

Article

Evaluating Traceability Technology Adoption in Food Supply Chain: A Game Theoretic Approach

Nainsi Gupta¹, Gunjan Soni², Sameer Mittal^{3,4,*}, Indrajit Mukherjee¹, Bharti Ramtiyal⁵, and Devesh Kumar²

¹Shailesh J. Mehta School of Management, I.I.T. Bombay, Mumbai- 400076, India; nainsi.gupta@simsom.in; indrajitmukherjee@iitb.ac.in

²Department of Mechanical Engineering, Malaviya National Institute of Technology, Jaipur- 302017, Rajasthan, India; gsoni.mech@mnit.ac.in; deveshkumar1993@gmail.com

³Unit of Information and Knowledge Management, Tampere University, Tampere- 33720, Finland

⁴J K Lakshmipath University, Jaipur- 302026, India

⁵Department of Management Studies, Graphic Era (Deemed to be University), Uttarakhan, Dehradun- 248002, India; bharti.mnit2022@gmail.com

*sameer.mittal@tuni.fi

Abstract: Food traceability in the supply chain is becoming increasingly important because of concerns such as fraud, adulteration, consumer requirements, and food loss. This study highlights the importance of food traceability in reducing food loss through the proper monitoring of food at every stage of the supply chain. The actions of all players in a food supply chain affect its traceability. Moreover, the decisions made by one player influence the decisions of the other players. Thus, traceability becomes more complex as the number of players increases. Owing to the complex nature of a food chain, it is important to analyze all the possible strategies that stakeholders consider and understand the influence of those possible strategies on the traceability of a food supply chain. In this study, we deploy a game theory model to analyze the strategic combinations of all possible actions of different stakeholders and understand the complexities present in a food supply chain, as well as how these strategic combinations help in decision-making for the adoption of traceability in a food supply chain. Furthermore, we analyzed the factors that may increase or decrease the probability of adopting traceability in a food supply chain.

Keywords: Food Traceability, Game Theory, Multi-stage game, Food supply chain

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1. Introduction

Food security is a major concern worldwide due to increase in population, climate change, and increasing demand of food . Around 30% of edible food is either converted to waste or lost in a supply chain. Similarly, around 14% of the food produced is lost in post-harvest stages excluding retail stage (FAO (2019); Seminar (2016); Mogale

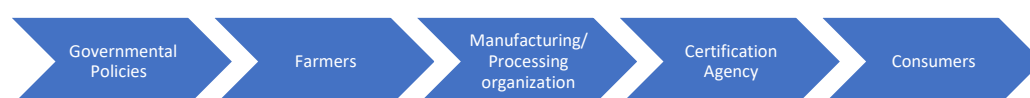
et al., (2019); Maiyar & Thakkar (2019)). Food loss is referred to as reduction of quality or quantity of food due to the decisions or actions taken by various stakeholders of the supply chain. Whereas food waste is referred to as the edible food converted to waste due to purchasing decisions of customers, or decisions of retailers and other food service providers (FAO, 2019). Food waste depends upon consumer behavior and their societal concerns regarding food waste (#) while food loss can be monitored as well as controlled with the help of modifications in various aspects like food policies, infrastructure, and technological investments. Food loss is considered as a threat for food security. Therefore, it is essential to monitor the causes of food loss present in a supply chain. The main causes of food loss in supply chain includes lack of storage facility, improper care, inefficient post-harvest management, poor processing management, inadequate packaging, and lack of refrigerated transportation. (Dandage et al., 2016; Mogale et al, 2020). Khapre and Pawar (2015) mentioned that most significant food quality and quantity deterioration takes place in warehouse storages due to collection of different seed quality food at single place. According to FAO (2019), post-harvest stage loss is essential to monitor and control to achieve sustainable development goal of zero hunger.

Traceability system in the food supply chain can help in monitoring the ambiguity of the food supply chain. According of World Economic Forum (2017), technological innovation is the foundation for development of traceability. Traceability is the ability of food chain that can track and trace the history and flow of food products throughout the supply chain by using different technical innovations like RFID, blockchain, food sensing technologies, and barcoding. Seminar (2016) exposed the vulnerability of food chain and developed a framework for transparency and traceability in supply chain to surveillance food loss and waste in supply chain. Sidwani et al. (2020) also developed a wireless sensor network model at a grain warehouse in India to monitor the health of grains. Data collected from this study was analyzed to reduce the grain loss during storage. An efficient traceable system will help to trace and track the food present in the supply chain starting from the farm to fork. Traceability is the ability to access all the information throughout the supply chain related with food (Dandage et al., 2016; FAO, 2019). Traceability systems are based on effective utilization of technologies like internet of things, big data, and cloud computing (Padmaja et al., 2020; Giagnocavo et al. 2016). Development of efficient and effective traceability system is a complex process that requires not only the understanding of technical development, but also requires business, organizational, social, economic, and environmental perspective (Giagnocavo et al., 2016).

Implementation of traceability throughout the supply chain is not a one stage phenomenon. This involves the decision of several players at different stages of supply chain. The choice to develop the traceable system at every level depends upon the risk, capital investment, governmental policies, technological information, and social & environmental concern (###) along with this information symmetry among multiple levels is difficult to achieve. Therefore, it becomes highly complex to understand the strategy of every player like whether a particular player would invest their resources to develop traceable system or not. Such decisions are purely based on the revenue from the

traceable goods and cost involved in this. The core players of traceable food chain considered in this study include government, farmers, manufacturing/processing organization, certification agencies, and consumers. There might be other players like transportation agencies for movement of food, public/ private warehouse storage of food, and distributors involved as well. Based on the decisions of different stakeholders and enterprises traceability system throughout the food chain can be developed (Li et al., 2010). Game theory is one of the most favorable tools for decision making where multiple players at different levels are involved.

Figure 1: Core players of food supply chain



Researchers have discovered several challenges regarding implementation of traceability in food chain, especially in India, where the supply chain is completely scattered around the country (Khapre and Pawar, 2016). Such complexity of food supply chain can be included in multi-stage game model, where several players are being involved to discover their strategy. Game theory is the study of strategic interaction among more than one player, when there are more several choices are available to make final decision.

Implementation of game theoretic model will help to understand the strategic decisions of multiple players and identify the factors that influence them to implement traceability in supply chain. This study will discover the component that will motivate the players to adopt traceability in supply chain and follow transparent strategies to become profitable and safe. The objectives of this study are as follows: 1) what are the possible strategies of stakeholders in supply chain to implement traceability in food chain; 2) Conditions to understand the key factors that affect the decision of traceability adoption in food chain; 3) Numerical example based on hypothetical data to show the utility of framework developed.

The remainder of the paper is organized as follows. In section 2, literature review has been presented along with research gaps and key findings of the present study. In section 3, research methodology and mathematical notations has been included. Section 4 includes mathematical model along with a practical example to get understanding of the game theoretic model. Analysis of the mathematical model has been included in section 5. Section 6 includes the implication of the research followed by concluding remarks and future directions in section 7.

2. Literature Review

This study explores two important elements in the field of food supply chain. Section 2.1 covers the importance of food traceability in context of food loss and challenges in implementing traceability throughout the supply chain. Section 2.2 provides a review on

the application of game theory in the food industry. Finally, section 2.3 identifies the gaps in the scientific literature and key findings of the present study to overcome these gaps.

2.1 Traceability needs and implantation in food supply chain

Food supply chain is one of the most vulnerable supply chains due to perishable nature of food that can be easily contaminated. Along with presence of multiple stakeholders around the globe makes the food supply chain even more complex. Several incidents in food sector are demanding an appropriate system due to its hazardous and perishable nature, and to prevent various incidents and fraudulence (Dandge et al., 2016; Balaji and Arsinder, 2016). Ghardas et al., (2017) performed a study in vegetable & fruits supply chain to identify the following three factors of post-harvest losses in context of India: 1) lack of technology and advance technique in food processing units, 2) lack of linkage between government, industry, and institution, 3) lack of linkage between farmers and processing units. Moreover, there are also several other factors like global population, food borne illness, and fraudulence, that also demands the need of traceability in a food supply chain. A fundamental transformation is also required in a food supply chain by technological investment to make it more efficient, sustainable, healthy, and credible. As, due to the spread of COVID19 customers have become more interested in knowing about what they are consuming and how the food comes to them (Galimberti et al. 2020).

Basu (2010) proposed that it is necessary to improve the current policies towards modifying the facilities, because it can lead to huge grain loss. Khapre and Pawar (2015) considered post-harvest loss as one of the major losses in a food supply chain. Further, storing grain for multiple seasons due to inadequate storage systems also leads to food loss (Khapre and Pawar, 2015). Gokarn and Kuthambalayan (2016) performed a study that identifies the key challenges for reducing food loss in supply chains, and they also suggested that transparency in supply chain can reduce food loss. Seminar (2016) and Gokarn and Kuthambalayan (2016) performed a review to give an overview of the various challenges of food chain that causes food loss, and how traceability can be deployed to overcome those challenges was also discussed (Seminar, 2016). Shanmugasundaram et al. (2020) also performed an overview of application of traceability and information technology in vegetable supply chains to analyze the technical advancements in the Indian food market.

As per World Economic Forum (2017), traceability provides a solution to the challenges faced in the food systems. As traceability helps in making the supply chain “visible” by facilitating complete tracking of the environmental, health, economic, and social consequences of various agricultural production processes. Additionally, traceability also helps in dealing with credibility issue in consumer’s view by providing transparent supply chain, minimizing food safety problems & cost involved in product recalls, reducing food loss, and developing an optimized food chain. Furthermore, this study (World Economic Forum, 2017) identified twelve transformative technologies that may affect food systems. The transformative technologies that affect traceability include food sensing technologies for tracking of food safety and quality, and internet of things for tracing real time information, blockchain enabled traceability.

At First International Day of Awareness of Food loss and waste, Food and Agriculture Organization (FAO) of US (<http://www.fao.org/news/story/en/item/1310271/icode/>, accessed on 26/6/2021), published a study that discusses the global food security issues. The study discussed that the issue of global hunger can be overcome only by reducing food loss. Further it says that technology and innovation is only a way to reduce this food loss. According to this study, “Innovative post-harvest treatment, digital agriculture in food systems and re-modelling market channels offer huge potential to tackle the challenges of food loss and waste”. FAO has built a partnership with Microsoft, IBM, and Vatican to empower artificial intelligence techniques in food systems. This initiative will help in achieving a transparent food chain and achieving the objective of reducing food loss.

Pappa et al., (2018) performed a study that illustrates the factors affecting the adoption of electronic traceability in dairy sector to ensure food quality and safety. In this study, they developed a mixed model combining TAM2 and TPB. The study concludes that electronic traceability systems can be successfully integrated within food supply chains to ensure its added value (Pappa et al., 2018). Similarly, Padmaja et al. (2020) highlights the application of information systems in food chain to improve productivity by analyzing about how Internet of things has become the foundation for reducing food loss and traceability. Sidwani et al., (2020) performed a study at grain warehouse where they utilize Wi-Fi enabled sensors to measure the real time data of variables like temperature, carbon dioxide concentration, relative humidity, and pressure to prevent food grain. It predicts grain quality. Rowan and Galanakis (2016) discussed the role of traceability in green supply chains to achieve sustainable production of food products and considered the impact of COVID19 towards the need of transparent supply chain and waste mitigation. Sharma et al., (2020) developed a conceptual guidance to know what information needs to be captured for considering traceability in grain supply chain and how it is implemented.

Xiao et al, (2015) developed a traceable framework for aquatic food products in cold chain logistics using wireless sensor network (WSN) and QR scan codes. Cold chain logistics utilizes artificial refrigeration systems to maintain low temperature during storage and transportation of food products to ensure their quality and safety. The key aspect of cold chain is temperature and pressure with application of wireless sensors. This data can also be collected and monitored for future analysis. The study (Xiao et al., 2015) also compared QR scan codes and WSN based system with traditional methods of monitoring the cold chain and concluded effective results and better monitoring.

Li et al., (2016) developed a framework for implementing traceability in dairy supply chain. This network structure includes breeding farms, dairy processing enterprises, distributors, retailers, and consumers. The model developed in this study (Li et al., 2016) using barcoding and QR scan codes can easily locate the root-cause of the problem if there are any safety related issues present in the food supply chain. The barcoding and QR scan code technologies are less expensive as compared to RFID systems that are expensive for the supply chain having low-margin profits. Implementation of

traceability leads to increase in effectiveness of a milk supply chain by easily tracking and tracing along with the increase in value by providing transparent supply chain to consumers with detailed information about the product.

Astill et al., (2019) performed a study to give an overview of technologies that aids in enabling a transparent supply chain. These technological enablers are data acquisition technologies (like sensor, bio-sensor), Internet of things (technologies that provide communication between devices like cloud computing, RFID tags, etc.), and platforms to manage collected data (includes different centralized and decentralized systems like blockchain). The adequate effort from all the stakeholders to develop a traceable system were also highlighted as the study (Astill et al., 2019) also focuses towards challenges faced in application of the mentioned data acquisition technologies, e.g., poor internet connectivity, data privacy and security issue, consumer acceptance, and economic sustainability. Galvez et al. (2018) also considered blockchain technology as a true innovation and adequate approach for assuring the quality of food products and reducing the economic losses due to falsification of food products. Kamble et al. (2019) also reveals various benefits of blockchain in agri-food supply chain and identified thirteen enablers that help in implementation of blockchain. Similarly, Iftekhhar et al. (2020) considered blockchain as an emerging technology that provides tamper-proof real-time data sharing and helps to ensure that all safety measures has been considered to minimize the risk of COVID-19. In this way there is ample amount of literature present that says that traceability implementation in food chain may help in reducing food loss, improve productivity of supply chain and increase credibility of food chain for stakeholders.

2.2 Game theory implementation in food supply chain

Game theory is a field of mathematics that deals with the situations where two or more decision makers are involved to take decision. Game theory is a tool that is being preferred in supply chain optimization and decision making due to its structure having multiple players. There have been several studies in literature that utilizes game theory concepts in different context to optimize the efficiency and effectiveness of supply chain. Rationality of players and common knowledge among players are two assumptions in most of the games. Vasnani et al. (2019) conducted a literature review that discusses the trends and applications game theory in supply chain. The application of Nash equilibrium concept and Stackelberg game model with their application in different supply chain has also been explored (Vasnani et al., 2019). Further, this study (Vasnani et al., 2019) also focuses on how game theory is different from other decision making and optimization methodologies. Chavoshou et al., (2019) introduced fuzzy game theory model to understand customer requirement of green product. Asrol et al. (2020) proposes a cooperative game theory model based on Shapley value for fair profit allocation among stakeholders in a sugarcane industry to perform a comparative analysis among the current policies and the proposed policies. Asian et al., (2018) identified the role of sharing economy in case of organic small farmers under cooperative environment.

Song and Zhuang (2017) presented a study of strategic interaction among government, farmer, and manufacturer to analyze risky behavior of stakeholders in food

supply chains to maximize their own payoffs. This study (Song and Zhang, 2017) discusses three different types of interactions among stakeholders, and a comparative analysis of all these models. The first one is “government against manufacturer against farmer”, second one is “a centralized government-manufacturer-farmer model”, and the third one is “government vs. farmer and manufacturer model”. Mangethi et al. (2021) proposes an analysis in context of sustainable production of food products by utilizing a different dairy supply chain with one manufacturer and two suppliers in competition.

Li et al. (2010) conducts a comprehensive analysis for developing a decision-making traceable system by utilizing game theory to establish a traceability system for fresh agricultural products. The study (Li et al., 2010) identified revenue, cost, technological conditions, law & policies, purchase intention, industrial environment as key factors that influence development of traceability system. Findings of the study (Li et al., 2010) also suggest that an organization adopts traceability system if there are less chances of safety incidents along with less constructing cost of traceable system while more purchase intension of consumer.

Tang (2013) also developed a two-echelon system for establishment of traceability in food supply chains that consists of downstream and upstream node enterprises. Assumptions made in this study (Tang, 2013) include rationality of upstream and downstream enterprises, long-term collaboration in establishing food traceability system, and dynamic nature of strategies. This study (Tang, 2013) also concludes that chances of cooperation between upstream and downstream is positively correlated with probability of disruption, total revenue; and negatively correlated with cost of establishment. This study utilizes evolutionary game theory to deal with dynamic nature of strategies. Evolutionary game theory is based on long-term evolution of multi-agent multi-criteria decision-making technique under consideration of uncertainty (Debnath et al., 2017). MA (2010) also utilizes evolutionary game theory in food supply chain to analyze implementation of incentive policy for quality control of food products.

Wu et al. (2013) proposes a game model to analyze the feasibility of a traceability system in agri-food supply chain and it's economic sustainability. In this study (Wu et al., 2013) a duopoly model has been set up while implementing traceability. This study concludes that government intervention may encourage the players to adopt traceability voluntary.

Wang and Yang (2014) implement game theory for organic tea certification in tea industry. Along with this they also analyze the strategic decisions made by certification agencies and farmers to setup traceability system in industry. In a further study by Wang and Yang (2019) propose a game theoretic model in herbal product industry by including multiple stakeholders of supply chain. In this way, literature discusses about different methodologies of game theory, and how these methodologies have been utilized in food supply chain.

2.3 Research gaps and key contributions

Supply chain involves multiple stakeholders, where decision made by every player matters. Every decision made by different stakeholders place an important role and it may

affect the decision of others. There are multiple studies that have developed traceability framework for various food chains, but none of them considers strategic interaction among stakeholders, their contribution as an individual in supply chain. Since every stakeholder in supply chain is a different entity and tries to maximize their utility value. In such case it becomes difficult to understand how different players make their decisions, either as an independent player to maximize their own payoffs or by cooperation with other players to maximize the utility of whole supply chain. Several studies have been performed on decision making and supply chain optimization. But these studies have highlighted either overall view of supply chain or a particular node of supply chain.

In the current study game theory is being utilized by considering supply chain as a multi-player game having multiple strategies. Limited studies have implemented game theory in food supply chain by considering two or three players in supply chain. But food supply chain involves multiple players starting from farmer to retailers and end consumers. The key findings of this study are as follows:

- Develop a multi-player game to get a view of strategies that can be made by different stakeholders of supply chain.
- Analysis of game model to understand the key factors that affect the decision of traceability adoption in food chain.

3. Assumptions and notations

The key purpose of food traceability is to provide detailed information of food throughout the supply chain. This is ambiguous due to the complexity as well as changing scenarios of food chain. Causes of ambiguity may be information complexity, information asymmetry, cost-benefit tradeoff, government intervention etc. (Wang and Yang, 2019).

This study considers government, farmers, processing organization, certification agencies, and consumers as key stakeholders of food supply chain. Following points justifies the selection of key players:

- Government authorities can be considered as a key player of food supply chain by imposing policies and laws, punishing risky player, providing subsidy for establishing traceable system (Song and Zhuang, 2017; Wu et al., 2013; Chavoshou et al., 2019). Government can monitor food loss by implementation of traceability and modify the policies to reduce food loss in post-harvest stages.
- Farmers are the ones who grow the food and transport it to market or industries. Due to the lack of resources major food loss can take place at this stage. Along with this addition of unwanted chemicals to protect the food may affect the quality of food.
- Around 10% food st either in processing or storage at warehouses of processing enterprises. Such loss may be caused by factors like lack of infrastructure, poor methods of processing/ storage, and lack of technological advancement. Therefore, processing organization is one of the major players of a food supply chain.
- Certification agencies are the ones that audit and verify the whole process and documentation regarding food production. If they collude with other stakeholders for falsely certification, this may act as a threat for whole supply chain.

- Adoption of traceability also depends upon consumer's perception regarding traceable food product and their readiness to pay premium prices for traceable food (Galimberti et al. 2020) because consumers are the key source of revenue for a particular supply chain.

The current study considers key stakeholders as players of the game and the decision choices of every stakeholder act as possible strategy of the game. The current study considers following assumptions: All the players of this game are rational, i.e., they can take decision of their choice and every player is aware of the strategies of other player. Objective of this game model is to observe the strategic combination for developing a comprehensive traceability system throughout the food chain.

Government authorities may choose either active promotion of traceability or passively promotion of traceability. Active promotion of traceability involves modification in policies and standards of food products to enforce traceability in supply chain, while passive promotion depends upon consumer requirement and willingness of other stakeholders to adopt a traceable food production system without direct involvement of authority. Farmers can choose whether to establish a traceable system. Processing organization may also choose whether to purchase traceable food from farmers and establish a comprehensive traceable system at their enterprise. Certification agencies can choose either to maintain their independence without colluding with processing organization or to lose their independence by colluding with processing organization & issue false certification. Consumer may also choose whether to purchase traceable food products.

Following notations have been used throughout the game model.

R_a : Revenue of authority from actively promoting traceability

R_n : Revenue of authority from passively promoting traceability

C_a : Cost to authority for actively promoting traceability

C_n : Cost to authority for passively promoting traceability

R_f : Revenue of farmers generated from sales of from traceable food products

R_t : Revenue of farmers generated from sales of non-traceable food products

F_a : Cost to farmers for establishing a traceable system

F_c : Cost to farmers for establishing a non-traceable system

R_f : Cost to processing enterprises in purchasing traceable food products

R_t : Cost to processing enterprises in purchasing non-traceable food products

F_t : Cost to processing enterprises in developing a comprehensive traceable system

F_n : Cost to processing enterprises in developing a non-traceable system

F_b : Certification fees for processing enterprises when developing a traceable system

S_h : Revenue of processing enterprises generated from sale of traceable labeled food product

S_n : Revenue of processing enterprises generated from sale of non-traceable labeled food product

F_b : Revenue of certification agencies generated from certification fees paid by processing enterprises

C_c : Revenue of certification agencies generated from collusion with processing enterprises for issuing false certification

W_c : Damage compensation imposed on certification agencies, for issuing falsely labeled food product as traceable

Q_a : Cost to certification agencies for finding new client, when it works independently and refuses to issue false certification. Cost of losing a client and finding a new one might be more than cost involved in collusion ($Q_a > C_c - W_c$)

S_h : Cost to consumer in purchasing traceable labeled food products

S_n : Cost to consumer in purchasing non-traceable labeled food products

U_a : Revenue of consumer in purchasing traceable labeled food products in terms of monetary value

U_b : Revenue of consumer in purchasing traceable labeled food products in terms of monetary value

Here

$$R_a > R_n$$

$$C_a > C_n$$

$$F_a > F_c$$

$$R_f > R_t$$

$$F_t > F_n$$

$$S_h > S_n$$

$$U_a > U_b$$

W_g : Damage compensation imposed on authorities when food product is falsely labeled as traceable product and authorities promote it passively

W_f : Damage compensation imposed on farmers, when product is falsely labeled as traceable and farmers do not develop a traceable system

When processing organization either doesn't purchase traceable food from farmers or they don't develop a traceable system then following cost may be involved:

C_c : Cost to processing enterprise in colluding with certification agency

W_p : Damage compensation imposed on processing organization when the food product is falsely labeled as traceable food product

Q_n : Cost to processing enterprise for switching certification agency when certification agency does not collude in issuing false certificate

W_a : Damage compensation imposed on certification agency when the food product is falsely labeled as traceable food product

W_t : Damage compensation provided to consumers if product is falsely labeled as traceable

4. Mathematical Model and practical application

Extensive-form games are specialized game that represents sequential moves of players, their strategies at every decision-making node i.e., at one stage one player might be taking some decision and at the next stage other player might be taking decision based on action taken by the first player. In such games each player has information about the move of other players while making their decision. These games are listed in form of a tree. Extensive games can be classified in two categories: 1) Game with perfect

information: players when making decisions know about all the actions that have previously occurred; 2) Game with imperfect information: players when making decisions may not be perfectly informed about some (or all) of the events previously occurred. There are basically two methodologies to solve an extensive form game that are backward induction and a sub-game equilibrium. Solution of a game is considered as finding the Nash equilibrium of the game. Nash equilibrium in extensive game is defined in such a way that if any player deviates from equilibrium, her payoff will not increase i.e., a player has no incentive in deviating from Nash Equilibrium.

Table 1 represents the 28 of strategic interactions among the key players of the game and strategic combination of authority, farmers, processing enterprises, certification agencies and consumers.

Table 1: Strategic Combination of Game

Strategic Combination	Node 1 (Authority)'s Action	Node 2 (Farmer)'s Action	Node 3 (Processing Organization)'s Action	Node 4 (Certification Agency)'s Action	Node 5 (Consumer)'s Action
1	Actively promoted traceability system in food chain	Farmer developed a comprehensive Traceability system	Purchased traceable food from farmers and also establish a traceability system	Certification Agency issued traceable labeled certificate	Purchase "Traceable Labeled Food Product"
2					Did not purchase "Traceable Labeled Food Product"
3		Farmer did not Develop a comprehensive Traceability system	Processing organization did not purchase traceable food from farmers, but establish a traceability system at enterprise	Certification Agency colluded with other stakeholders and issued false certificate	Purchase "Traceable Labeled Food Product"
4					Did not purchase "Traceable Labeled Food Product"
5				Certification Agency refused to issue falsely labeled traceable food product	Purchase "Traceable Labeled Food Product"
6					Did not purchase "Traceable Labeled Food Product"
7				Switch current certification agency when certification agency refused to collude with processing organization for	Purchase "Traceable Labeled Food Product"
8					Did not purchase "Traceable Labeled Food Product"

				falsely label food product as traceable	
9				Certification Agency colluded with other stakeholders and issued false certificate	Purchase “Traceable Labeled Food Product”
10					Did not purchase “Traceable Labeled Food Product”
11			Processing organization neither purchased traceable food from farmers, nor establish a traceability system at enterprise	Certification Agency refused to issue falsely labeled traceable food product	Purchase “Traceable Labeled Food Product”
12					Did not purchase “Traceable Labeled Food Product”
13				Switch current certification agency when certification agency refused to collude with processing organization for falsely label food product as traceable	Purchase “Traceable Labeled Food Product”
14					Did not purchase “Traceable Labeled Food Product”
15		Farmer developed a comprehensive Traceability system	Purchased traceable food from farmers and also establish a traceability system	Certification Agency issued traceable labeled certificate	Purchase “Traceable Labeled Food Product”
16					Did not purchase “Traceable Labeled Food Product”
17	Passively promoted traceability system in food chain	Farmer did not Develop a comprehensive Traceability system	Processing organization did not purchase traceable food from farmers, but establish a traceability system at enterprise	Certification Agency colluded with other stakeholders and issued false certificate	Purchase “Traceable Labeled Food Product”
18					Did not purchase “Traceable Labeled Food Product”
19				Certification Agency refused to issue falsely labeled	Purchase “Traceable Labeled Food Product”

20				traceable food product	Did not purchase "Traceable Labeled Food Product"
21				Switch current certification agency when certification agency refused to collude with processing organization for falsely label food product as traceable	Purchase "Traceable Labeled Food Product"
22					Did not purchase "Traceable Labeled Food Product"
23				Certification Agency colluded with other stakeholders and issued false certificate	Purchase "Traceable Labeled Food Product"
24					Did not purchase "Traceable Labeled Food Product"
25				Certification Agency refused to issue falsely labeled traceable food product	Purchase "Traceable Labeled Food Product"
26					Did not purchase "Traceable Labeled Food Product"
27				Switch current certification agency when certification agency refused to collude with processing organization for falsely label food product as traceable	Purchase "Traceable Labeled Food Product"
28					Did not purchase "Traceable Labeled Food Product"

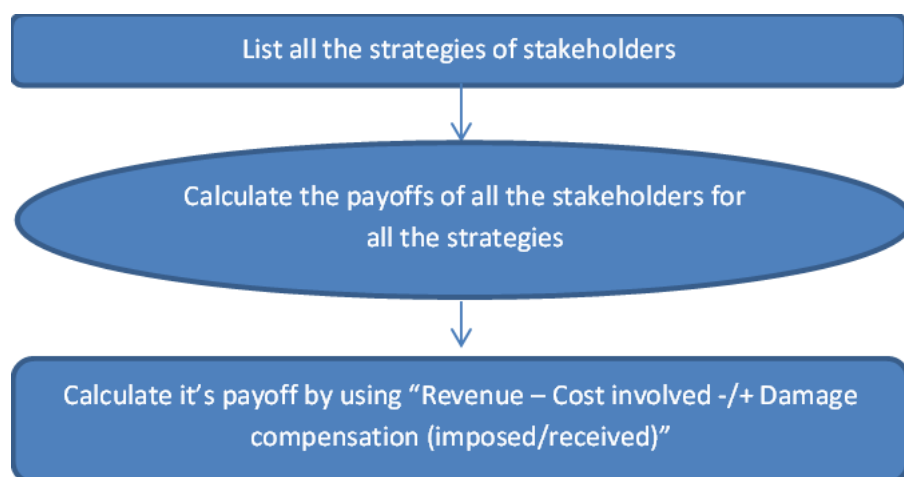


Figure 2: Steps to calculate profits of all the stakeholders.

Figure 2 represents the steps required for calculation of payoff values for all the stakeholders. And sub-game perfect equilibrium has been utilized for calculation of Nash Equilibrium. Now after calculation of payoff values next step is to identify optimum strategy for the players to develop a traceable system throughout the food chain. Sub-games are considered as sub-set of a game which is broken into sub-game. Sub-games are extracted from backward induction. Figure 3 represents the steps for getting best strategy using sub-game perfect equilibrium.

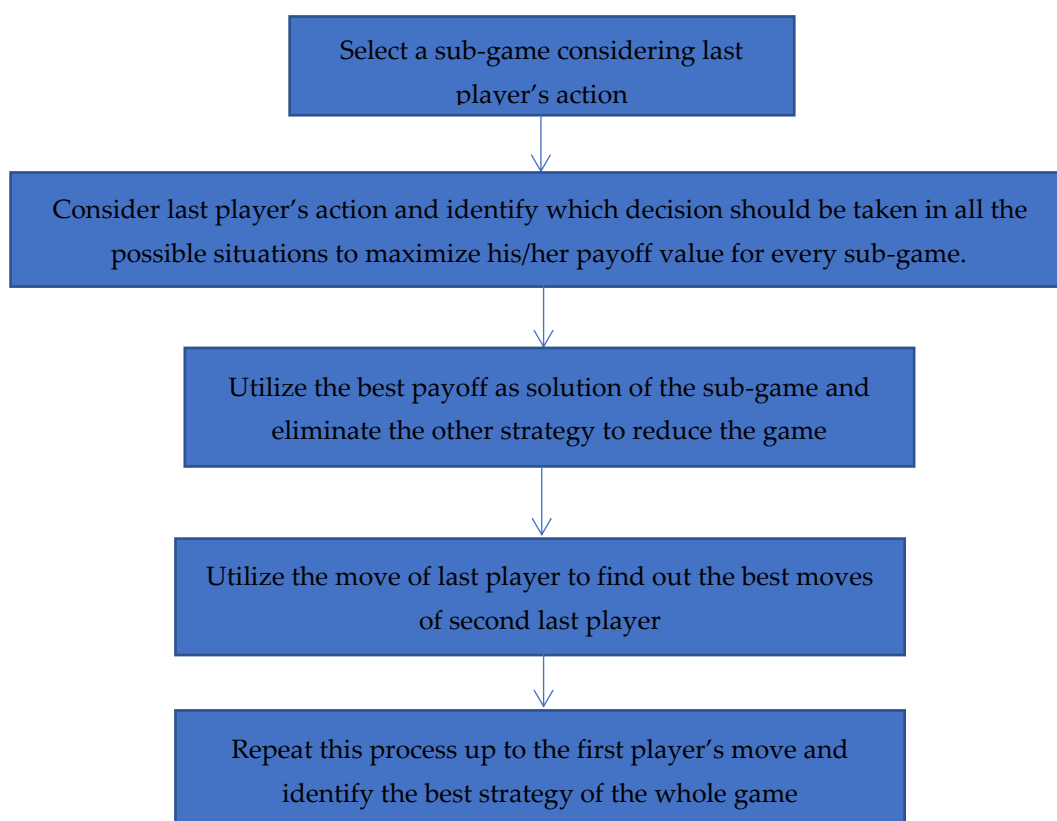


Figure 3: Steps to find out the best strategies of the game by sub-game equilibrium.

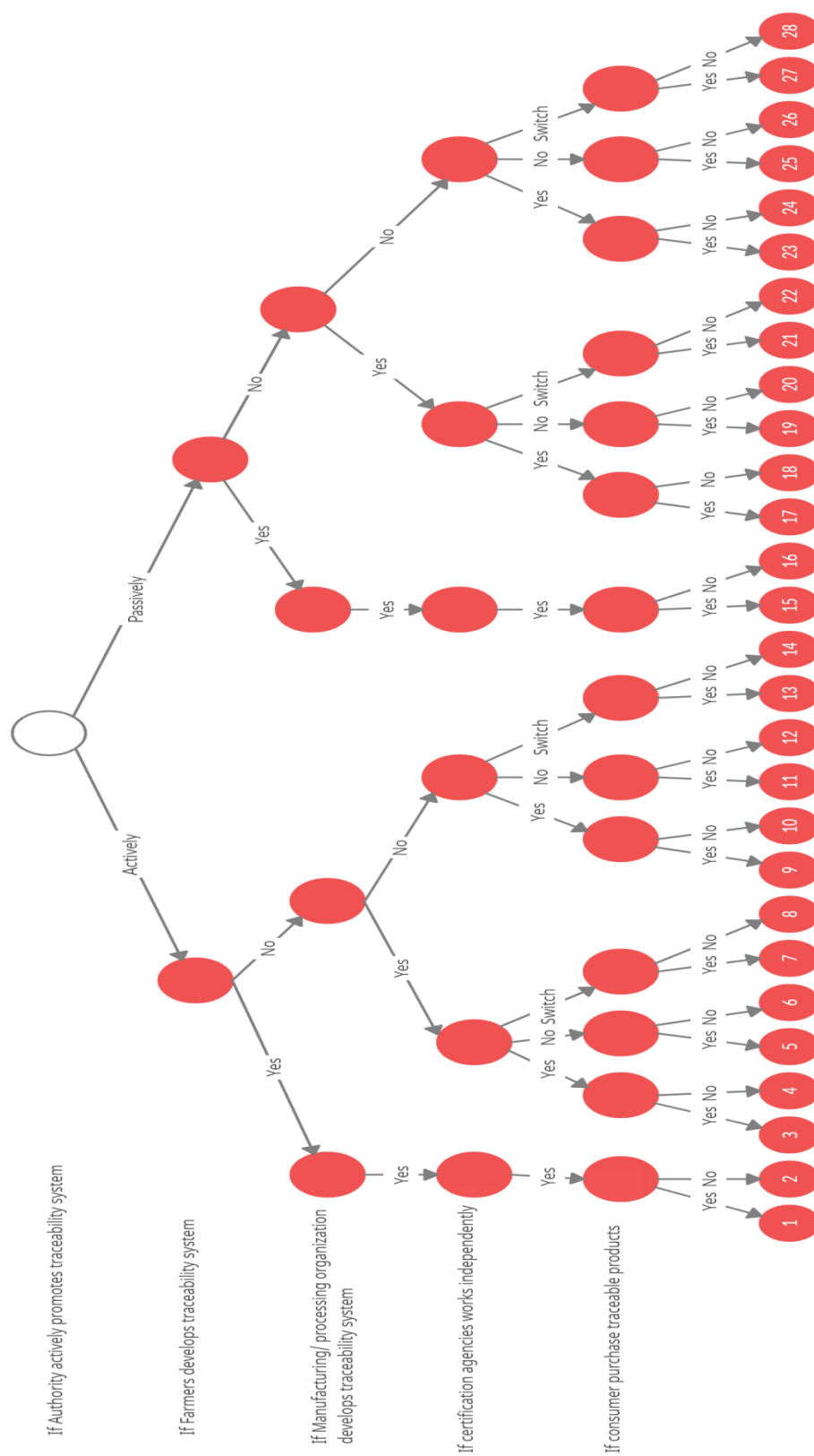


Figure 2 Multi-stage game model representing strategies of stakeholders of food chain

Table 2 represents the payoff values of authority, farmers, processing enterprises, certification agencies, and consumers. Backward induction has been used for calculation of payoffs in this game model.

Table 2: Payoff matrix of multi-stage game model

Strategic Combination	Authority	Farmers	Processing Enterprises	Certification Agencies	Consumers
1	$R_a - C_a$	$R_f - F_a$	$S_h - (R_f + F_t) - F_b$	F_b	$U_a - S_h$
2	$-C_a$	$-F_a$	$-(R_f + F_t) - F_b$	F_b	0
3	$R_a - C_a - W_g$	$R_t - F_c - W_f$	$S_h - (R_t + F_t) - F_b - C_c - W_p$	$F_b + C_c - W_a$	$U_b - S_h + W_t$
4	$-C_a$	$-F_c$	$-(R_t + F_t) - F_b - C_c - W_p$	$F_b + C_c$	0
5	$R_a - C_a - W_g$	$R_t - F_c - W_f$	$S_n - (R_t + F_t) - F_b$	F_b	$U_a - S_n$
6	$-C_a$	$-F_c$	$-(R_t + F_t) - F_b$	F_b	0
7	$R_a - C_a - W_g$	$R_t - F_c - W_f$	$S_h - (R_t + F_t) - F_b - C_c - W_p - Q_n$	$F_b - Q_a$	$U_b - S_h + W_t$
8	$-C_a$	$-F_c$	$-(R_t + F_t) - F_b - C_c - W_p - Q_n$	$F_b - Q_a$	0
9	$R_a - C_a - W_g$	$R_t - F_c - W_f$	$S_h - (R_t + F_n) - F_b - C_c - W_p$	$F_b + C_c - W_a$	$U_b - S_h + W_t$
10	$-C_a$	$-F_c$	$-(R_t + F_n) - F_b - C_c - W_p$	$F_b + C_c$	0
11	$R_a - C_a - W_g$	$R_t - F_c - W_f$	$S_n - (R_t + F_n) - F_b$	F_b	$U_b - S_n$
12	$-C_a$	$-F_c$	$-(R_t + F_n) - F_b$	F_b	0
13	$R_a - C_a - W_g$	$R_t - F_c - W_f$	$S_h - (R_t + F_n) - F_b - C_c - W_p - Q_n$	$F_b - Q_a$	$U_b - S_h + W_t$
14	$-C_a$	$-F_c$	$-(R_t + F_n) - F_b - C_c - W_p - Q_n$	$F_b - Q_a$	0
15	$R_n - C_n$	$R_f - F_a$	$S_h - (R_f + F_t) - F_b$	F_b	$U_a - S_h$
16	$-C_n$	$-F_a$	$-(R_f + F_t) - F_b$	F_b	0
17	$R_n - C_n - W_g$	$R_t - F_c - W_f$	$S_h - (R_t + F_t) - F_b - C_c - W_p$	$F_b + C_c - W_a$	$U_b - S_h + W_t$
18	$-C_n$	$-F_c$	$-(R_t + F_t) - F_b - C_c - W_p$	$F_b + C_c$	0
19	$R_n - C_n - W_g$	$R_t - F_c - W_f$	$S_n - (R_t + F_t) - F_b$	F_b	$U_b - S_n$
20	$-C_n$	$-F_c$	$-(R_t + F_t) - F_b$	F_b	0
21	$R_n - C_n - W_g$	$R_t - F_c - W_f$	$S_h - (R_t + F_t) - F_b - C_c - W_p - Q_n$	$F_b - Q_a$	$U_b - S_h + W_t$
22	$-C_n$	$-F_c$	$-(R_t + F_t) - F_b - C_c - W_p - Q_n$	$F_b - Q_a$	0
23	$R_n - C_n - W_g$	$R_t - F_c - W_f$	$S_h - (R_t + F_n) - F_b - C_c - W_p$	$F_b + C_c - W_a$	$U_b - S_h + W_t$
24	$-C_n$	$-F_c$	$-(R_t + F_n) - F_b - C_c - W_p$	$F_b + C_c$	0
25	$R_n - C_n - W_g$	$R_t - F_c - W_f$	$S_n - (R_t + F_n) - F_b$	F_b	$U_b - S_n$
26	$-C_n$	$-F_c$	$-(R_t + F_n) - F_b$	F_b	0
27	$R_n - C_n - W_g$	$R_t - F_c - W_f$	$S_h - (R_t + F_n) - F_b - C_c - W_p - Q_n$	$F_b - Q_a$	$U_b - S_h + W_t$
28	$-C_n$	$-F_c$	$-(R_t + F_n) - F_b - C_c - W_p - Q_n$	$F_b - Q_a$	0

Strategic combination 1 can be considered as Nash equilibrium for the game when authority promotes actively traceable food products and Strategic combination 15 can be considered as Nash equilibrium when authority promotes traceable food products passively. Following figure 5 gives a detailed view of the steps included in getting optimum strategy using sub-game equilibrium.

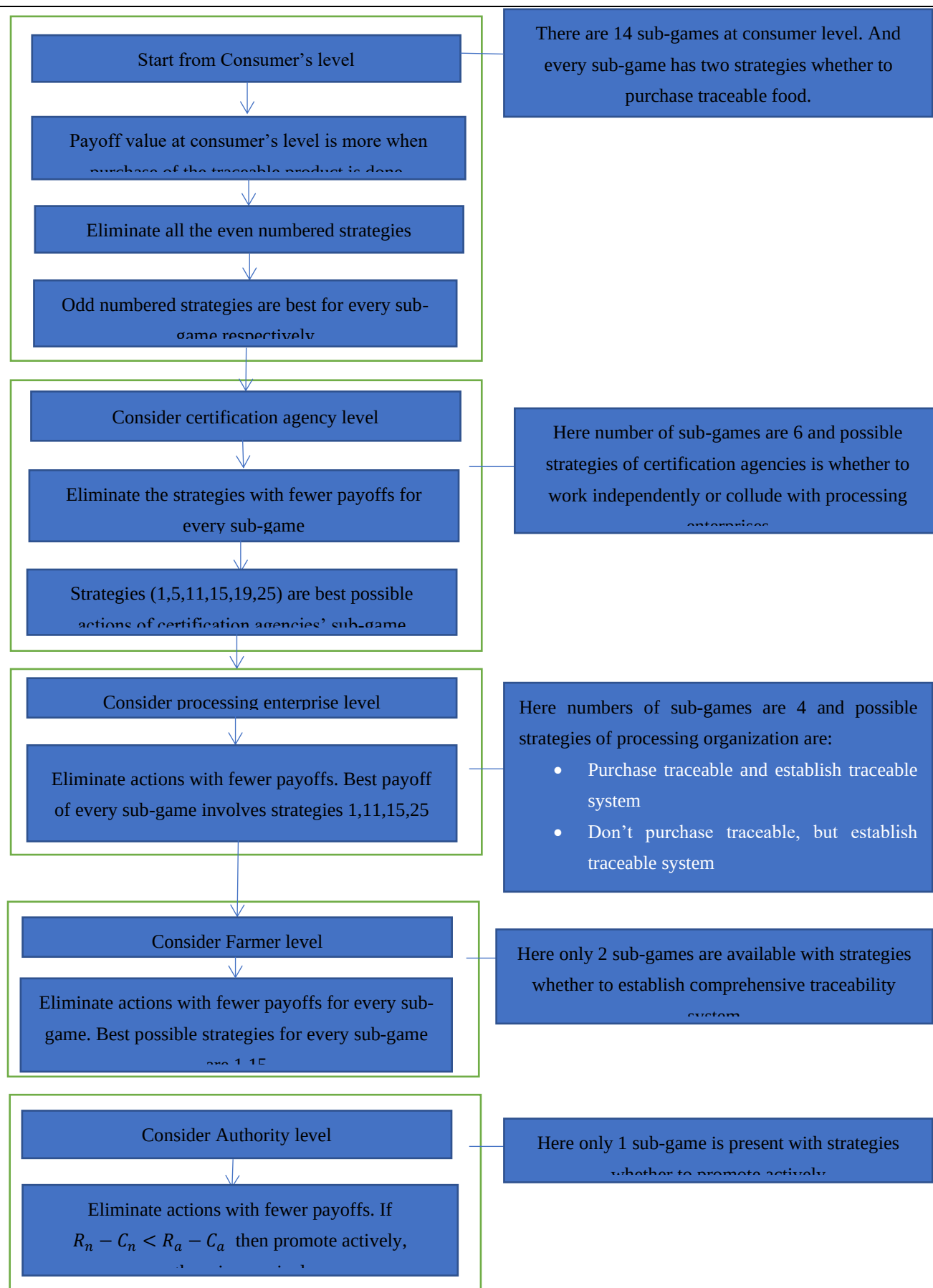


Figure 5: Steps involved in finding Nash Equilibrium using sub-game equilibrium of proposed game model.

Table 3 illustrates every node of the game model after performing a derivation & comparison (Wang and Yang, 2019) of Figure 1 and Table 1. This table gives the conditions of every node for establishment of traceable food production system.

Table 3: Each decision point conditions of the game

Decision Point	Strategy	Conditions
(5) If consumer buys traceable food products	Purchase	a) Certification agency is not working independently: $U_b - S_h + W_t > 0$ b) Certification agency is working independently: $U_b - S_n > 0$ (for not developing a traceability system) $U_a - S_h > 0$ (for developing a traceability system)
(4) What is the strategy adopted by certification agency?	Issue the certification	$C_c - W_a > 0$ (for not developing a traceability system)
	Not issue the certification	$C_c - W_a < 0$ (for not developing a traceability system)
(3) If processing enterprises develops comprehensive traceability system?	Non-develop	a) Certification agency is not working independently $S_n - S_h + C_c + F_b + (R_f + F_t) - (R_t + F_n) - W_p < 0$ b) Certification agency is working independently $S_n - S_h + F_b + (R_f + F_t) - (R_t + F_n) > 0$
	Develop	a) Certification agency is not working independently $S_n - S_h + C_c + F_b + (R_f + F_t) - (R_t + F_n) - W_p < 0$ b) Certification agency is working independently $S_n - S_h + F_b + (R_f + F_t) - (R_t + F_n) < 0$
(2) If Farmers adopts traceability practices?	Non-develop	a) Certification agency is not working independently $R_t + F_a - R_f - F_c - W_f > 0$ b) Certification agency is working independently $R_t + F_a - R_f - F_c > 0$
	Develop	a) Certification agency is not working independently $R_t + F_a - R_f - F_c - W_f < 0$ b) Certification agency is working independently $R_t + F_a - R_f - F_c < 0$
(1) If authority actively promotes traceability system?	Actively	a) Certification agency is not working independently $R_n - R_a + C_a - C_n - W_g < 0$ b) Certification agency is working independently

		$R_n - R_a + C_a - C_n < 0$
	Passively	a) Certification agency is not working independently $R_n - R_a + C_a - C_n - W_g > 0$ b) Certification agency is working independently $R_n - R_a + C_a - C_n > 0$

5. Analysis of Mathematical Model

This section highlights the decision made by all the stakeholders and analyzes the conditions mentioned in the above table. Here we will analyze the factors of every player of food chain that encourage them to establish traceability system.

Factors affecting government authorities for actively promoting food traceability system

- Increase in value of R_n and W_g represents high chances of authorities to promote food traceability system actively.
- Increase in value of R_n and C_a represents low chances of authorities to go for active promotion of traceability system.

Evidence: According to game model derivation conclusions and every decision of the game (Table 2), various scenarios in which government authorities promote traceable production of food actively can be illustrated as following inequalities:

When certification agency is not working independently, and the farmers and processing enterprises do not develop a comprehensive traceability system:

$$R_n - R_a + C_a - C_n - W_g < 0$$

When certification agency is working independently:

$$R_n - R_a + C_a - C_n < 0$$

Here, positive and negative relation among several parameters influence the decision of authorities i.e. either authority will promote traceability actively or not. Revenue of authorities when promoting traceable production of food actively (R_a); Cost to authorities when promoting traceable production of food passively (C_h); damage compensation imposed on authorities when authorities passively promote traceability and food products are falsely labeled as traceable (W_g); represents a positive relationship with actively promotion of traceability i.e. increase in value of these parameters represents high chances of actively promotion of traceability.

Revenue of authorities for passively promotion of traceability (R_n); cost to authorities in actively promotion of traceability of food products (C_a) represents negative relationship with actively promotion of traceability i.e. increase in value of these parameters represents low chances of actively promotion of traceability.

Factors affecting farmers to establish a traceable production of food

- i. Increase in the values of R_f, F_c, W_f represents high chances of farmers to develop a food traceability system.
- ii. Increase in values of R_t, F_a represents low chances of farmers to develop a food traceability system.

Evidence: According to game model derivation conclusions and every decision of the game (Table 2), various scenarios in which farmers establish a comprehensive traceable food production system can be illustrated as following inequalities:

When certification agency is not working independently:

$$R_t + F_a - R_f - F_c - W_f < 0$$

When certification agency is working independently:

$$R_t + F_a - R_f - F_c < 0$$

Here positive and negative relation among several parameters influence farmers either to establish a comprehensive food traceability or not. Revenue of farmers from sale of traceable food products (R_f); Cost to farmers to develop a non-traceable system (F_c); damage compensation imposed on farmers when product is falsely labeled as traceable and farmer does not develop a traceable system (W_f); represents positive relationship with development of traceability i.e. increase in value of these parameters represents high chances of adopting traceability by farmers.

Revenue of farmers from sale of non-traceable food products (R_t); cost to farmers in establishing a traceability system of food products (F_a) represents negative relationship with establishment of traceability system i.e. increase in value of these parameters represents low chances of adopting traceability by farmers.

Factors affecting processing enterprises to purchase traceable food and develop a comprehensive traceability system

- i. Increase in value of S_h, R_t, F_n, W_p represents high chances of processing organization to purchase traceable food from farmers and establish a food traceability system at enterprise.
- ii. Increase in value of S_n, C_c, F_b, R_f, F_t represents low chances of processing organization to purchase traceable food from farmers and establish a food traceability system at enterprise.

Evidence: According to game model derivation conclusions and every decision of the game (Table 2), various scenarios in which processing enterprise purchase traceable food from farmers and establish a comprehensive traceable food production system can be illustrated as following inequalities:

When certification agency is not working independently:

$$S_n - S_h + C_c + F_b + (R_f + F_t) - (R_t + F_n) - W_p < 0$$

When certification agencies is working independently:

$$S_n - S_h + F_b + (R_f + F_t) - (R_t + F_n) < 0$$

Here positive and negative relation among several parameters influence processing enterprises whether to purchase and establish a comprehensive food traceability system. Revenue of processing enterprises from sale of traceable labeled food products (S_h); Cost of purchasing non-traceable products from farmers (R_t); Cost of non-developing traceable

system at enterprise (F_n); damage compensation imposed on processing enterprises when product is falsely labeled as traceable (W_p); represents a positive relationship with purchase of traceable food from farmers and development of comprehensive food traceability system at the organization i.e. increase in the value of these parameter leads to high probability of processing enterprise to adopt traceable methodologies.

Revenue of processing enterprises from sale of non-traceable labeled food products (S_n); Cost of purchasing traceable products from farmers (R_f); Cost of developing traceable system at enterprise (F_t); Cost of collusion with certification agencies (C_c); Certification fees paid to certification agency (F_b); represents a negative relationship with purchase of traceable food from farmers and development of comprehensive food traceability system at the organization i.e. increase in the value of these parameter indicates to low probability of processing enterprise to adopt traceable methodologies.

Factors affecting certification agencies to work independently and refuse false certification

- i. Increased value of W_a represents high chances that certification agency will work independently.
- ii. Increased value of C_c represents low chances that certification agency will work independently.

Evidence: According to game model derivation conclusions and every decision of the game (Table 2), when the farmer or processing organization does not develop food traceability system, following inequality indicates that certification agency work independently and maintain their integrity by refusing to issue falsely labeled traceable food products:

$$C_c - W_a < 0$$

Here positive and negative relation among several parameters influence certification agencies to work independently without losing their integrity. Damage compensation of issuing false certification (W_a) represents positive relationship with certification agencies working independently i.e., higher the damage compensation, higher the chances that certification agency will not issue false certificate.

Collusion cost with processing enterprises (C_c) represents negative relationship with issuance of true certification i.e., higher the collusion cost certification agency will get, higher the chance of losing independence and issue false certificate.

Factors affecting consumers to purchase traceable labeled food products

- i. Increase in values of U_b, U_a, W_t represents high chances that consumer will purchase traceable labeled food products.
- ii. Increase in values of S_n, S_n represents low chances that consumer will purchase traceable labeled food products.

Evidence: According to game model derivation conclusions and every decision of the game (Table 2), when food product is labeled as traceable (maybe truly or falsely labeled), following inequalities represents the conditions that consumer purchase the traceable labeled food product:

When certification agency is not working independently:

$$U_b - S_h + W_t > 0$$

When certification agency is working independently and refuses to issue false certificate, and the food production system does not have comprehensive traceable system:

$$U_b - S_n > 0$$

When certification agency is working independently, and the food production system have comprehensive traceable system:

$$U_a - S_h > 0$$

Here positive and negative relation among several parameters influence consumers to purchase traceable labeled food product. Revenue generated from sale of traceable labeled food product U_a ; Revenue generated from sale of non-traceable labeled food product U_b ; damage compensation received by consumers W_t ; represents positive relationship with consumer's choice to purchase traceable labeled product.

Cost paid by consumer to purchase traceable labeled food product S_h ; Cost paid by consumer to purchase non-traceable labeled product; indicates a negative relationship with consumer's choice to purchase traceable labeled product.

5.1 Numerical example

In this study we have included a numerical example based to get an understanding of the mathematical model developed in this study. Table 4 represents the parameters value for numerical example:

Table 4: Parameter values for numerical example

Decision Node	Parameter	Numerical Value
Authority	R_a	100
	R_n	90
	C_a	80
	C_n	70
	W_g	10
Farmers	R_f	50
	R_t	40
	F_a	30
	F_c	20
	W_f	10
Processing Enterprises	F_t	30
	F_n	20
	S_h	150
	S_n	140
	F_b	15
	C_c	10
	W_p	10

	Q_n	5
Certification Agency	W_c	10
	Q_a	5
Consumer	U_a	170
	U_b	160
	W_t	10

Table 5 represents payoff values of different stakeholders based on the methodology proposed. Further we will utilize Gambit Software to calculate Nash equilibrium (NE) of the game model. This software provides Pure NE as well as Mixed NE. Mixed strategy contains probability for selection of a particular strategy.

Table 5: Payoff Values of Numerical Example

Strategic Combination	Authority	Farmers	Processing Enterprises	Certification agency	Consumers
1	20	20	55	15	20
2	-80	-30	-95	15	0
3	10	10	45	15	20
4	-80	-20	-105	25	0
5	10	10	55	15	20
6	-80	-20	-85	15	0
7	10	10	40	10	20
8	-80	-20	-110	10	0
9	10	10	55	15	20
10	-80	-20	-95	25	0
11	10	10	65	15	20
12	-80	-20	-75	15	0
13	10	10	50	10	20
14	-80	-20	-100	10	0
15	20	20	55	15	20
16	-70	-30	-95	15	0
17	10	10	35	15	20
18	-70	-20	-105	25	0
19	10	10	55	15	20
20	-70	-20	-85	15	0
21	10	10	40	10	20
22	-70	-20	-110	10	0
23	10	10	55	15	20
24	-70	-20	-95	25	0
25	10	10	65	15	20
26	-70	-20	-75	15	0

Strategic Combination	Authority	Farmers	Processing Enterprises	Certification agency	Consumers
27	10	10	50	10	20
28	-70	-20	-100	10	0

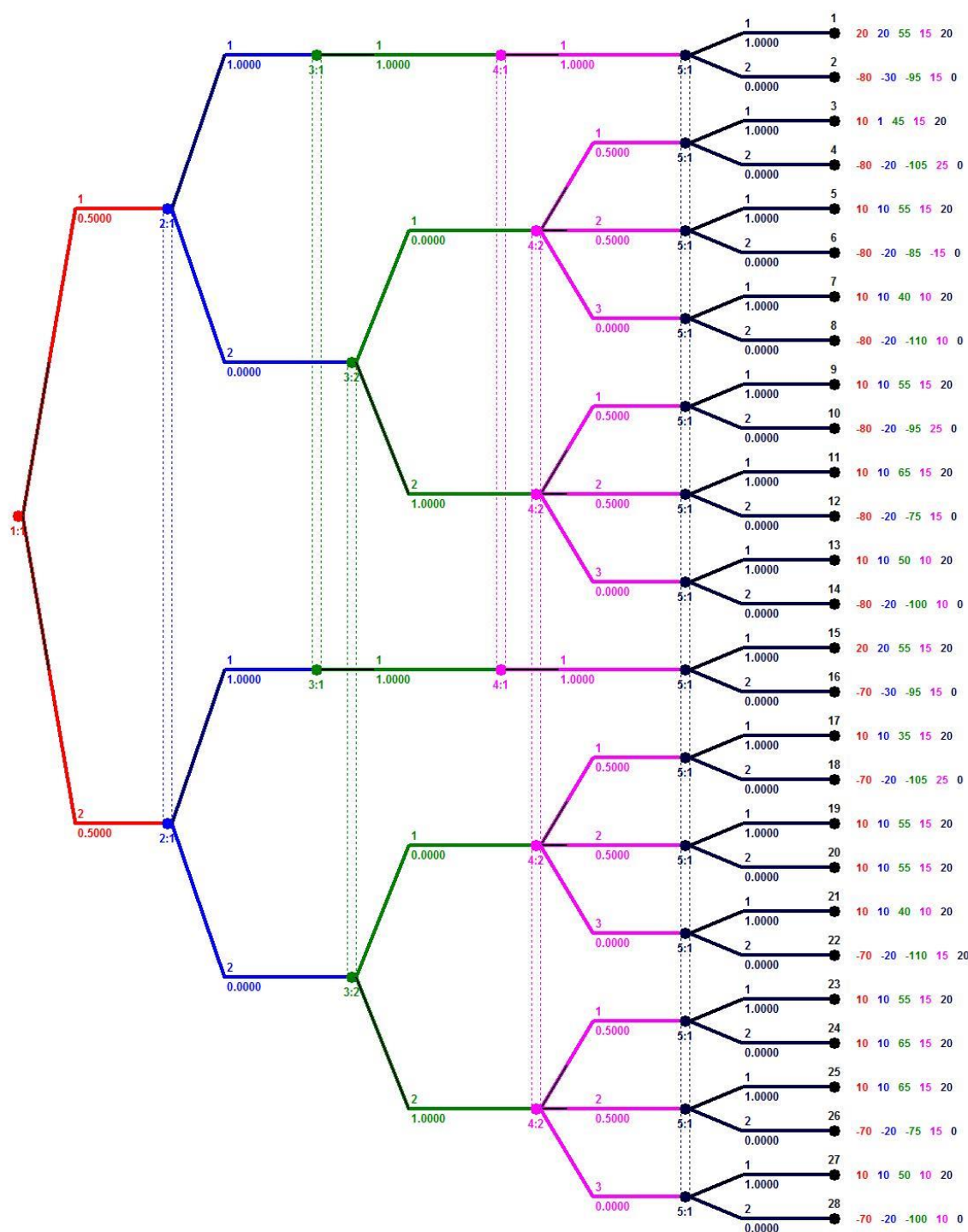


Figure 3: Numerical Example Solution using Gambit Software

This game solution Figure 3 concludes strategic combination 1 and 15 as Pure Nash Strategy if authority promotes traceability system actively and passively respectively. This also validates the proposed framework.



6. Discussion and Research Implication

Analysis of game theoretic model highlights that strategic interaction among different stakeholders plays an important role in a food supply chain. Since every stakeholder tries to optimize their own payoff values, then there is a high possibility of conflict among stakeholders while making their decisions. For example, increased cost of traceable food products (S_h), leads to high chances for processing enterprises to adopt traceability, but low chances for consumers to purchase traceable labeled food products; increased collusion cost (C_c) represents high chances for processing organization to establish comprehensive food traceability system, but low chances for certification agencies to work independently.

In this way there might be several circumstances where one player wants to maximize a particular cost, while other wants to minimize. In such situations, decision should be made by trade-off among players. This research can be utilized where several players are involved in such a way that decision made by one player influences the decision of other players. Similar framework may be utilized by government authority or managerial level to get a strategic view of possible outcomes before taking any decision. This research can further be extended by increasing the number of stakeholders and actions taken by them. Here the key findings are the strategic view by combination of different strategies of different stakeholders in a food supply chain. The current research highlights real time circumstances for developing traceability system in a food supply chain.

7. Conclusion and Future directions

The current study contributes to understand the strategies of stakeholders present in application of traceability throughout food supply chain by application of game theory. This gives a broad view of factors that may affect the food chain. The game developed in this study gives a comprehensive view of possible strategies of players to make decision in supply chain, how every player can maximize their utility, how decision taken by one player affect the decisions of other player to maximize their payoffs. Further a practical case has been solved to show how this model can be utilized in real life problems.

This study considers risk as a constant value for all the stakeholders that do not give emphasis on the effect of different value of risk for different players. Future research can be made by considering risk as a fuzzy variable and solve the problem considering the uncertainty in supply chain. Researchers can include cooperation among multiple players in the supply chain to overcome conflict occurrence. A comparative study can also be performed among competition and cooperation of different players.

This study has been performed to understand the strategic interaction of players while implementing traceability in food chain. But it does not analyze the situations after traceability development. Since food supply chain is highly time dependent. Such situation can also play a great contribution in scientific research. Involving dynamic situations may give a better idea for traceability application. Observation of dynamic nature can be a great idea for future research as well.

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References

1. Giagnocavo, C.; Bienvenido, F.; Ming, L.; Yurong, Z.; Sanchez-Molina, J.A.; Xinting, Y. Agricultural cooperatives and the role of organizational models in new intelligent traceability systems and big data analysis. *Int. J. Agric & Biol Eng* 2017, 10(5), 115-125. doi: 10.25165/j.ijabe.20171005.3089
2. Dandage, K.; Badia-Melis, R.; Ruiz-Garcia, L. Indian Perspective in food traceability: A review. *Food Control* 2016, 71, 217-227. <http://dx.doi.org/10.1016/j.foodcont.2016.07.005>
3. Seminar, K.B. Food Chain Transparency for Food Loss and Waste Surveillance. *Journal of Development in Sustainable Agriculture* 2016, 11, 17-22.
4. FAO. The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction. Rome. Licence 2019, CC BY-NC-SA 3.0 IGO.
5. Mogale, D.G.; Kumar, S.K.; Tiwari, M.K. Green Food supply chain design considering risk and post-harvest losses: a case study. *Annals of Operation research* 2020, 295, 257-284. <https://doi.org/10.1007/s10479-020-03664-y>
6. Mogale, D.G.; Ghadge, A.; Kumar, S. K.; Tiwari, M. K. Modeling supply chain network for procurement of food grains in India. *International Journal of Production Research* 2019, 28, 21, 6492-6512. <https://doi.org/10.1080/00207543.2019.1682707>
7. Senneset, G. Foras, E. Challenges regarding implementation of electronic chain traceability. *British Food Journal* 2007, 109(10), 805-818. <https://doi.org/10.1108/00070700710821340>
8. Basu, K. The Economics of food grain management in India. 2010.
9. Padmaja, Ch.; Swathi, N.; Anuradha, P.; Prashanth, B. Sustainable development in agriculture using internet of things- A Review. *IOP Conf. Series: Materials Science and Engineering* 2020, 981. Doi: 10.1088/1757-899X/981/3/032032
10. Khapre, A.P.; Pawar, V.S. Storage losses of Food Grains: Major Issue of Food Grain Market. *Popular Kheti* 2015, 3(1), 102-109.
11. Sidwani, A.; Kumar, A.; Gautam, C.; Puhorit, G.; Tanwar, P. Prediction and Monitoring of stored food grains health using IoT Enable nodes. *IEEE International Conference on Computing, Power and Communication Technologies* 2020, 516-522.
12. Mogale, D. G.; Ghadge, A.; Kumar, S. K.; Tiwari, M. K. Modelling supply chain network for procurement of food grains in India. *International Journal of Production Research* 2019, 52(21), 6493-6512. <https://doi.org/10.1080/00207543.2019.1682707>
13. Galimberti, A.; Cena, H.; Campone, L.; Ferri, E.; Agli, M. D.; Sangiovanni, E.; Belingheri, M.; Riva, M. A.; Casiraghi, M.; Labra, M. Rethinking Urban and Food Policies to Improve Citizens Safety After COVID-19 Pandemic. *Frontiers in Nutrition* 2020, 7. <https://doi.org/10.3389/fnut.2020.569542>
14. Balaji, M.; Arshinder, K. Modeling the causes of food wastage in Indian perishable food supply chain. *Resources, Conservation and Recycling* 2016, 114, 153-167. <http://dx.doi.org/10.1016/j.resconrec.2016.07.016>
15. Ghardas, B. B.; Raut, R. D.; Narkhede, B. Modeling casual factors of post-harvesting losses in vegetable and fruit supply chain: An Indian perspective. *Renewable and Sustainable Energy Reviews* 2017, 80, 1355-1371. <http://dx.doi.org/10.1016/j.rser.2017.05.259>

16. Shanmugasundaram, M.; Chellaiah, R.; Chauhan, O. M.; Kizhekkedath, J. Application of Information and Technology in Supply Chain Management of Fruits and Vegetables- A Brief Overview. *International Journal of Innovative Science and Research Technology* 2020, 5(4), 1370-1376.
17. Kamble, S. S.; Gunasekaran, A.; Sharma, R. Modeling the blockchain enabled traceability in agriculture supply chain. *International Journal of Information Management* 2019. <https://doi.org/10.1016/j.ijinfomgt.2019.05.023>
18. Xiao, X.; He, Q.; Fu, Z.; Xu, M.; Zhang, X. Applying CS and WSN methods for improving efficiency of frozen and chilled aquatic products monitoring system in cold chain logistics. *Food Control* 2016, 60, 656-666. <http://dx.doi.org/10.1016/j.foodcont.2015.09.012>
19. Pappa, I. C.; Iliopoulos, C.; Massouras, T. What determines the acceptance and use of electronic traceability systems in agri-food supply chains? *Journal of Rural Studies* 2018, 58, 123-135. <https://doi.org/10.1016/j.jrurstud.2018.01.001>
20. Galvez, J. F.; Mejuto, J. C.; Simal-Gandara, J. Future challenges on the use of blockchain for food traceability analysis. *Trends in Analytical Chemistry* 2018. Doi: [10.1016/j.trac.2018.08.011](https://doi.org/10.1016/j.trac.2018.08.011)
21. Li, H.; Zhang, B.; Zhang, L.; Xue, Y.; He, M.; Ren, C. A food traceability framework for dairy and other low-margin products. *IBM J. RES. & DEV.* 2016, 60(5/6), 10. doi: 10.1147/JRD.2016.2598610
22. Xiao, X.; Fu, Z.; Zhang, Y.; Peng, Z.; Zhang, X. SMS-CQ: A quality and safety traceability system for aquatic products in cold-chain integrated WSN and QR code. *Journal of Food Process Engineering* 2015. doi:10.1111/jfpe.12303
23. Gokarn, S.; Kuthambalayan, T.S. Analysis of Challenges Inhibiting the Reduction of Waste in Food Supply Chain. *Journal of Cleaner Production* 2017. Doi:10.1016/j.jclepro.2017.09.028
24. Rowan, N. J.; Galanakis, C. M. Unlocking challenges and opportunities presented by COVID-19 pandemic for cross-cutting disruption in agri-food and green deal innovations: Quo Vadis? *Science of Total Environment* 2020. Doi: <https://doi.org/10.1016/j.scitotenv.2020.141362>
25. Astill, J.; Dara, R. A.; Campbell, M.; Farber, J. M.; Fraser, E. D. G.; Sharif, S.; Yada, R. Y. Transparency in food supply chains: A review of enabling technology solutions. *Trends in Food Science & Technology* 2019, 91, 240-247. <https://doi.org/10.1016/j.tifs.2019.07.024>
26. World Economic Forum. Innovation with a Purpose: Improving Traceability in Food Value Chains through Technology Innovations. 2019.
27. Sharma, R.; Hurburgh, C.; Mosher, G. A. Developing guidance templates and terminology to support multiple traceability objectives in grain supply chain. *Cereal Chemistry*, 98, 52-69. <https://doi.org/10.1002/cche.10388>
28. Iftekhhar, A.; Cui, X. Blockchain-based Traceability System that ensures food safety measures to protect consumer safety and COVID-19 free supply chain. *Foods* 2021, 10, 1289. <https://doi.org/10.3390/foods10061289>
29. Vasnani, N. N.; Chua, F. L. S.; Ocampo, L. A.; Pacio, L. B. M. Game theory in supply chain management: current trends and applications. *International Journal of Applied Decision Sciences* 2019, 12(1), 56-97.
30. Maiyar and Thakkar. Robust optimization of sustainable food grain transportation with uncertain supply and intentional disruptions. *International Journal of Production Research* 2019, 58(18), 5651-5675. <https://doi.org/10.1080/00207543.2019.1656836>
31. Li, Y.; Mao, M.; Wang, K. The Decision-making of constructing Traceability System for Fresh Agricultural Products. *ICLEM 2010: Logistics for Sustained Economic Development*.
32. Tang, S. An Evolutionary Game Model of the Establishment of Traceability System in Food Supply Chain. *Applied Mechanics and Materials* 2013, 423-426, 2190-2195. doi: [10.4028/www.scientific.net/AMM.423-426.2190](https://doi.org/10.4028/www.scientific.net/AMM.423-426.2190)
33. Wu, J.; Wu, C.; Liu, Y. The Economics and Feasibility of Traceability in Agri-food Supply Chain: Analysis with Game Theory between Double Oligarchs. *Applied Mechanics and Materials* 2013, 347-400, 2574-2580. <https://doi.org/10.4028/www.scientific.net/AMM.397-400.2574>

34. Wang, M.-Ch.; Yang, Ch.-Y. Analyzing the traceability system in herbal product industry by game theory. *Agricultural Economics-Czech* 2019, 65, 74-81. <https://doi.org/10.17221/102/2018-AGRICECON>
35. Ma, X. Analysis on Quality Control in Food Supply Chain Based on Dynamics Evolutionary Game Model. *International Conference on Optoelectronics and Image Processing* 2010. DOI 10.1109/ICOIP.
36. Asrol, M.; Marimin; Macfud; Yani, M. Supply chain Fair Profit Allocation based on Risk and Value Added for sugarcane agro-industry. *Operations and supply chain management* 2020, 13, 2, 150-165.
37. Debnath, A.; Bandyopadhyay, A.; Roy, J.; Kar, S. Game theory based multi criteria decision making problem under uncertainty: A case study on Indian Tea Industry. *Journal of Business Economics and Management* 2017, 19(1), 154-175. <https://doi.org/10.3846/16111699.2017.1401553>
38. Chavoshlou, A. S.; Khameseh, A. A.; Naderi, B. An optimization model of three-player payoff based on fuzzy game theory in green supply chain. *Computers & Industrial Engineering* 2019, 128, pp. 782-794. <https://doi.org/10.1016/j.cie.2018.12.057>
39. Asian, S.; Hafezalkotob, A.; John, J. J. Sharing economy in organic food supply chains: A pathway to sustainable development. *International Journal of Production Economics* 2019. <https://doi.org/10.1016/j.ijpe.2019.06.010>
40. Song, C.; Zhuang, J. Modelling a Government-Manufacturer-Farmer Game for Food Supply Chain Risk Management. *Food Control* 2017, 78, 443-455.
41. Wang, M.-Ch.; Yang, Ch.-Y. Analyzing organic tea certification and traceability system within the Taiwanese tea industry. *J Sci Food Agric* 2014, 95, pp. 1252-1259.
42. Guo, R. Chapter 5- Cross-Border Resource Management: Methods. *Cross Border Resource Management* 2018, 3, 109-137. <https://doi.org/10.1016/B978-0-444-64002-4.00005-2>