industry. All experts are responsible for taking decisions in their specific area. In this process of data collection, the main intention is to analyze the logistics challenges to implement sustainability in the dairy industry. Data was collected through a questionnaire (please see appendix A). Data was collected in two steps as described below.

6.2 Most common accepted challenges

27 challenges from the literature review were listed in the initial version of this work. Based on a survey questionnaire, we verified the challenges from experts' scores measured on a scale of 1 – 7 (where, 1-least significant and 7-most relevant). It was decided to delete any challenge with a score of 1 or 2. We also requested any addition/modification that experts judged to be relevant. Based on this input, two challenges were added under the main challenges; Maintenance cost and Insufficient cold chain capacity. Cost of maintenance in transportation is very high due to labour and equipment. Insufficient infrastructure and inadequate capacity of cold chain vehicles can disrupt service delivery. A total of 29 challenges were thus listed under 7 main challenges (please refer to Appendix B).

6.3 Evaluating priority and inter-relationships of challenges

The direction to the challenges and sub-challenges are provided by behavioural digraph, based on their inter-dependencies. Nodes and edges provide digraphs in which nodes denote the total number of challenges for logistics and directed edges denote the dependencies among the challenges. If direction of edge is towards (y), this means that challenge (x) has relative importance above challenge (y) and is denoted by (d_{xy}); if direction of edge is towards (x), this means that challenge (y) has relative importance above challenge (x) and is denoted by (d_{yx}) (Rao, 2007). Figure 2 shows the index evaluation digraph for the main challenges. The index evaluation directed digraph for sub-challenges has also been drawn (shown in Appendix C).

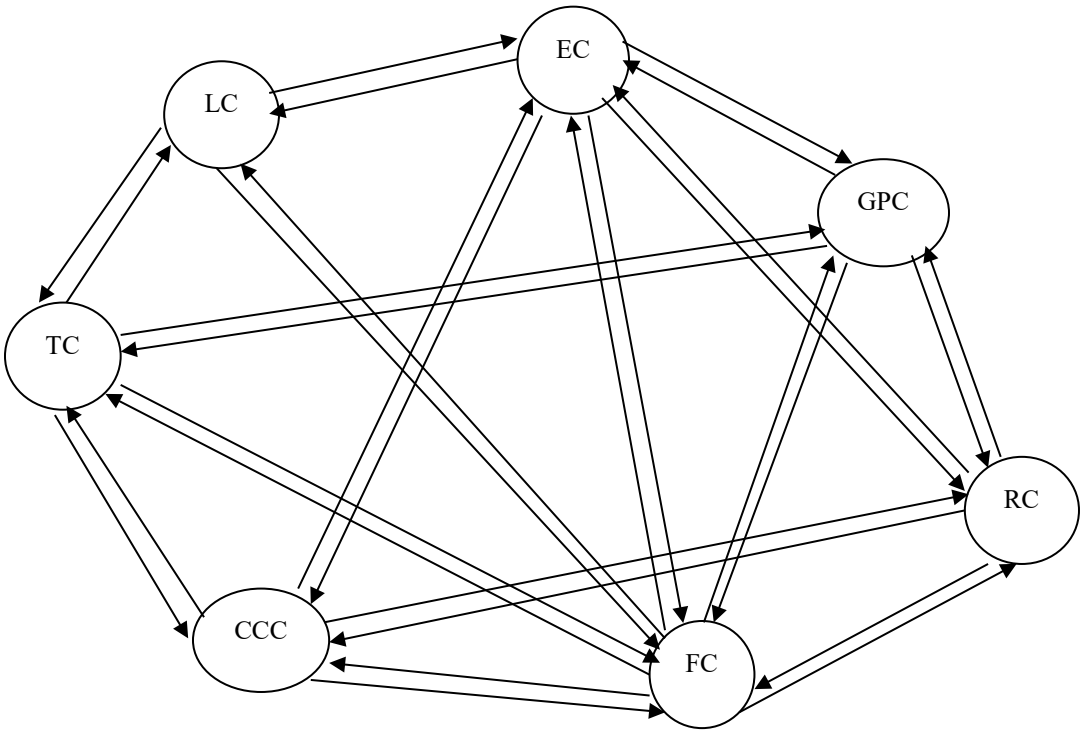

Figure: 2 Index evaluation digraph for logistics based challenges for sustainability in FSC in dairy industry

The above digraph gives one to one representation of the main challenges that represent the matrix. The matrix for main challenges is explained as:

$$\text{Main challenges} = \begin{pmatrix} \text{EC} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} & a_{17} \\ a_{21} & \text{GPC} & a_{23} & a_{24} & a_{25} & a_{26} & a_{27} \\ a_{31} & a_{32} & \text{RC} & a_{34} & a_{35} & a_{36} & a_{37} \\ a_{41} & a_{42} & a_{43} & \text{FC} & a_{45} & a_{46} & a_{47} \\ a_{51} & a_{52} & a_{53} & a_{54} & \text{CCC} & a_{56} & a_{57} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & \text{TC} & a_{67} \\ a_{71} & a_{72} & a_{73} & a_{74} & a_{75} & a_{76} & \text{LC} \end{pmatrix} \quad 1$$

Where, EC, GPC, RC, FC, CCC, TC and LC represent the value of challenges denoted by node where $d_{xy}$is the relative importance of challenge 'x' over challenge 'y'.

Next, the permanent values of main challenge Environmental Related Challenges (EC) for companies 1(I1), 2 (I2) 3 (I3) and 4 (I4) are planned according to Eq. 2 as shown below:

$$Per^{I1}(EC) = \begin{pmatrix} EC1 & a_{12} & a_{13} & a_{14} \\ a_{21} & EC2 & a_{23} & a_{24} \\ a_{31} & a_{32} & EC3 & a_{34} \\ a_{41} & a_{42} & a_{43} & EC4 \end{pmatrix} = \begin{pmatrix} 4 & 6 & 4 & 3 \\ 4 & 6 & 7 & 4 \\ 6 & 3 & 5 & 6 \\ 7 & 6 & 4 & 4 \end{pmatrix} = 14343$$

$$Per^{I2}(EC) = \begin{pmatrix} 5 & 4 & 3 & 4 \\ 6 & 6 & 7 & 6 \\ 7 & 3 & 5 & 3 \\ 6 & 4 & 7 & 4 \end{pmatrix} = 13724 Per^{I3}(EC) = \begin{pmatrix} 6 & 5 & 3 & 5 \\ 5 & 5 & 6 & 4 \\ 7 & 4 & 3 & 5 \\ 5 & 6 & 5 & 4 \end{pmatrix} = 13482$$

$$Per^{I4}(EC) = \begin{pmatrix} 3 & 6 & 5 & 6 \\ 4 & 5 & 7 & 5 \\ 5 & 3 & 7 & 4 \\ 4 & 5 & 6 & 4 \end{pmatrix} = 13778$$

Where, Per^{I1} (EC), Per^{I2} (EC) Per^{I3} (EC) and Per^{I4} (EC) denote the index values for the challenge Environmental Related Challenges (EC) for companies 1, 2, 3 and 4 respectively.

The permanent values of other challenges for companies 1(I1), 2 (I2), 3 (I3) and 4 (I4) are shown in Appendix C.

The implementation index of logistics-based challenges to sustainability in FSC (Index) is estimated by calculating the permanent function of the main matrix of challenges.

$$Per^{I1}(\text{sustainability in FSC}) = \begin{pmatrix} 14343 & 7 & 6 & 7 & 6 & 6 & 7 \\ 3 & 11349 & 4 & 7 & 4 & 7 & 3 \\ 4 & 6 & 13233 & 5 & 4 & 6 & 7 \\ 3 & 3 & 5 & 238169 & 4 & 6 & 4 \\ 4 & 6 & 6 & 6 & 293534 & 7 & 6 \\ 4 & 3 & 4 & 4 & 3 & 688 & 7 \\ 3 & 7 & 3 & 6 & 4 & 3 & 9811 \end{pmatrix} = 1.01 \times 10^{30}$$

$$Per^{I2}(\text{sustainability in FSC}) = \begin{pmatrix} 13724 & 6 & 5 & 8 & 6 & 6 & 7 \\ 4 & 9521 & 4 & 7 & 4 & 4 & 7 \\ 5 & 6 & 12605 & 7 & 4 & 7 & 7 \\ 2 & 3 & 3 & 238708 & 7 & 4 & 7 \\ 4 & 6 & 6 & 3 & 251680 & 5 & 6 \\ 4 & 6 & 3 & 6 & 5 & 587 & 8 \\ 3 & 3 & 3 & 3 & 4 & 2 & 9559 \end{pmatrix} = 5.5 \times 10^{30}$$

Per^{I3}(sustainability in FSC)

$$= \begin{pmatrix} 13482 & 6 & 5 & 8 & 4 & 6 & 7 \\ 4 & 10136 & 4 & 7 & 4 & 7 & 7 \\ 5 & 6 & 12000 & 7 & 4 & 6 & 6 \\ 2 & 3 & 3 & 250249 & 7 & 4 & 7 \\ 6 & 6 & 6 & 3 & 263814 & 5 & 6 \\ 4 & 3 & 4 & 6 & 5 & 770 & 8 \\ 3 & 3 & 4 & 3 & 4 & 2 & 13331 \end{pmatrix}$$

$$= 9.5 \times 10^{30}$$

Per^{I4}(sustainability in FSC)

$$= \begin{pmatrix} 13778 & 5 & 6 & 7 & 5 & 7 & 6 \\ 5 & 11349 & 5 & 6 & 5 & 7 & 6 \\ 4 & 5 & 11294 & 8 & 5 & 7 & 5 \\ 3 & 4 & 2 & 222829 & 7 & 4 & 6 \\ 5 & 5 & 5 & 3 & 274069 & 5 & 7 \\ 3 & 3 & 3 & 6 & 5 & 639 & 7 \\ 4 & 4 & 5 & 4 & 3 & 3 & 11821 \end{pmatrix}$$

$$= 5.7 \times 10^{30}$$

The index values and the best and worst values of all main challenges are shown in Table 5.

Table 5: Index values of logistics-based challenges to sustainability in FSC for companies 1, 2, 3 and 4

Company	EC	GPC	RC	FC	CCC	TC	LC	Index
I1	14343	11349	13233	238169	293534	688	9811	1.01 x 10^{30}
I2	13724	9521	12605	238708	251680	587	9559	5.50 x 10^{30}
I3	23482	10136	12000	250249	263814	770	13331	9.50 x 10^{30}
I4	13778	11349	11294	222829	274069	639	11821	5.70 x 10^{30}
Best Value	15000	15000	15000	375000	375000	326	15000	5.30 x 10^{30}
Worst Value	6776	6776	6776	168376	168376	326	6776	1.90 x 10^{28}

The theoretical best value of the challenge is found by giving the best value to all its sub-challenges i.e. 5.

Best value for challenge 1, Environmental Related Challenges (EC)

$$Per(EC)^{Best} = \begin{pmatrix} 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 \end{pmatrix} = 15000$$

Likewise, the best value for sustainability concepts in FSC index is

$$Per(\text{sustainability in FSC})^{Best}$$
$$= \begin{pmatrix} 15000 & 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 15000 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 15000 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 375000 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 375000 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 750 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 & 15000 \end{pmatrix}$$
$$= 5.3 \times 10^{30}$$

The theoretical worst value of the challenges is attained by giving the worst value to all its sub-challenges i.e. 1.

$$Per(EC)^{Worst} = \begin{pmatrix} 1 & 5 & 5 & 5 \\ 5 & 1 & 5 & 5 \\ 5 & 5 & 1 & 5 \\ 5 & 5 & 5 & 1 \end{pmatrix} = 6776$$

Also, the worst value for sustainability concepts in FSC index is

$$Per(\text{sustainability in FSC})^{Worst}$$
$$= \begin{pmatrix} 6776 & 5 & 5 & 5 & 5 & 5 & 5 \\ 5 & 6776 & 5 & 5 & 5 & 5 & 5 \\ 5 & 5 & 6776 & 5 & 5 & 5 & 5 \\ 5 & 5 & 5 & 168376 & 5 & 5 & 5 \\ 5 & 5 & 5 & 5 & 168376 & 5 & 5 \\ 5 & 5 & 5 & 5 & 5 & 326 & 5 \\ 5 & 5 & 5 & 5 & 5 & 5 & 6776 \end{pmatrix} = 1.9 \times 10^{28}$$

The GTMA analysis also provides the preference order or rank of challenges as shown in Table 6. The closeness of challenge index value near to the best value indicates it has higher importance; the challenge index value near to the worst value indicates less importance.

Table 6: Relative ranks of challenges in logistics to implement sustainability in FSC in dairy sector

Challenges	Company 1 (I1)	Rank	Company 2 (I2)	Rank	Company 3 (I3)	Rank	Company 4(I4)	Rank

EC	14343	3	13724	3	13842	3	13778	3
GPC	11349	5	9521	6	10136	6	11349	5
RC	13233	4	12605	4	12000	5	11294	6
FC	238169	2	238708	2	250249	2	222829	2
CCC	293534	1	251680	1	263814	1	274069	1
TC	688	7	587	7	770	7	639	7
LC	9811	6	9559	5	13331	4	11821	4

7. Discussions

The index values of logistics-based challenges to sustainability in FSC are - 1.01×10^{30}, 5.50×10^{30}, 9.50×10^{30} and 5.70×10^{30}. Based on Table 6, the preference order of the challenges for company 1 is CCC>FC>EC>RC>GPC>LC>TC, for company 2 is CCC>FC>EC>RC>LC>GPC>TC, for company 3 is CCC>FC>EC>LC>RC>GPC>TC and for company 4 is CCC>FC>EC>LC>GPC>RC>TC. The higher the index value then the higher the rank of challenge becomes. The index values of Cold chain related challenges (CCC) for companies 1, 2, 3 and 4 are 293534, 251680, 263814 and 274069 respectively; these are also higher than other challenges in the index value list. Based on index values of CCC, the importance of Cold chain is higher in company 1 and less in company 2. Among the main challenges, Cold chain related challenges are determined as the most significant. An interesting report was published in The Hindu: Business Line on May 31, 2016, "Dairy sector needs more cold chain facilities." According to the report, India needs more cold chain facilities to maximize economic profits and to be able to export more products to the world, considering India's presence in diary sector. The Cold chain related main challenge has five sub-challenges, namely CCC1, CCC2, CCC3, CCC4 and CCC5. Managers and policy makers need to focus on these challenges to enhance overall business sustainability.

For financial related challenges: GTMA analysis indicates the index values of Financial challenge (FC) for case companies 1, 2, 3 and 4 are 238169, 238708, 250249 and 222829 respectively. Investment and funding is needed to make changes to the system, a major concern for food organizations in India (Balaji and Arshinder, 2016). Similarly, Muduli et al. (2013) and

Shirinivas et al. (2010) also indicated that various diary industries are constantly trying to improve their cold chain facilities but financial challenges acts as primary obstacle in enhancing the performance. Thus, overcoming the financial challenges can assist the managers to develop actions to tackle other challenges effectively.

For environmental related challenges (EC): GTMA analysis shows the index values of Environmental challenge (EC) for organizations 1, 2, 3 and 4 are 14343, 13724, 23482 and 13778 respectively. Regulations regarding environment protection are very important and organizations should respond positively in adopting recommended environmental standards in its business activities (Chandra, 2015). In order to withstand the global competition, sustainability has become one of the most essential aspects for diary industries. Beske et al. (2014) also insisted to focus on environmental challenges, as dairy products being consumed on daily basis. This means they may have a high impact on human health. Hence, it is essential to observe the environmental challenges that strongly influence the performance of dairy industries. In many countries across the globe, government has started developing the environmental favouring policies to benefit their citizens.

For road related challenges (RC): GTMA analysis shows the index values of Road challenge (RC) for case firms 1, 2, 3 and 4 are 13233, 12605, 12000 and 11294 respectively. To achieve sustainability, organizations need to improve poor networks of road and incorporate new technologies to handle road issues such as traffic signals (Mehta and Rajan, 2017). It is further highlighted by Meneghetti and Monti (2015) that improved transportation is extremely essential for dairy industries because of short life of its products. The managers are constantly focusing on the challenges related to roads and transportation to make sure that the product is delivered to the end user in a minimal possible time.

For Government/political related challenges (GPC): GTMA analysis indicates the index values of Government/political challenge (GPC) for case companies 1, 2, 3 and 4 are 11349, 9521, 10136 and 11349 respectively. For case companies 1 and 4 it attains fifth position; for company 2 and 3 it acquires sixth position. Government/political challenge plays an important role in effective adoption of transportation-based sustainable development (Tirado et al., 2010, Porter and Kramer, 2019).

For technology related challenges (TC): GTMA analysis shows the index values of Technology challenge (TC) for case companies 1, 2, 3 and 4 are 688, 587, 770 and 639 respectively. For companies 1, 2, 3 and 4 it attains seventh place. Technology plays a crucial role in managing logistics issues for dairy products (Venugopal, 2017). It has been observed that the developed countries have switched to advanced technologies to improve the performance of dairy sectors (Leamer and Storper, 2014). However, the developing nations are still practicing the traditional technologies for their entire process structure within diary sector. Hence, it is immediately required to adopt the advanced technologies in supply and logistics functions in dairy sectors. This will definitely help in enhancing its business sustainability.

7.1 Implications for managers and policy makers

This research gives an in-depth understanding in effective management of logistics-based challenges for sustainability in Indian dairy organizations through the permanent of a matrix and adoption index values. This research can help private as well as public sector organizations, policy makers and senior managers. Challenges to sustainability faced by the dairy industry can be tackled successfully. Some projected implications of the present study are mentioned below:

Role of efficient cold chain for higher green growth

In the dairy sector in India, most milk that is spoiled is because of a lack of proper cold chain facilities (Kumar et. al 2018a). To deal with this, managers need to promote research by developing high-class dairy technologists and professionals. The industry needs to become more attractive to enlist young talented workers. Adulteration and contamination needs to be addressed at its root. Although India is the world's largest producer of milk, but still are the poorest in per capita yield. Proper cold chain in transportation will increase profits and help in the country's growth. Companies can also create a collaborate network to contribute to cold chain development to improve their logistics performance considering their financial capabilities and governmental policies to support food wastage campaign in a nation.

Role of government regularity bodies

Government plays an important role for managing logistics related concerns. Government regularity bodies can help to overcome problems of policy implementation, security, assurance

and monitoring. Co-ordination of central and state governments helps the nation to overcome the issues of roads, lack of funds and electricity. A co-ordination mechanism can also help in systematic distribution and management of resources to improve communication and information transparency among stakeholders in food value chain. In India, government action is crucial for sustainable business development in the food sector. Effective action also increases the profitability of dairy industries.

Requirements of funds for maintenance and up-gradation of systems

Enough funds and resources are important for effective management of logistics. Funding and investments are essential for maintenance and upgrading out of date systems. In transportation of dairy products, maintenance costs are very high due to safety and security. Managers need to use new methodologies, techniques and equipment to minimize losses in the whole food supply chain. New technologies and innovations also overcome the negative impact of logistics on the environment. Such as, the implementation of blockchain, big data, and advanced information technologies can improve overall business sustainability. Adopting automated milking systems improves the productivity growth of dairy farms and, thus, their prospects of long-term survival. Automated mastitis detection and dairy shed technologies also improve the sustainability of the organization.

Developing infrastructure facility for people and community welfare

Currently in India, road accidents are increasing at an alarming rate. This is directly related to poor road infrastructures, mixed traffic and lack of awareness among people. To overcome this, government should upgrade roads and infrastructure. Organizations should be motivated to develop their workforces in delivering food products to consumers in the most sustainable way. In addition, logistics optimization is important in sustainable food management, which includes loading, speed, route, reverse logistics, use of alternative fuels, logistics collaboration etc. Thus, investments on developing reverse logistics is an important need in diary industries.

People management for their expertise and skills

In India, agro-food organizations lacks in people management in distributing diary based products to the customers. The supply chains of perishable products are very complex due to short life cycle, huge variation in demand and price, etc. In this sense, the perishable products need appropriate handling and control to reduce food wastage. In so doing, human resource skills and expertise can serve the purpose for improving operational effectiveness of diary based organizational supply chains.

Apart from the above stated implications for managers and policy makers, this study is equally beneficial for researchers and practitioners. An exhaustive set of 27 unique challenges to logistics related food chain in diary sector are identified in this study. The categorized set can help the academicians to develop new frameworks for diary industries and test it in future research. The practitioners can also deeply assess the identified challenges and formulate action plans to overcome these challenges by monitoring the weights of the included challenges. It is obvious that tackling all the challenges simultaneously is extremely difficult. Hence, the prioritized set of challenges along with their interdependence will facilitate the practitioners to improve the FSC performance in diary sector.

8. Conclusions

This research focuses on the logistics related challenges (focusing on related people and process related issues) as well as sub-challenges to implement corporate (ecological-economic-social) sustainability in FSC in diary sector successfully. The key challenges are underpinned by a literature survey and experts' opinions. GTMA based approach is used to analyze these challenges to establish their priority and inter-relationships. Results show the priority order of the main challenges - cold chain related challenges come top; economic related challenges are next; these are followed by financial related challenges; road related challenges come next; next are government/political related challenges; these are followed by technology related challenges and finally legal related challenges. The findings of this study are obtained from the case application within the four dairy organizations in India.

This research provides several directions for future studies. This work has generally focused on logistics challenges to implement sustainability orientation in FSC in the Indian context. However, this study may also be extended to other developing economies such as India, China, Thailand with some modifications. In addition, this work mainly focused on collecting opinions from four major dairy production organizations. In future, the sample size may be increased and an empirical investigation may be conducted for theoretical building. This research presents an interesting chance to undertake a more broad-based investor outlook on the challenges for educating stakeholders and developing suitable policies and achieving successful corporate sustainability in A-FSC initiatives in the dairy industry.

REFERENCES

Aggarwal, P. & Jain, S. (2016). Energy demand and CO2 emissions from urban on-road transport in Delhi: current and future projections under various policy measures. *Journal of Cleaner Production*, *128*, 48-61.

Ahmadi, H. B., Kusi-Sarpong, S. & Rezaei, J. (2017). Assessing the social sustainability of supply chains using Best Worst Method. *Resources, Conservation and Recycling*, *126*, 99-106.

Allaoui, H., Guo, Y., Choudhary, A. & Bloemhof, J. (2018). Sustainable agro-food supply chain design using two-stage hybrid multi-objective decision-making approach. *Computers & Operations Research*, *89*, 369-384.

Amui, L. B. L., Jabbour, C. J. C., de Sousa Jabbour, A. B. L., Kannan, D., 2017. Sustainability as a dynamic organizational capability: a systematic review and a future agenda toward a sustainable transition. Journal of Cleaner Production. 142, 308-322.

Ashok, A., Brison, M. & LeTallec, Y. (2017). Improving cold chain systems: Challenges and solutions. *Vaccine, 35*(17), 2217-2223.

Balaji, M. & Arshinder, K. (2016). Modeling the causes of food wastage in Indian perishable food supply chain. *Resources, Conservation and Recycling*, *114*, 153-167.

Banaeian, N., Mobli, H., Fahimnia, B., Nielsen, I. E. & Omid, M. (2018). Green supplier selection using fuzzy group decision making methods: A case study from the agri-food industry. *Computers & Operations Research*, *89*, 337-347.

BBC (2017). Brazil meat-packing giants 'exported rotten beef'. 18 March 2017. https://www.bbc.co.uk/news/world-latin-america-39311336. Accessed on 2 July 2018.

Bendul, J. C., Rosca, E. & Pivovarova, D. (2017). Sustainable supply chain models for base of the pyramid. *Journal of Cleaner Production*, *162*, S107-S120.

Bloemhof, J. M. & Soysal, M. (2017). Sustainable food supply chain design. In *Sustainable Supply Chains* (pp. 395-412). Springer, Cham.

Buranelli, F. C. (2018). One Belt, One Road and Central Asia: Challenges and Opportunities. In *The Belt & Road Initiative in the Global Arena* (pp. 207-230). Palgrave Macmillan, Singapore.

Carter, C. R. & Rogers, D. S. (2008). A framework of sustainable supply chain management: moving toward new theory. *International Journal of Physical Distribution & Logistics Management*, *38*(5), 360-387.

Castillo-Manzano, J. I., Castro-Nuño, M. & Fageda, X. (2016). Exploring the relationship between truck load capacity and traffic accidents in the European Union. *Transportation Research Part E: Logistics and Transportation Review*, *88*, 94-109.

Chandra, M. (2015). Environmental concerns in India: Problems and solutions. *J. Int'l Bus. & L.*, *15*, 1.

Coley, D., Howard, M. & Winter, M. (2009). Local food, food miles and carbon emissions: A comparison of farm shop and mass distribution approaches. *Food Policy*, *34*(2), 150-155.

Dandage, K., Badia-Melis, R. & Ruiz-García, L. (2017). Indian perspective in food traceability: a review. *Food Control*, *71*, 217-227.

Dey, K. C., Mishra, A. & Chowdhury, M. (2015). Potential of intelligent transportation systems in mitigating adverse weather impacts on road mobility: a review. *IEEE Transactions on Intelligent Transportation Systems*, *16*(3), 1107-1119.

Douphrate, D. I., Hagevoort, G. R., Nonnenmann, M. W., Lunner Kolstrup, C., Reynolds, S. J., Jakob, M. & Kinsel, M. (2013). The dairy industry: a brief description of production practices, trends, and farm characteristics around the world. *Journal of Agromedicine*, *18*(3), 187-197.

Elhedhli, S. & Merrick, R. (2012). Green supply chain network design to reduce carbon emissions. *Transportation Research Part D: Transport and Environment*, *17*(5), 370-379.

Financial Express (2018). Meat scandal in Kolkata hits restaurant sales after 20,000 kg carcass meat seized; inter-state racket suspected. https://www.financialexpress.com/india-news/kolkata-

meat-scandal-hits-restaurant-sales-after-20000-kg-rotten-meat-seized-inter-state-racket-suspected/1151459/. Accessed on 2 July 2018.

Fredriksson, A. & Liljestrand, K. (2015). Capturing food logistics: a literature review and research agenda. *International Journal of Logistics Research and Applications*, *18*(1), 16-34.

Gandhi, V. P. & Zhou, Z. (2014). Food demand and the food security challenge with rapid economic growth in the emerging economies of India and China. *Food Research International*, *63*, 108-124.

Govindan, K., Azevedo, S. G., Carvalho, H. & Cruz-Machado, V. (2014). Impact of supply chain management practices on sustainability. *Journal of Cleaner Production*, *85*, 212-225.

Govindan, K., Kadziński, M. & Sivakumar, R. (2017). Application of a novel promethee-based method for construction of a group compromise ranking to prioritization of green suppliers in food supply chain. *Omega*, *71*, 129-145.

Goyal, S., Routroy, S. & Shah, H. (2018). Measuring the environmental sustainability of supply chain for Indian steel industry: a graph theoretic approach. *Business Process Management Journal*, *24*(2), 517-536.

Hertel, S., Tagliarina, C. M. & Buerger, C. (2017). Cheap Talk on Food: Party Politics in India and the Challenge of Implementing the Right to Food. *Human Rights Quarterly*, *39*(2), 449-467.

Jabbour, C. J. C., & de Sousa Jabbour, A. B. L., (2016). Green human resource management and green supply chain management: Linking two emerging agendas. Journal of Cleaner Production, 112, 1824-1833.

Jabbour, C. J. C., de Sousa Jabbour, A. B. L., Govindan, K., Teixeira, A. A., & de Souza Freitas, W. R., (2013). Environmental management and operational performance in automotive companies in Brazil: the role of human resource management and lean manufacturing. Journal of Cleaner Production, . 47, 129-140.

Jabbour, C. J. C., Jugend, D., de Sousa Jabbour, A. B. L., Gunasekaran, A., & Latan, H., (2015). Green product development and performance of Brazilian firms: measuring the role of human and technical aspects. Journal of Cleaner Production, . 87, 442-451.

Jain, V. & Raj, T. (2016). Modeling and analysis of FMS performance variables by ISM, SEM and GTMA approach. *International Journal of Production Economics*, *171*, 84-96.

Junior, M. L. & Godinho Filho, M. (2010). Variations of the kanban system: Literature review and classification. *International Journal of Production Economics*, *125*(1), 13-21.

Kaewunruen, S., Sussman, J. M. & Matsumoto, A. (2016). Grand challenges in transportation and transit systems. *Frontiers in built environment*, *2*, 4.

Kamana, O., Jacxsens, L., Kimonyo, A. & Uyttendaele, M. (2017). A survey on hygienic practices and their impact on the microbiological quality and safety in the Rwandan milk and dairy chain. *International Journal of Dairy Technology, 70(1),* 52-67.

Kayisu, A. K., Joseph, M. K. & Kyamakya, K. (2018). COMPRAM Assessment and System Dynamics Modeling and Simulation of Car-Following Model for Degraded Roads. In *Recent Advances in Nonlinear Dynamics and Synchronization* (pp. 191-224). Springer, Cham.

Khan, R. H., Varshney, Y., Ahmad, A., Alam, M. S. & Chaban, R. C. (2018). Technical and Economic Feasibility Analysis for deployment of xEV Wireless Charging Infrastructure in India. In *ISGW 2017: Compendium of Technical Papers* (pp. 151-164). Springer, Singapore.

Khan, S. A. R., Jian, C., Zhang, Y., Golpîra, H., Kumar, A., & Sharif, A. (2019). Environmental, social and economic growth indicators spur logistics performance: From the perspective of South Asian Association for Regional Cooperation countries. *Journal of Cleaner Production*, *214*, 1011-1023.

Khisty, C. J. & Lall, B. K. (2017). *Transportation Engineering*. Pearson Education India.

Klose, M., Damm, B. & Terhorst, B. (2015). Landslide cost modeling for transportation infrastructures: a methodological approach. *Landslides*, *12*(2), 321-334.

Krishnadevarajan, P., Muthukrishnan, D., Balasubramanian, S. & Kannan, N. (2015). Supply chain in India "2011-2015"–A review: Challenges, solution framework and key best practices. *International Journal of Management*, *6*(10), 135-149.

Kumar, P., Singh, R. K. & Kumar, R. (2017). An integrated framework of interpretive structural modeling and graph theory matrix approach to fix the agility index of an automobile manufacturing organization. *International Journal of System Assurance Engineering and Management*, *8*(1), 342-352.

Kumar, V. Wankhede, K. G., & Gena, H. C. (2015). Role of cooperatives in improving livelihood of farmers on sustainable basis. *American Journal of Educational Research*, *3*(10), 1258-1266.

Kumar, A., Mangla, S. K., Luthra, S., & Ishizaka, A. (2019). Evaluating the human resource related soft dimensions in green supply chain management implementation. *Production Planning & Control*, *30*(9), 699-715.

Kumar, A., Zavadskas, E. K., Mangla, S. K., Agrawal, V., Sharma, K., & Gupta, D. (2018a). When risks need attention: adoption of green supply chain initiatives in the pharmaceutical industry. *International Journal of Production Research*, 1-23.

Kumar, A., Mangla, S. K., Luthra, S., Rana, N. P., & Dwivedi, Y. K. (2018b). Predicting changing pattern: building model for consumer decision making in digital market. *Journal of Enterprise Information Management*, *31*(5), 674-703.

Kumar, A., Luthra, S., Khandelwal, D. K., Mehta, R., Chaudhary, N., & Bhatia, S. (2017). Measuring and improving customer retention at authorised automobile workshops after free services. *Journal of Retailing and Consumer Services*, *39*, 93-102.

Leamer, E. E. & Storper, M. (2014). The economic geography of the internet age. In *Location of International Business Activities* (pp. 63-93). Palgrave Macmillan, London.

Lee, C. T., Hashim, H., Ho, C. S., Van Fan, Y. & Klemeš, J. J. (2017). Sustaining the low-carbon emission development in Asia and beyond: Sustainable energy, water, transportation and low-carbon emission technology. *Journal of Cleaner Production*, *146*, 1-13.

Li, D., Wang, X., Chan, H. K. & Manzini, R. (2014). Sustainable food supply chain management. *International Journal of Production Economics*, (152), 1-8.

Luthra, S., & Mangla, S. K. (2018). When strategies matter: Adoption of sustainable supply chain management practices in an emerging economy's context. *Resources, Conservation and Recycling*, *138*, 194-206.

Mangla, S. K., Bhattacharya, A., & and Luthra. S. (2018b). Achieving Sustainability in Supply Chain Operations in the interplay between Circular Economy and Industry 4.0. Taylor & Francis Online, June 4, 2018. http://explore.tandfonline.com/cfp/est/jmt05555-tppc-achieving-sustainability-in-supplychain-operations?utm_source=CPB&utm_medium=cms&utm_campaign=JMT05555

Mangla, S. K., Luthra, S., Rich, N., Kumar, D., Rana, N. P., & Dwivedi, Y. K. (2018a). Enablers to implement sustainable initiatives in agri-food supply chains. *International Journal of Production Economics*, *203*, 379-393.

Mariano, E. B., Sobreiro, V. A. & do Nascimento Rebelatto, D. A. (2015). Human development and data envelopment analysis: A structured literature review. *Omega*, *54*, 33-49.

Marsden, G. & Reardon, L. (2017). Questions of governance: Rethinking the study of transportation policy. *Transportation Research Part A: Policy and Practice*, *101*, 238-251.

Mattevi, M. & Jones, J. A. (2016). Traceability in the food supply chain: Awareness and attitudes of UK Small and Medium-sized Enterprises. *Food Control*, *64*, 120-127.

Mehta, Y. & Rajan, A. J. (2017). Manufacturing Sectors in India: Outlook and Challenges. *Procedia engineering*, *174*, 90-104.

Meneghetti, A. & Monti, L. (2015). Greening the food supply chain: an optimisation model for sustainable design of refrigerated automated warehouses. *International Journal of Production Research*, *53*(21), 6567-6587.

Mercier, S., Villeneuve, S., Mondor, M. & Uysal, I. (2017). Time–Temperature Management Along the Food Cold Chain: A Review of Recent Developments. *Comprehensive Reviews in Food Science and Food Safety, 16(4),* 647-667.

Mishra, P. K. & Raja Shekhar, B. (2012). Evaluating supply chain risk in Indian dairy industry: a case study. *International Journal of Decision Sciences, Risk and Management*, *4*(1-2), 77-91.

Mor, R. S., Singh, S. & Bhardwaj, A. (2018). Exploring the causes of Low-Productivity in Dairy Supply Chain using AHP. *Jurnal Teknik Industri*, *19*(2), 83-92.

Mtisi, S., Dube, A. & Dube, T. (2017). Assessing the challenges faced by rural agro-dealers in Matabeleland North Province, Zimbabwe. *African Journal of Business Management*, *11*(9), 183-193.

Negi, S. & Anand, N. (2015). Issues and challenges in the supply chain of fruits & vegetables sector in India: a review. *International Journal of Managing Value and Supply Chains*, *6*(2), 47-62.

Negi, S. & Anand, N. (2017). Wastage and Cold Chain Infrastructure Relationship in Indian Food Supply Chain. *Supply Chain Management Strategies and Risk Assessment in Retail Environments*, 247.

Nkomo, J. C. (2017). The impact of higher oil prices on Southern African countries. *Journal of Energy in Southern Africa*, *17*(1), 10-17.

Osti, R. & Nakasu, T. (2016). Lessons learned from southern and eastern Asian urban floods: from a local perspective. *Journal of Flood Risk Management*, *9*(1), 22-35.

Patankar, M., Patwardhan, A. & Verbong, G. (2010). A promising niche: waste to energy project in the Indian dairy sector. *Environmental Science & Policy*, *13*(4), 282-290.

Porter, M. E. & Kramer, M. R. (2019). Creating shared value. In *Managing Sustainable Business* (pp. 327-350). Springer, Dordrecht.

Rajeev, A., Pati, R. K., Padhi, S. S. & Govindan, K. (2017). Evolution of sustainability in supply chain management: A literature review. *Journal of Cleaner Production*, *162*, 299-314.

Rajendran, K. & Mohanty, S. (2004). Dairy Co-operatives and Milk Marketing in India: Constraints and Opportunities. *Journal of Food Distribution Research*, *35*, 34-41.

Rao, R. V. (2007). *Decision making in the manufacturing environment: using graph theory and fuzzy multiple attribute decision making methods*. Springer Science & Business Media.

Redshaw, P., Dijkstra, T., Free, M., Jordan, C., Morley, A. & Fraser, S. (2017, May). Landslide Risk Assessment for the Built Environment in Sub-Saharan Africa. In *Workshop on World Landslide Forum* (pp. 5-12). Springer, Cham.

Rodrigue, J. P., Comtois, C. & Slack, B. (2016). *The geography of transport systems*. Routledge.

Roy, S. & Sahu, A. S. (2017). Potential interaction between transport and stream networks over the lowland rivers in Eastern India. *Journal of environmental management*, *197*, 316-330.

Ryan, J. M. (2017). Guide to Food Safety and Quality During Transportation: Controls, Standards and Practices. Academic Press.

Sahu, K. K. (2017). Trend, Growth, and Problems of Road Transport in India. *Handbook of Research on Economic, Financial, and Industrial Impacts on Infrastructure Development; Das, RC, Ed*, 201-223.

Sarkis, J. (2018). Sustainable and green supply chains: Advancement through Resources, Conservation and Recycling.(In Press)

Saurav, S. & Potti, R. (2016). Cold chain logistics in India: a study. *Innovative Solutions for Implementing Global Supply Chains in Emerging Markets*, 159-172.

Schiller, P. L. & Kenworthy, J. R. (2017). *An introduction to sustainable transportation: Policy, planning and implementation*. Routledge.

Sgarbossa, F. & Russo, I. (2017). A proactive model in sustainable food supply chain: Insight from a case study. *International Journal of Production Economics*, *183*, 596-606.

Shamsi, A. F., Panhwar, I. A., Iqbal, B. & Cheema, K. (2014). India as an emerging economy. *Transnational Corporations Review*, *6*(1), 15-25.

Sharma, Y. K., Mangla, S. K., Patil, P. P. & Uniyal, S. (2018a). Sustainable Food Supply Chain Management Implementation Using DEMATEL Approach. In *Advances in Health and Environment Safety* (pp. 115-125). Springer, Singapore.

Sharma, Y. K., Yadav, A. K., Mangla, S. K. & Patil, P. P. (2018b). Ranking the Success Factors to Improve Safety and Security in Sustainable Food Supply Chain Management Using Fuzzy AHP. *Materials Today: Proceedings*, *5*(5), 12187-12196.

Shirinivas, S. G., Vetrivel, S. & Elango, N. M. (2010). Applications of graph theory in computer science an overview. *International Journal of Engineering Science and Technology*, *2*(9), 4610-4621.

Simangunsong, E., Simangunsong, E., Hendry, L. C., Hendry, L. C., Stevenson, M. & Stevenson, M. (2016). Managing supply chain uncertainty with emerging ethical issues. *International Journal of Operations & Production Management*, *36*(10), 1272-1307.

Singh, B., Grover, S. & Singh, V. (2017). Evaluation of benchmarking attribute for service quality using multi attitude decision making approach. *International Journal of System Assurance Engineering and Management*, *8*(2), 617-630.

Smith, G. (2017). Food and drink industry second most affected by product recalls, new research shows. https://www.newfoodmagazine.com/news/46760/food-and-drink-recall-losses/. Accessed on 2 July 2018.

Tassou, S. A., De-Lille, G. & Ge, Y. T. (2009). Food transport refrigeration–Approaches to reduce energy consumption and environmental impacts of road transport. *Applied Thermal Engineering*, *29*(8-9), 1467-1477.

Tirado, M. C., Cohen, M. J., Aberman, N., Meerman, J. & Thompson, B. (2010). Addressing the challenges of climate change and biofuel production for food and nutrition security. *Food Research International*, *43*(7), 1729-1744.

Tortajada, C. (2016). Policy dimensions of development and financing of water infrastructure: The cases of China and India. *Environmental Science & Policy*, *64*, 177-187.

Tostivint, C., de Veron, S., Jan, O., Lanctuit, H., Hutton, Z. V. & Loubière, M. (2017). Measuring food waste in a dairy supply chain in Pakistan. *Journal of cleaner production*, *145*, 221-231.

Van Donselaar, K. H. & Broekmeulen, R. A. (2012). Approximations for the relative outdating of perishable products by combining stochastic modeling, simulation and regression modeling. *International Journal of Production Economics*, *140*(2), 660-669.

Venkatesh, V. G. & Luthra, S. (2016). Role of sustainable procurement in sustainable manufacturing operations: an indian insight. In *Strategic Management of Sustainable Manufacturing Operations* (pp. 132-148). IGI Global.

Villarreal, B., Garza-Reyes, J. A., Kumar, V. & Lim, M. K. (2017). Improving road transport operations through lean thinking: a case study. *International Journal of Logistics Research and Applications*, *20*(2), 163-180.

Vlajic, J. V., van Lokven, S. W., Haijema, R. & van der Vorst, J. G. (2013). Using vulnerability performance indicators to attain food supply chain robustness. *Production Planning & Control*, *24*(8-9), 785-799.

Wagner, S. M. & Neshat, N. (2010). Assessing the vulnerability of supply chains using graph theory. *International Journal of Production Economics*, *126*(1), 121-129.

Wang, J. & Yue, H. (2017). Food safety pre-warning system based on data mining for a sustainable food supply chain. *Food Control*, *73*, 223-229.

Wang, Z., Mathiyazhagan, K., Xu, L. & Diabat, A. (2016). A decision making trial and evaluation laboratory approach to analyze the barriers to Green Supply Chain Management adoption in a food packaging company. *Journal of Cleaner Production*, *117*, 19-28.

WCED (1987). Our common future (World Commission on Environment and Development, Bruntland Commission). Oxford University Press, Oxford.

Winston, C. (2000). Government failure in urban transportation. *Fiscal Studies*, *21*(4), 403-425.

Yadav, M., Kumar, A., Mangla, S. K., Luthra, S., Bamel, U., & Garza-Reyes, J. A. (2018). Mapping the human resource focused enablers with sustainability viewpoints in Indian power sector. *Journal of Cleaner Production, in press*.

Yadav, R., Sahu, L. K., Beig, G. & Jaaffrey, S. N. A. (2016). Role of long-range transport and local meteorology in seasonal variation of surface ozone and its precursors at an urban site in India. *Atmospheric Research*, *176*, 96-107.

Yu, B., Ma, N., Cai, W., Li, T., Yuan, X. & Yao, B. (2013). Improved ant colony optimisation for the dynamic multi-depot vehicle routing problem. *International Journal of Logistics Research and Applications*, *16*(2), 144-157.

Yu, V. F., Hu, K. J. & Chang, A. Y. (2015). An interactive approach for the multi-objective transportation problem with interval parameters. *International Journal of Production Research*, *53*(4), 1051-1064.

Zhang, J., Li, W. & Qiu, F. (2015). Optimizing single-depot vehicle scheduling problem: fixed-interval model and algorithm. *Journal of Intelligent Transportation Systems*, *19*(3), 215-224.

Zhang, R., Yun, W. Y. & Moon, I. (2009). A reactive tabu search algorithm for the multi-depot container truck transportation problem. *Transportation Research Part E: Logistics and Transportation Review*, *45*(6), 904-914.

Appendix A

Survey Questionnaire

Dear Sir/Madam,
Greetings!!!
We are conducting this research to evaluate the effect of logistics based aspects (challenges) to implement sustainability in the food supply and logistics system in the dairy sector in Indian context. The data for this work is collected in 2 phases:

PHASE 1: Most common challenges to logistics to implement sustainability in GSC in diary industry
We have listed 27 sub-challenges under 7 main challenges using literature. Please add/delete/reword any other challenge relevant to logistics to implement sustainability in FSC in the Indian dairy industry.

	Environmental related challenges (EC)	**Degree of Priority**
1	Floods in plains	
2	Landslides in hilly areas	
3	CO_2 gas emission	
4	Lack of weather forecasting	
	(Please mention any other challenge)	
	(Please mention any other challenge)	

	Government / political related challenges (GPC)	**Degree of Priority**
5	Lack of policies	
6	Lack of security assurance	
7	Failure of government	
8	Lack of monitoring	
	(Please mention any other challenge)	
	(Please mention any other challenge)	

	Roads related challenges (RC)	Degree of Priority
9	Toll taxes	
10	Mixed traffic	
11	Lack of road infrastructure	
12	Lack of facilities	
	(Please mention any other challenge)	
	(Please mention any other challenge)	

	Financial related challenges (FC)	Degree of Priority
13	Increase in crude oil price	
14	Lack of proper investment	
15	Lack of funds	
16	Currency variation	
	(Please mention any other challenge)	
	(Please mention any other challenge)	

	Cold Chain related challenges (CCC)	Degree of Priority
18	Poor pest control	
19	Lack of temperature controlling	
20	Lack of equipment	
21	Lack of availability of services and resources	
	(Please mention any other challenge)	

	Technology related challenges (TC)	Degree of Priority
23	Lack of adoption	
24	Lack of skilled labour	
25	Lack of information technology (IT) application	
	(Please mention any other challenge)	
	(Please mention any other challenge)	

	Legal related challenges (LC)	Degree of Priority
26	Disputes between partners	
27	Lack of safety	
28	Lack of transparency	
29	Lack of trust	
	(Please mention any other challenge)	

PHASE 2: **Determine the priority of challenges**

After listing the main challenges and their sub-challenges, we aim to prioritize their importance. Please respond using the given scale.

Table: Relative importance of challenge (dxy) (Muduli et al., 2013)

Definition	Relative importance of attributes	
	d_{xy}	d_{yx}= 10-d_{xy}
Comparing challenges are equally important	5	5
One challenge is moderately important over another	6	4
One challenge is strongly important over another	7	3
One challenge is very strongly important over another	8	2
One challenge is extremely important over another	9	1
One challenge is extraordinarily important over another	10	0

Appendix B

Table: Most accepted challenges to logistics for sustainability in FSC in dairy industry

S. No.	Challenges	Source
Environmental related challenges (EC)		
1	Floods in plains	Kaewunruen, et al., (2016); Osti and Nakasu, (2016)
2	Landslides in hilly areas	Klose, et al., (2015); Redshaw, et al., (2017)
3	CO_2 gas emission	Coley, et al., (2009); Lee,et al., (2017)
4	Lack of weather forecasting	Dey, et al., (2015); Yadav, et al., (2016)
Government / political related challenges (GPC)		
5	Lack of policies	Marsden and Reardon, (2017); Dandage, et al., (2017)
6	Lack of security assurance	Mattevi and Jones, (2016); Roy and Sahu, (2017)
7	Failure of government	Winston, (2000); Patankar, et al., (2010)
8	Lack of monitoring	Gandhi and Zhou, (2014); Dandage, et al., (2017).
Roads related challenges (RC)		
9	Toll taxes	Sahu, (2017); Kayisu, et al., (2018).
10	Mixed traffic	Castillo-Manzano, et al., (2016)
11	Lack of road infrastructure	Sahu, (2017); Roy and Sahu, (2017); Kayisu et al., (2018)
12	Lack of facilities	Atombo et al., (2017); Khan, et al., (2018)
Financial related challenges (FC)		
13	Hike in crude oil	Khan et al., (2018)

14	Lack of proper investment	Khisty and Lall, (2017); Buranelli, F. C. (2018)
15	Lack of funds	Sahu, (2017)
16	Currency variation	Nkomo, (2017); Mtisi, et al., (2017)
17	Maintenance cost	Expert's inputs
Cold Chain related challenges (CCC)		
18	Poor pest control	Saurav and Potti, (2016); Kamana et al., (2017)
19	Lack of temperature controlling	Tassou et al., (2009); Mercier et al., (2017)
20	Lack of equipment	Ashok et al., (2017)
21	Lack of availability of services and resources	Krishnadevarajan et al., (2015); Ashok, et al., (2017)
22	Insufficient cold chain capacity	Expert's inputs
Technology related challenges (TC)		
23	Lack of adoption	Misra, (2008); Nazir et al., (2017)
24	Lack of skilled labour	Shamsi et al., (2014).
25	Lack of information technology (IT) application	Negi and Anand, (2015), Negi and Anand, (2017).
Legal related challenges (LC)		
26	Disputes between the partners	Venkatesh and Luthra, (2016)
27	Lack of safety	Simangunsong et al., (2016); BBC, (2017)
28	Lack of transparency	Tortajada, (2016); Venkatesh and Luthra, (2016)
29	Lack of trust	Hertel et al., (2017)

Appendix C – GTMA Analysis

Directed digraph for challenges;

Listed below figures show the directed digraph for challenges; Environmental Related Challenges (EC), Government/Political Related Challenges (GPC), Roads Related Challenges (RC), Financial Related Challenges (FC),Cold Chain Related Challenges (CCC),Technology Related Challenges (TC) and Legal Related Challenges (LC) respectively.

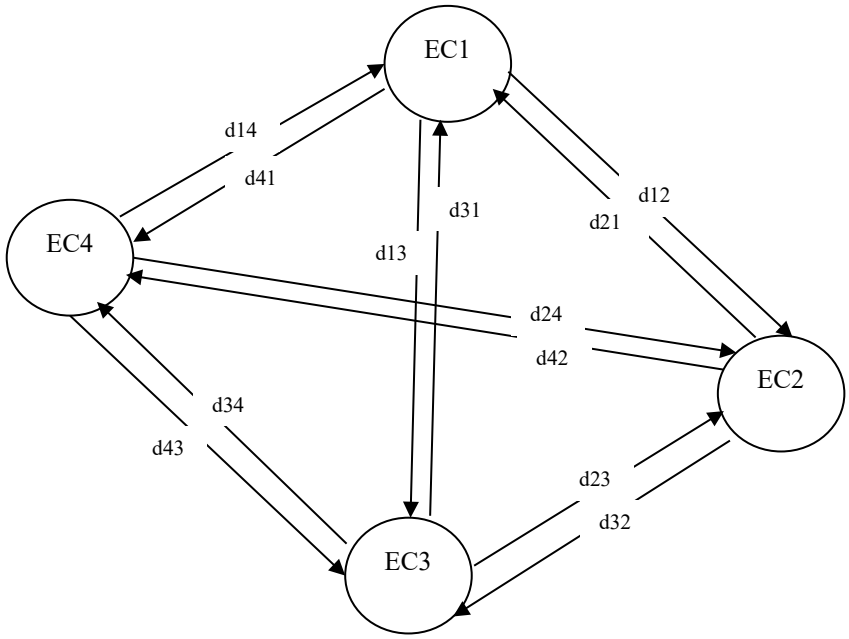

Figure: 3 Digraph for environmental related challenges (EC)

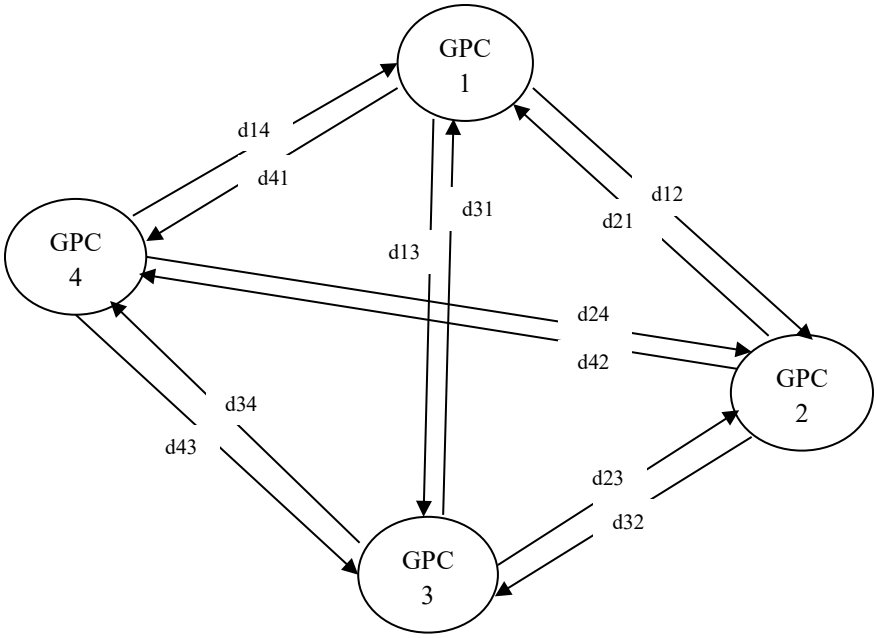

Figure: 4 Digraph for government/political related challenges (GPC)

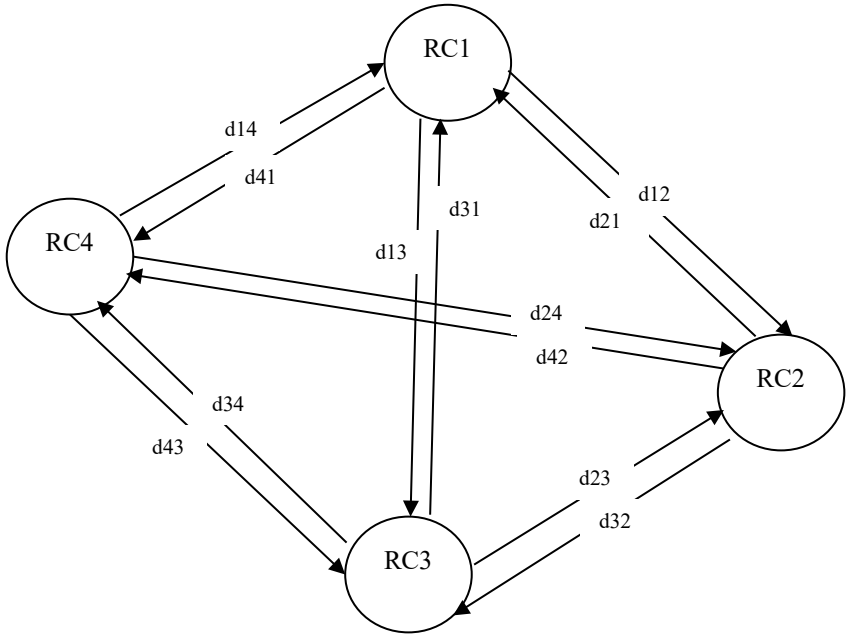

Figure: 5 Digraph for roads related challenges (RC)

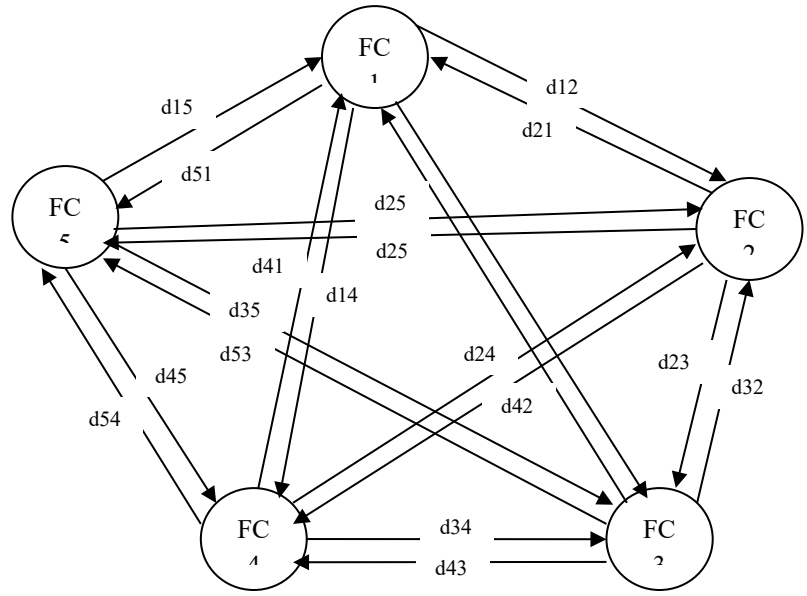

Figure: 6 Digraph for financial related challenges (FC)

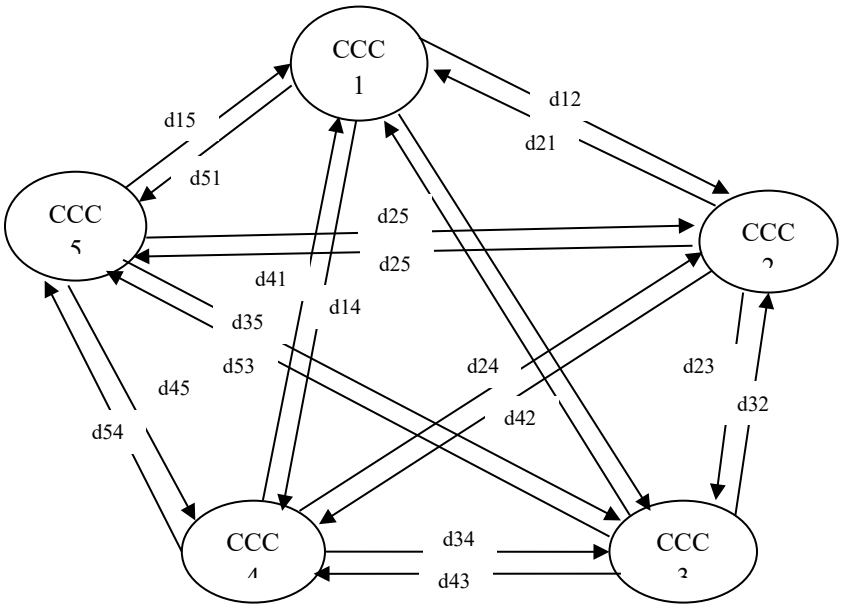

Figure: 7 Digraph for cold chain related challenges (FC)

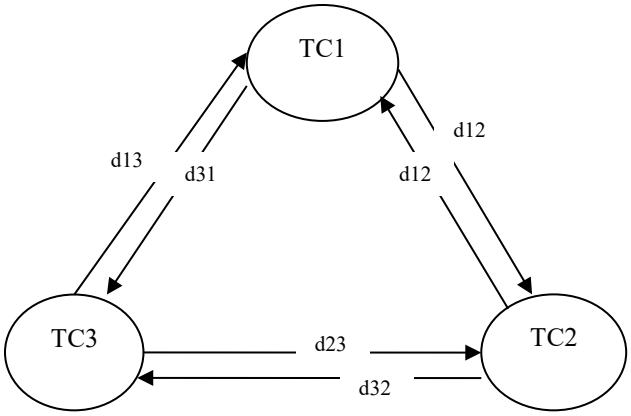

Figure: 8 Digraph for technology related challenges (FC)

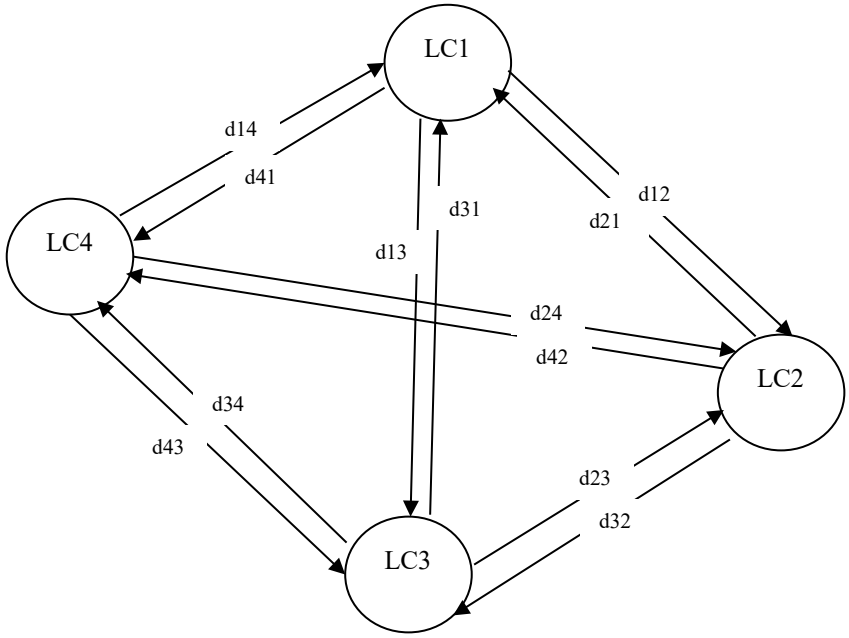

Figure: 9 Digraph for legal related challenges (LC)

Representation of Matrix

Likewise, the digraph for each challenge is changed into matrices as per the expression (1).

$$Per(EC) = \begin{pmatrix} EC1 & a_{12} & a_{13} & a_{14} \\ a_{21} & EC2 & a_{23} & a_{24} \\ a_{31} & a_{32} & EC3 & a_{34} \\ a_{41} & a_{42} & a_{43} & EC4 \end{pmatrix}$$

$$Per(GPC) = \begin{pmatrix} GPC1 & a_{12} & a_{13} & a_{14} \\ a_{21} & GPC2 & a_{23} & a_{24} \\ a_{31} & a_{32} & GPC3 & a_{34} \\ a_{41} & a_{42} & a_{43} & GPC4 \end{pmatrix}$$

$$Per(RC) = \begin{pmatrix} EC1 & a_{12} & a_{13} & a_{14} \\ a_{21} & RC2 & a_{23} & a_{24} \\ a_{31} & a_{32} & RC3 & a_{34} \\ a_{41} & a_{42} & a_{43} & RC4 \end{pmatrix}$$

$$Per(FC) = \begin{pmatrix} FC1 & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & FC2 & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & FC3 & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & FC4 & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & FC5 \end{pmatrix}$$

$$Per(CCC) = \begin{pmatrix} CCC1 & a_{12} & a_{13} & a_{14} & a_{15} \\ a_{21} & CCC2 & a_{23} & a_{24} & a_{25} \\ a_{31} & a_{32} & CCC3 & a_{34} & a_{35} \\ a_{41} & a_{42} & a_{43} & CCC4 & a_{45} \\ a_{51} & a_{52} & a_{53} & a_{54} & CCC5 \end{pmatrix}$$

$$Per(TC) = \begin{pmatrix} TC1 & a_{12} & a_{13} \\ a_{21} & TC2 & a_{23} \\ a_{31} & a_{32} & TC3 \end{pmatrix}$$

$$Per(LC) = \begin{pmatrix} LC1 & a_{12} & a_{13} & a_{14} \\ a_{21} & LC2 & a_{23} & a_{24} \\ a_{31} & a_{32} & LC3 & a_{34} \\ a_{41} & a_{42} & a_{43} & LC4 \end{pmatrix}$$

Permanent values of other challenges for industry 1(I1), 2 (I2) 3 (I3) and 4 (I4) are:

$$Per^{I1}(GPC) = \begin{pmatrix} 4 & 7 & 7 & 8 \\ 3 & 2 & 7 & 4 \\ 3 & 3 & 6 & 7 \\ 2 & 6 & 3 & 6 \end{pmatrix} = 11349 Per^{I2}(GPC) = \begin{pmatrix} 3 & 6 & 8 & 7 \\ 4 & 4 & 6 & 5 \\ 2 & 4 & 5 & 6 \\ 3 & 5 & 4 & 2 \end{pmatrix} = 9521$$

$$Per^{I3}(GPC) = \begin{pmatrix} 2 & 5 & 7 & 6 \\ 5 & 4 & 4 & 5 \\ 3 & 6 & 2 & 7 \\ 4 & 5 & 3 & 5 \end{pmatrix} = 10136 Per^{I4}(GPC) = \begin{pmatrix} 3 & 5 & 5 & 6 \\ 5 & 2 & 6 & 4 \\ 5 & 4 & 4 & 7 \\ 4 & 6 & 3 & 5 \end{pmatrix} = 11349$$

$$Per^{I1}(RC) = \begin{pmatrix} 6 & 5 & 4 & 5 \\ 5 & 5 & 7 & 5 \\ 6 & 3 & 4 & 4 \\ 5 & 5 & 6 & 3 \end{pmatrix} = 13233 Per^{I2}(RC) = \begin{pmatrix} 4 & 5 & 6 & 4 \\ 5 & 4 & 4 & 5 \\ 4 & 6 & 5 & 3 \\ 6 & 5 & 7 & 4 \end{pmatrix} = 12605$$

$$Per^{I3}(RC) = \begin{pmatrix} 3 & 8 & 6 & 3 \\ 2 & 4 & 5 & 7 \\ 4 & 5 & 5 & 6 \\ 7 & 3 & 4 & 2 \end{pmatrix} = 12000 Per^{I4}(RC) = \begin{pmatrix} 3 & 8 & 6 & 3 \\ 2 & 4 & 4 & 7 \\ 4 & 6 & 4 & 5 \\ 7 & 3 & 5 & 2 \end{pmatrix} = 11294$$

$$Per^{I1}(FC) = \begin{pmatrix} 4 & 5 & 4 & 6 & 3 \\ 5 & 3 & 4 & 5 & 4 \\ 6 & 6 & 2 & 7 & 5 \\ 4 & 5 & 3 & 3 & 3 \\ 7 & 6 & 5 & 7 & 5 \end{pmatrix} = 238169 Per^{I2}(FC) = \begin{pmatrix} 4 & 6 & 4 & 5 & 3 \\ 4 & 4 & 3 & 4 & 5 \\ 6 & 7 & 3 & 6 & 6 \\ 5 & 6 & 4 & 3 & 3 \\ 7 & 5 & 4 & 7 & 2 \end{pmatrix} = 238708$$

$$Per^{I3}(FC) = \begin{pmatrix} 4 & 5 & 3 & 6 & 4 \\ 5 & 3 & 4 & 3 & 3 \\ 7 & 6 & 3 & 4 & 5 \\ 4 & 7 & 6 & 2 & 3 \\ 6 & 7 & 5 & 7 & 5 \end{pmatrix} = 250249 Per^{I4}(FC) = \begin{pmatrix} 3 & 7 & 5 & 4 & 3 \\ 3 & 4 & 3 & 5 & 4 \\ 5 & 7 & 3 & 7 & 7 \\ 6 & 5 & 3 & 2 & 3 \\ 7 & 6 & 3 & 7 & 3 \end{pmatrix} = 222829$$

$$Per^{I1}(CCC) = \begin{pmatrix} 4 & 6 & 5 & 3 & 5 \\ 4 & 5 & 4 & 4 & 7 \\ 5 & 6 & 3 & 5 & 6 \\ 7 & 6 & 5 & 5 & 4 \\ 5 & 3 & 4 & 6 & 2 \end{pmatrix} = 293534 Per^{I2}(CCC) = \begin{pmatrix} 3 & 5 & 5 & 3 & 4 \\ 5 & 4 & 3 & 3 & 6 \\ 5 & 7 & 3 & 5 & 6 \\ 7 & 7 & 5 & 4 & 4 \\ 6 & 4 & 4 & 6 & 2 \end{pmatrix} = 251680$$

$$Per^{I3}(CCC) = \begin{pmatrix} 4 & 4 & 3 & 5 & 4 \\ 6 & 3 & 4 & 3 & 3 \\ 7 & 6 & 5 & 4 & 4 \\ 5 & 7 & 6 & 4 & 3 \\ 6 & 7 & 6 & 7 & 3 \end{pmatrix} = 263814 Per^{I4}(CCC) = \begin{pmatrix} 5 & 5 & 4 & 6 & 7 \\ 5 & 3 & 6 & 5 & 3 \\ 6 & 4 & 4 & 4 & 5 \\ 4 & 5 & 6 & 2 & 6 \\ 3 & 7 & 5 & 4 & 3 \end{pmatrix} = 274069$$

$$Per^{I1}(TC) = \begin{pmatrix} 4 & 5 & 7 \\ 5 & 6 & 4 \\ 3 & 6 & 4 \end{pmatrix} = 688 Per^{I2}(TC) = \begin{pmatrix} 5 & 6 & 8 \\ 4 & 5 & 4 \\ 2 & 6 & 3 \end{pmatrix} = 587$$

$$Per^{I3}(TC) = \begin{pmatrix} 6 & 5 & 7 \\ 5 & 6 & 5 \\ 3 & 5 & 4 \end{pmatrix} = 770 Per^{I4}(TC) = \begin{pmatrix} 4 & 6 & 7 \\ 4 & 7 & 4 \\ 3 & 6 & 3 \end{pmatrix} = 639$$

$$Per^{I1}(LC) = \begin{pmatrix} 3 & 8 & 8 & 3 \\ 2 & 4 & 7 & 4 \\ 2 & 3 & 4 & 5 \\ 7 & 6 & 5 & 2 \end{pmatrix} = 9811 Per^{I2}(LC) = \begin{pmatrix} 4 & 5 & 8 & 6 \\ 5 & 4 & 7 & 4 \\ 2 & 3 & 3 & 4 \\ 4 & 6 & 6 & 3 \end{pmatrix} = 9559$$

$$Per^{I3}(LC) = \begin{pmatrix} 4 & 6 & 5 & 6 \\ 4 & 4 & 4 & 5 \\ 5 & 6 & 6 & 7 \\ 4 & 5 & 3 & 5 \end{pmatrix} = 13331 Per^{I4}(LC) = \begin{pmatrix} 4 & 5 & 5 & 6 \\ 5 & 3 & 3 & 6 \\ 5 & 7 & 5 & 7 \\ 4 & 4 & 3 & 5 \end{pmatrix} = 11821$$

Appendix D – Representation of Permanent Function

1. Permanent representation: The permanent of the matrix (Jurkat and Ryser, 1966) is then obtained using the equation below.

$$
\begin{aligned}
Per\,(F) = {} & \prod_{x=1}^{6} F_x + \sum_{x=1}^{5}\sum_{y=x+1}^{6}\sum_{z=1}^{3}\sum_{a=z+1}^{4}\sum_{b=p+1}^{5}\sum_{c=q+1}^{6}\left(d_{xy}d_{yx}\right)F_zF_aF_bF_c \\
& + \sum_{x=1}^{4}\sum_{y=x+1}^{5}\sum_{z=y+1}^{6}\sum_{a=1}^{4}\sum_{b=a+1}^{5}\sum_{c=b+1}^{6}\left(d_{xy}d_{yz}d_{zx} + d_{xz}d_{zy}d_{yx}\right)F_aF_bF_c \\
& + \left(\begin{array}{l}
\sum_{x=1}^{3}\sum_{y=x+1}^{6}\sum_{z=x+1}^{5}\sum_{a=x+2}^{6}\sum_{b=1}^{5}\sum_{c=b+1}^{6}\left(d_{xy}d_{yx}\right)\left(d_{za}d_{az}\right)F_bF_c + \\
\sum_{x=1}^{3}\sum_{y=x+1}^{5}\sum_{z=x+1}^{6}\sum_{a=y+1}^{6}\sum_{b=1}^{5}\sum_{c=b+1}^{6}\left(d_{xy}d_{yz}d_{za}d_{ax} + d_{xa}d_{az}d_{zy}d_{yx}\right)F_bF_c
\end{array}\right) \\
& + \left(\begin{array}{l}
\sum_{x=1}^{4}\sum_{y=x+1}^{5}\sum_{z=y+1}^{6}\sum_{a=1}^{5}\sum_{b=a+1}^{6}\sum_{c=1}^{6}\left(d_{xy}d_{yz}d_{zx} + d_{xz}d_{zy}d_{yx}\right)\left(d_{ab}d_{ba}\right)F_c + \\
\sum_{x=1}^{2}\sum_{y=x+1}^{5}\sum_{z=x+1}^{6}\sum_{a=x+1}^{5}\sum_{b=y+1}^{6}\sum_{c=1}^{6}\left(d_{xy}d_{yz}d_{za}d_{ab}d_{bx} + d_{xb}d_{ba}d_{az}d_{zy}d_{yx}\right)F_c
\end{array}\right) \\
& + \left(\begin{array}{l}
\sum_{x=1}^{3}\sum_{y=x+1}^{5}\sum_{z=x+1}^{6}\sum_{a=y+1}^{6}\sum_{b=1}^{5}\sum_{c=b+1}^{6}\left(d_{xy}d_{yz}d_{za}d_{ax} + d_{xa}d_{az}d_{zy}d_{yx}\right)\left(d_{bc}d_{cb}\right) \quad + \\
\sum_{x=1}^{1}\sum_{y=x+1}^{5}\sum_{z=y+1}^{6}\sum_{a=1}^{4}\sum_{b=a+1}^{5}\sum_{c=b+1}^{6}\left(d_{xy}d_{yz}d_{zx} + d_{xz}d_{zy}d_{yx}\right)\left(d_{ab}d_{bc}d_{ca} + d_{ac}d_{cb}d_{ba}\right) + \\
\sum_{x=1}^{1}\sum_{y=x+1}^{6}\sum_{z=x+1}^{3}\sum_{a=x+2}^{6}\sum_{b=z+1}^{5}\sum_{c=z+2}^{6}\left(d_{xy}d_{yx}\right)\left(d_{za}d_{az}\right)\left(d_{bc}d_{cb}\right) \quad + \\
\sum_{x=1}^{1}\sum_{y=x+1}^{5}\sum_{z=x+1}^{6}\sum_{a=x+1}^{6}\sum_{b=x+1}^{6}\sum_{c=1}^{6}\left(d_{xy}d_{yz}d_{zp}d_{ab}d_{bc}d_{cx} + d_{xc}d_{cb}d_{ba}d_{az}d_{zy}d_{yx}\right)
\end{array}\right)
\end{aligned}
$$

Eq. 1

The permanent expression terms are arranged in S + 1 groupings. The physical significance of each expression is mentioned below:

Group 1: explains only one expression and represents interactions of the seven main challenges.

Group 2: not present as self-loop is absent in the digraph.

Group 3: explains two expressions; individual expression shows two challenge inter-dependency, i.e. $d_{xy}d_{yx}$ and measure of remaining S - 2 challenges.

Group 4: each expression of this group displays a set of three challenges inter-dependency $d_{xy}d_{yz}d_{zx}$ or its pair $d_{xz}d_{zy}d_{yx}$ and measure of remaining S - 3 challenges.

Group 5: two sub groups are arranged in this group. The first sub-group is a set of two, two-challenge inter-dependency, i.e. $d_{xy}d_{yx}$ and $d_{za}\,d_{az}$ and measure of remaining S - 4 challenges. The second sub-group is a set of four-challenge inter-dependency i.e. $d_{xy}d_{yz}d_{za}\,d_{ax}$ and $d_{xa}\,d_{az}d_{zy}d_{yx}$ and measure of remaining S - 4 challenges.

Group 6: The terms of this group are also settled in two sub-groups. The first sub-group is a set of two challenges inter-dependency i.e $d_{xy}\,d_{yx}$, a set of three challenges inter-dependency, i.e $c_{za}c_{ab}c_{bz}$ or its pair $c_{zb}c_{ba}c_{az}$and measure of remaining S - 5 challenges. The second sub-group is a set of five challenges inter-dependency i.e. $d_{xy}\,d_{yz}\,d_{za}d_{ab}d_{bx}$ or its pair $d_{xa}d_{ba}c_{az}\,d_{zy}\,d_{yx}$ and measure of remaining S - 5 challenges.

Group7: the terms are settled in a set of two and four challenges inter-dependency; two, three challenges inter-dependency; three, two challenges inter-dependency and six challenges inter-dependency.