Supply chain with use of Game theory

BY

RAJAT CHAUHAN

CY CERGY Paris University

SUPERVISED

BY

M. MARIETTA MANOLESSOU

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Introduction

1.1 What is game theory?

Game theory is the theory of strategic interactions that studies the decision-making behavior of individuals and organizations in situations where the outcome is determined by the actions of two or more who interact with each other. Game theory has found applications in diverse areas such as anthropology, auctions, biology, business, economics, management-labor arbitration, philosophy, politics, sports and warfare.

In game theory, a game is a situation in which players make decisions that affect each other's outcomes. A set of rules specifies the players, the available actions, and the payoffs associated with each outcome. Players try to maximize their payoffs, which can be monetary rewards, social status, or other benefits.

Players' behavior in a game is influenced by their understanding of the game, their beliefs about other players' actions, and their preferences for the outcomes. Game theory provides tools for analyzing how players interact with one another and how they might behave in various situations.

Decision-making problems are central to game theory. In many games, players must decide on a course of action that will affect the outcome of the game. These decisions can be influenced by a variety of factors, including risk aversion, strategic thinking, and bounded rationality.

Overall, game theory provides a strong framework for comprehending and analyzing strategic interactions among decision-makers. It has numerous applications and has the potential to provide insights into a wide range of complex problems.

1.2 GAME THEORY'S HISTORY

Game theory is a field of study that analyzes strategic decision-making in a wide range of contexts. Its history dates back to the 18th century, but its main development began in the 1920s with the work of mathematician John von Neumann and scientist Emile Borel. Their work culminated in the 1944 release of "Theory of Games and Economic Behavior," a pivotal moment in the evolution of game theory.

The 1950s saw the entrance of game-theoretic models into economic theory, while political scientists and psychologists began examining how test participants act in simulations. By the 1970s, game theory was being applied to evolutionary biology. Today, game-theoretic techniques are widely used in many areas of economics and other social and behavioral disciplines, and have increasingly come to dominate microeconomic theory.

In addition to its theoretical importance, game theory has proven to be an invaluable tool for analyzing strategic decision-making in numerous fields. For example, game theory is used to model the behavior of firms in competitive markets, to analyze the effects of different policy interventions, and to study the behavior of political actors and the outcomes of different voting systems. Game theory has also been applied to fields such as psychology, computer science, biology, and international relations.

At its core, game theory relies on mathematical models of decision-making and strategic behavior. These models are based on the idea that individuals or groups make decisions based on the potential outcomes of different choices and the actions of others involved in the decision. By understanding the principles of game theory, researchers can better explain and predict behavior in situations where individuals or groups have competing interests and face strategic decisions.

The contributions of game theorists John C. Harsanyi, John F. Nash, and Reinhard Selten were recognized with the 1994 Nobel Prize in Economics. Today, game theory remains an active area of research and development, and continues to be an important tool for understanding strategic decision-making.

1.3What is Supply Chain?

A supply chain is a complex system that involves various entities, including suppliers, manufacturers, distributors, retailers, and customers. It is a network of organizations that work together to ensure that materials flow downstream from suppliers to customers and information flows in both directions. Supply chain management (SCM) refers to the process of managing relationships, information, and materials flow across enterprise borders to deliver enhanced customer service and economic value through synchronized management of the flow of physical goods and associated information from sourcing to consumption.

The supply chain includes a wide range of activities such as sourcing raw materials, manufacturing, transportation, warehousing, inventory management, and distribution. Effective supply chain management requires a deep understanding of each of these activities and how they interact with each other. It also requires a focus on continuous improvement and the ability to adapt to changes in demand, technology, and other external factors.

Supply chain management has become increasingly important in today's global economy, where companies are under pressure to deliver high-quality products at lower costs and faster speeds. It is also an area where technology is playing an increasingly important role, with the use of data analytics, artificial intelligence, and other technologies enabling companies to improve visibility, efficiency, and decision-making in their supply chains.

The supply chain concept emerged due to various changes in the manufacturing environment, including increasing manufacturing costs, dwindling resources of manufacturing bases, shorter product life cycles, equalization of manufacturing competition, and the globalization of market economies. These changes necessitated a more coordinated and integrated approach to managing the flow of goods and services from raw materials to the end consumer.

The concept of reverse logistics, which involves the recovery and recycling of products, has also been included in the traditional supply chain concept. This enables companies to reduce waste and increase sustainability, while also generating new revenue streams.

In manufacturing research, the supply chain concept has largely grown out of two-stage multi-echelon inventory models, which have been extensively studied and analyzed. The design and analysis of two-echelon systems has been a major area of focus in this field, building on the classic work of Clark and Scarf in the 1960s.

Recent discussions on two-echelon models have been carried out by Diks et. al. and van Houtum et. al., while

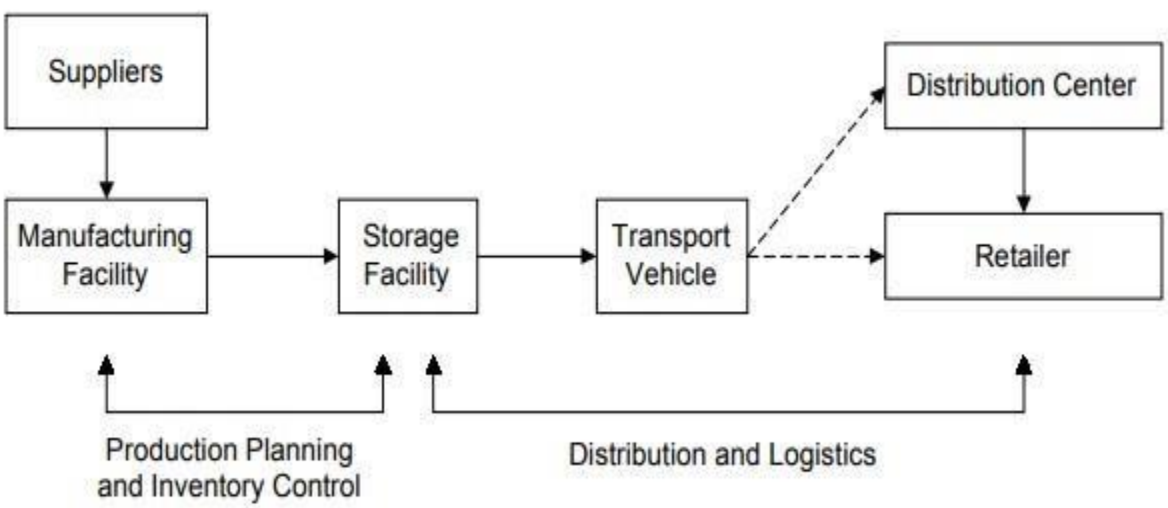
Federgruen and Bhatnagar et. al. has published comprehensive reviews of models of this type. Overall, the supply chain concept has become a critical aspect of modern manufacturing, enabling companies to better manage costs, resources, and environmental impact while improving customer satisfaction.

The Applications of supply chain management principles are numerous and varied. For example, effective supply chain management can help organizations reduce costs by optimizing inventory levels, minimizing transportation costs, and reducing waste. It can also help organizations improve customer service by ensuring timely delivery of products and enhancing product quality.

In addition, supply chain management Principles can be applied to various industries, including healthcare, retail, and manufacturing. In healthcare, supply chain management can help hospitals and clinics manage their medical supplies and equipment efficiently. In retail, supply chain management can help retailers manage their inventory levels and ensure that products are available to customers when and where they are needed. In manufacturing, supply chain management can help manufacturers optimize their production processes and reduce their overall costs.

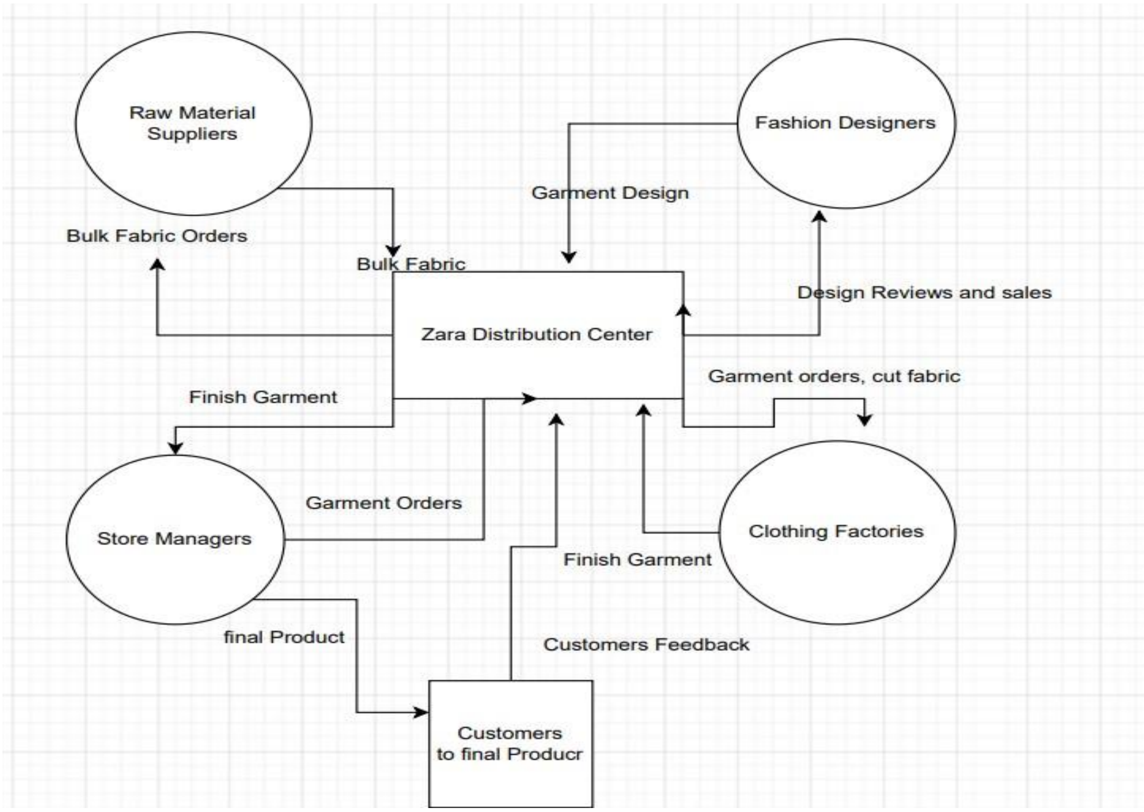
Evaluating the effectiveness of supply chain management requires a focus on key performance indicators (KPIs) such as inventory turnover, order fulfillment rates, and on-time delivery rates. By monitoring these KPIs, organizations can identify areas for improvement and make necessary adjustments to their supply chain processes.

In summary the principles of supply chain management are essential for organizations looking to remain competitive in today's global marketplace. By understanding and implementing these principles, organizations can optimize their supply chain processes and better serve their customers, while also improving their bottom line.



For Example, Zara's supply chain distribution system also includes a highly efficient logistics network. The company operates a centralized distribution center in Spain, which is responsible for receiving and processing orders from Zara stores around the world. This centralized system enables Zara to streamline its logistics operations, reduce costs, and improve delivery times.

In addition to its centralized distribution center, Zara also utilizes a unique just-in-time inventory system. This system allows the company to keep its inventory levels low, which helps to reduce costs and improve cash flow. When a new product is introduced, Zara produces a limited quantity and distributes it to its stores. If the product sells well, the company will quickly produce more to meet demand. If it doesn't sell well, the company will stop production and move on to the next product.



1.4 Game theory in the Supply chain

Game theory has also been applied in SCM to model the behavior of supply chain entities and analyze their interactions. Game theory provides a powerful framework for understanding strategic decision-making in competitive situations. Several reviews have focused on the application of game theory in economics or management science, with some specific to SCM. These reviews have covered a wide range of topics, from static game theory applications to differential game applications in management science and operations research. They have also discussed game theoretic models applied in operations management and information systems, with a particular focus on information sharing and manufacturing/marketing incentives.

In SCM, coordination and cooperation among supply chain channel members are significant and interesting topics. In a centralized supply chain, the decision maker coordinates the members' activities to increase the competitive capability of the supply chain. However, in a decentralized supply chain where each member is an independent decision maker, two issues arise: competition among supply chain members to improve their individual performance, and the potential for members to agree on a contract to coordinate their strategies to improve the global performance of the system as well as their individual profits. Non-cooperative and cooperative game theory is a prime methodological tool for dealing with these problems, focusing on the simultaneous or sequential decision-making of multiple players under complete or incomplete information. These game theory models can help achieve supply chain-wide optimization and prevent deviations from the global optimal solution.

For Example, the traditional "prisoner's dilemma" game used to analyze a supplier-retailer interaction is an illustration of game theory in SCM. In this case, the supplier and retailer have a choice between working together and sharing information to enhance the effectiveness of the supply chain and acting independently and keeping information to themselves to acquire a competitive edge. When both parties decide to suppress information, the supply chain's overall effectiveness diminishes. However, if both parties work together and exchange information, the supply chain performs better, increasing both sides' earnings.

Game theory in SCM has been criticized for assuming that all parties will act rationally. Game theory models may not adequately account for the real-world influences on supply chain decisions, which include things like emotions, interpersonal interactions, and cultural differences. Furthermore, game theory models might not consider the complexity of actual supply chains, including the existence of numerous tiers of suppliers and the influence of outside variables like natural catastrophes or economic crises. Because of this, game theory should be utilized in conjunction with other analytical techniques and real-world factors in order to completely capture the intricacies of SCM, even though it can offer useful insights into supply chain decision-making.

2 Related work:

The state of the art for game theory in supply chain management (SCM) is constantly evolving and expanding, with new models and applications being developed and studied. Some of the current research topics in game theory and SCM include:

2.1 Cooperative game theory:

This approach emphasizes collaboration between supply chain partners and
focuses on strategies that benefit all parties involved. In contrast to traditional non-cooperative game theory, cooperative game theory can help firms find mutually beneficial solutions that result in better supply chain performance.

In recent years, supply chain management has recognized that the decisions of decentralized firms impact each other's profit, and therefore, the profit of the entire supply chain. To model and analyze decision-making in such situations, game theory has become a popular choice. Game theory and economics tools are now used by researchers to help managers make strategic operational decisions in complex multi-agent supply chain systems. There are two main approaches to game theory: cooperative and non-cooperative.

Non-cooperative game theory focuses on individual player strategies and how they arrive at their decisions, while cooperative game theory looks at possible outcomes and the formation of coalitions among players to achieve those outcomes. Non-cooperative game theory is more focused on specific details while cooperative game theory takes a more macro approach to understanding the game. To delve deeper into two topics that are commonly analyzed in business, we have negotiation and alliances. The use of negotiation in determining the terms of procurement contracts is a common practice among sellers and buyers in supply chain relationships. Anecdotal evidence and academic literature have shown that negotiation is preferred over other mechanisms, such as auctions, in certain circumstances. For example, Bajari et al. (2002) found that 43% of all projects in the construction industry are awarded using negotiation, and Bonaccorsi et al. (2000) claimed that Other examples include the Taiwanese semiconductor industry association, timber procurement, automobile industry, and retail. These findings highlight the importance of adopting a negotiation framework to examine

revenue allocations and contracting parameters in supply chains. The importance of alliance formation in supply chains and provides examples of such alliances between component manufacturers in industries such as the semiconductor and automobile industries. One of the reasons for forming such alliances is to improve the relative negotiating position of the firms. The examples include SMIC and IMEC forming an alliance to sell chips to Texas Instruments, as well as alliances between Asyst and Shinko in semiconductor equipment manufacturing
[1].

2.2 State of Art

Blockchain technology

Cooperative game theory in supply chain management is the use of blockchain technology. Blockchain is a decentralized, secure, and transparent digital ledger that allows for the sharing of information and data between supply chain partners without the need for intermediaries. By using blockchain technology, supply chain partners can collaborate more effectively and efficiently, leading to improved supply chain performance and greater trust between partners.

[8] Blockchain is considered a general-purpose technology that serves as an enabler by creating new opportunities rather than providing complete solutions (Bresnahan and Trajtenberg, 1995). It complements existing innovations by supporting them to achieve previously unattainable goals. The creator of blockchain technology, Satoshi Nakamoto, initially developed it to support bitcoin transactions. The technology is based on a distributed ledger system that maintains a secure and transparent record of transactions across a network of computers. The decentralized nature of the blockchain ensures that no single entity has control over the system, making it a reliable and tamper-proof solution for various applications. The potential uses of blockchain technology extend far beyond its initial purpose of supporting cryptocurrency transactions, with many industries exploring its potential to revolutionize supply chain management, finance, and other areas of business. Several studies have highlighted the benefits of blockchain technology, including increased transparency, improved security, and reduced transaction costs. However, the adoption of blockchain technology is not without its challenges, such as regulatory issues, interoperability concerns, and the need for standardization. Despite these challenges, the potential benefits of blockchain technology make it a promising area for further research and development.

Aims to analyze a basic supply chain model to evaluate the operational and economic advantages that supply chain members can achieve by transitioning from a traditional platform to a blockchain-based platform for transactions. The model focuses on a supply chain consisting of one supplier, denoted as "he", and one retailer, denoted as "she". Both parties negotiate and set their strategies on an online platform. The supplier acts as the chain leader and sets a predetermined number of products to be supplied online. The model examines how the adoption of blockchain technology affects the operational and economic performance of the supply chain in comparison to traditional platforms

The article discusses the equilibria for two games, namely the "game" and "game," which are played using the Stackelberg model with the supplier as the leader. The supplier communicates their ability to produce and distribute a particular product and sell it at a wholesale price to the rest of the supply chain

Here Author proposes a game model for a supply chain consisting of a supplier and a retailer. The supplier sets the service strategy and sells goods to the retailer, who determines the optimal quantity to purchase and selling price. The supply chain can be managed through either a traditional online platform or a blockchain platform. The blockchain platform removes all risks associated with delivery and service and saves on transaction costs, but requires initial implementation investments and variable costs.

The benefits of blockchain include increased visibility, transparency, and security, which are measured in tokens. The paper identifies the conditions in which the blockchain is not worth implementing and investigates the suitability of smart contracts for better coordinating firms' relationships and negotiations. The use of smart contracts makes blockchain applications more operationally convenient and economically appealing in certain cases

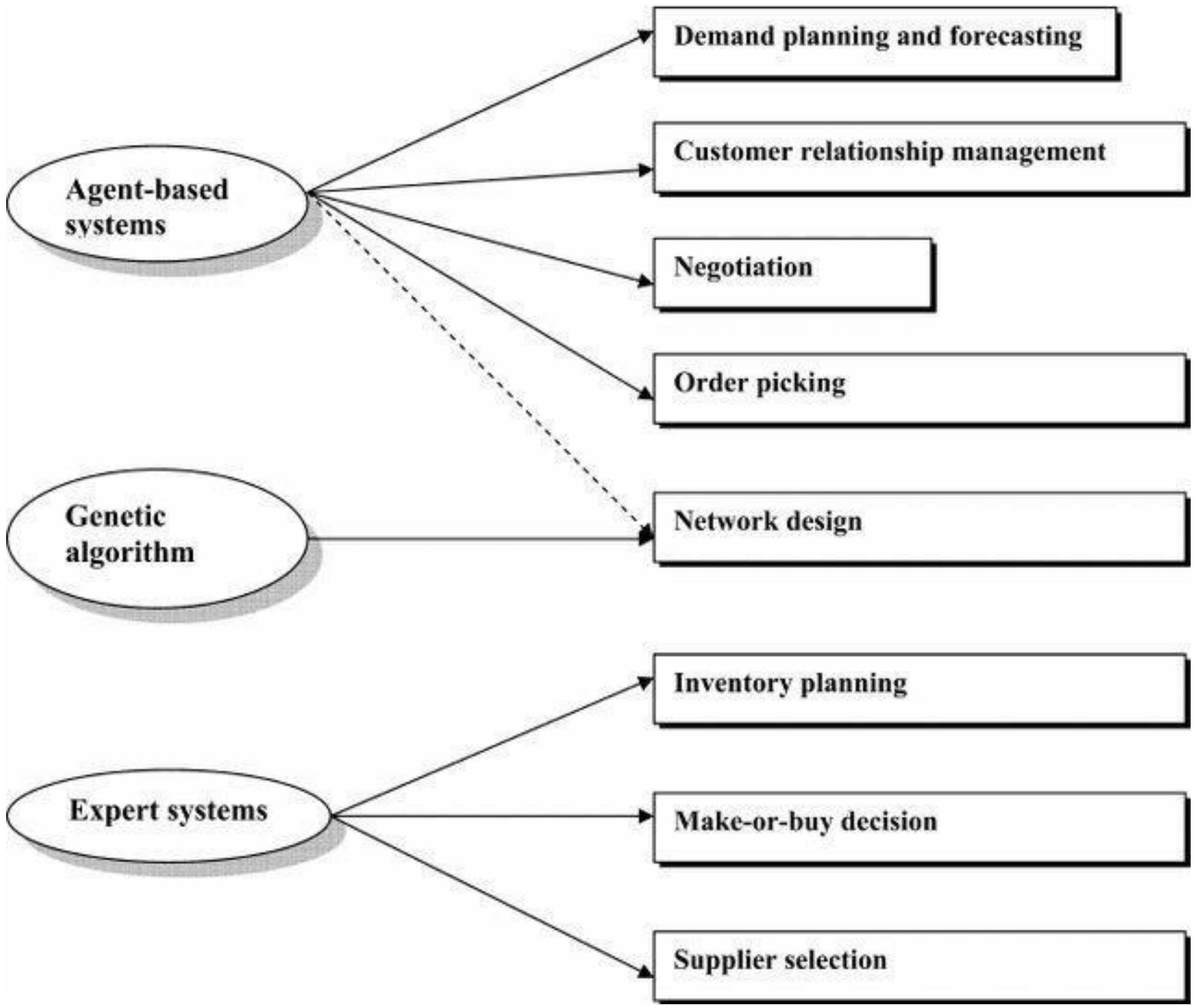
Game theory and supply chain management with AI

Artificial intelligence (AI) is a technology that has been developed to create machines capable of thinking, learning, and replacing human intelligence. Since the late 1970s, AI has been recognized for its potential in improving human decision-making processes and increasing productivity in various business sectors. AI is able to recognize business patterns, learn business phenomena, seek information, and analyze data intelligently. Despite its widespread acceptance as a decision-aid tool, AI has seen limited application in supply chain management (SCM).

To fully harness the potential benefits of AI in SCM, this paper explores various sub-fields of AI that are most suitable for solving practical problems relevant to SCM. Through a review of past successes in AI applications to SCM, the paper identifies the most promising areas of SCM to which AI can be applied. By doing so, the paper aims to bridge the gap between the potential of AI and its application in SCM.

The potential of AI to solve complex problems and gather information in the area of supply chain management (SCM) has not been fully realized in the past, despite the long history of AI. However, some pioneering efforts have been made to apply AI in SCM, particularly in sub-disciplines such as expert systems and genetic algorithms. These have been used to address SCM issues related to inventory management, purchasing, location planning, freight consolidation, and routing/scheduling problems. The areas of SCM that have been explored for AI applications, identifies specific subdisciplines of AI that have proven useful for improving supply chain decisions, and assesses their contributions to the decision-making process.

Article discusses the application of AI in Supply Chain Management (SCM) and identifies specific sub-disciplines of AI that have been found to be useful for improving SC decisions. The article outlines the areas of SCM that have been explored for AI applications, such as inventory control and planning, and transportation network design. It also assesses the contributions of these AI techniques to the decision-making process in the supply chain. The article includes examples of successful AI implementations and their impact on inventory management and transportation network design.



Link between popular AI tools and their SCM applications areas

The article discusses the importance of using Artificial Intelligence (AI) in Supply Chain Management (SCM) to help businesses connect with customers, suppliers, and partners by exchanging information and reducing the need for physical assets. Despite AI's presence in SCM for the last half-century, it has not been fully utilized to solve complex and ill-structured SC problems. Most AI applications are limited to well-structured and tactical problems, but recent studies have shown that agent-based systems have great potential for solving soft and strategic issues involving CRM, outsourcing relationships, SC coordination, demand planning, and negotiations.

Challenges for AI applications in SCM include programming errors, difficulty in implementation, and handling risk and uncertainty. However, with the maturation of SCM as an academic discipline, AI will have a promising future in the SCM area. The article suggests several AI research topics to advance SCM decision-making processes, including multiple agent-based systems, intelligent agents for real-time pricing and reverse auctioning, game theory, profiles of desirable SC partners, rule-based expert systems, hybrid meta-heuristics, fuzzy logic, and integrating AI with legacy systems.

2.3 Pricing strategies game theory:

Pricing decisions are a critical aspect of supply chain management, and game theory can help firms to analyze and optimize their pricing strategies. For example, firms can use game theory to study the impact of price wars or collusion among competitors, and to identify the optimal pricing strategy that maximizes their profits.

Following that, the two Stackelberg games of "consumer price promotion" and "retailer-consumer price promotion" are studied. The manufacturer is the leader in the Stackelberg games, while the retailer is the follower. The results show that the reference price and the customer's memory factor have a significant impact on the profits of supply chain members, optimal depth of price promotion, and advertising level. Impact of price promotion, reference price, and advertising on a manufacturer-retailer supply chain using game theory. The study finds that both consumer memory and price impact factors significantly affect the optimal price promotion depth and advertising value. The results also show that a negative price promotion can increase short-term profits but reduce market potential in the long term. However, if the consumer's sensitivity to the gap between the price and the reference price is high enough, a positive price promotion can increase channel profits. The study also reveals that advertising has an explicit effect on improving channel efficiency and incremental profits of supply chain members [2].

The use of game theory in pricing decisions is a well-established area of research in supply chain management. Game theory provides a framework to analyze the impact of pricing strategies on profits, such as price wars or collusion among competitors. A recent study has focused on two Stackelberg games of "consumer price promotion" and "retailer-consumer price promotion," in which the manufacturer is the leader and the retailer is the follower. The research shows that the reference price and customer memory have a significant impact on the profits of supply chain members, optimal depth of price promotion, and advertising level. Additionally, the study finds that advertising can improve channel efficiency and incremental profits of supply chain members. Overall, game theory is a valuable tool for analyzing pricing strategies and optimizing profits in supply chain management.

An example of a real-time application of game theory in supply chain management is dynamic pricing, where firms adjust their prices based on real-time market conditions and competitor behavior. By using game theory models, firms can anticipate how their competitors will respond to price changes and adjust their pricing strategies accordingly. Another example is the use of game theory to optimize inventory management, where firms use algorithms to determine optimal inventory levels based on demand forecasts and supplier lead times. This allows them to reduce inventory costs while still meeting customer demand in real-time.

[9] In a game-theoretic model for dynamic pricing in a two-echelon supply chain consisting of a single supplier and a single retailer. The supplier sets the wholesale price for the product, while the retailer sets the retail price and decides the order quantity. Both the supplier and the retailer aim to maximize their respective profits. The model considers demand uncertainty, inventory holding costs, and ordering costs. The equilibrium solutions for both the supplier and the retailer are obtained using backward induction. The model is analyzed numerically, and the results show that dynamic pricing can lead to improved profits for both the supplier and the retailer, as compared to a static pricing policy. Moreover, the results highlight the importance of considering the strategic interactions between the supplier and the retailer in determining the optimal pricing policies.

2.4 Behavioral game theory:

Behavioral game theory examines how people make decisions in real-life situations. This approach has been applied to supply chain management to understand how individual behaviors and decision-making processes impact the overall supply chain performance.

The use of game theory in supply chain decision making emphasizes the importance of the behavioral approach in this field. An experiment was carried out to assess the impact of decision-makers' characteristics on their logistics decisionmaking in supply chains, using game theory assumptions and statistical analysis. The conclusion is that the decisionpersonality makers can influence the outcomes of their decisions, and that assigning an appropriate decision scope can help rationalize these decisions [3]. The study examines the factors that influence the formation of a knowledgesharing alliance and employs numerical simulations to validate theoretical results as well as the effects of parameter changes on behavioral evolution. The findings show that knowledge-sharing behavior in construction supply chains evolves in different ways depending on the income relationship. The study also discovers that acceptance of the sharing strategy is positively correlated with the penalty coefficient, incentive coefficient, trust level, and synergy coefficient, and negatively correlated with cost. The findings provide theoretical guidance for establishing stable knowledge collaboration among enterprises and promoting long-term development in the construction supply chain [4].

Study examines the factors that influence the formation of a knowledge-sharing alliance and employs numerical simulations to validate theoretical results as well as the effects of parameter changes on behavioral evolution. The findings show that knowledge-sharing behavior in construction supply chains evolves in different ways depending on the income relationship. The study also discovers that acceptance of the sharing strategy is positively correlated with the penalty coefficient, incentive coefficient, trust level, and synergy coefficient, and negatively correlated with cost. The findings provide theoretical guidance for establishing stable knowledge collaboration among enterprises and promoting long-term development in the construction supply chain.

Real-time applications of these concepts could include using behavioral game theory to analyze the decision-making processes of supply chain partners and adjust decision-making scopes accordingly. Additionally, implementing knowledge-sharing alliances based on the findings of the second study could help enterprises in the construction supply chain collaborate more effectively and improve overall supply chain performance.

[10] Explores how individual decision-makers' characteristics impact logistics decision-making in supply chains using game theory assumptions and statistical analysis. The authors conducted an experiment in which participants played a supply chain game, and their decision-making processes were analyzed based on their characteristics, including risktaking propensity, decision scope, and cognitive reflection. The study concludes that decision-makers' characteristics can significantly influence the outcomes of their decisions, and that assigning an appropriate decision scope can help rationalize these decisions. The research provides insights into how individual decision-making impacts supply chain performance and highlights the importance of considering behavioral factors in supply chain management.

[11] Presents a static model of cooperative advertising in a supply chain, involving one manufacturer and one retailer. The authors correct a drawback in previous literature by showing that the sales-volume functions become negative for some values of the decision variables, as well as for the resulting Nash and Stackelberg equilibrium points. The model is analyzed under three advertising-coordination scenarios, including a leader-follower noncooperative game, a Nash game, and a Pareto-efficient points scenario. The analysis shows that the manufacturer may share the retailer's localadvertising costs in the leader-follower game, depending on the rates of cooperation and marginal profit. In the Nash game, each

party's advertising investment depends on their own marginal profit and negatively on that of their counterpart, while the same observation applies only to the manufacturer in the Stackelberg game.

Game theory-based contract design:

Contracts are a key tool for coordinating supply chain activities, and game theory can help firms to design contracts that align incentives and improve performance. For example, firms can use game theory to analyze the impact of different contract types, such as revenue-sharing or quantity discounts, and to identify the optimal contract terms that maximize their profits. Assume a manufacturer wishes to enter into a contract with a supplier for the supply of raw materials. In that case, they can use game theory to create a contract that aligns the supplier's incentives with their own goals. They can assess the impact of various contract types, such as revenue-sharing or quantity discounts, and determine the optimal terms that will maximize their profits while also providing the appropriate incentives to the supplier.

This research examined the coordination issues of a sustainable supply chain while simultaneously considering greening and corporate social responsibility (CSR) initiatives by supply chain agents. The paper analyzes the centrally controlled supply chain setting using five different contract types using a two-stage Stackelberg game-theoretic approach in which the supplier acts as the leader. The results of the analysis show that different contract types influence the optimal greening level, CSR level, retail price, and profits of supply chain agents. The study concludes that greening and social efforts are helpful for the entire supply chain as long as consumer awareness of greening and CSR exists. The paper points out the significance of channel coordinating mechanisms between supplier and buyer to improve greening and CSR levels and broadens understanding of supply chain coordination in the context of sustainability [5].

A recent research paper examined the coordination issues of a sustainable supply chain, taking into account both greening and corporate social responsibility (CSR) initiatives. Using a two-stage Stackelberg game-theoretic approach in which the supplier acts as the leader, the study analyzed five different contract types and found that they influenced the optimal greening level, CSR level, retail price, and profits of supply chain agents. The study concluded that greening and social efforts are helpful for the entire supply chain as long as consumer awareness of greening and CSR exists, and emphasized the importance of channel coordinating mechanisms between supplier and buyer to improve greening and CSR levels.

A real-time application of game theory-based contract design in supply chain management could involve an ecommerce platform that connects buyers and sellers. The platform can use game theory to design contracts that align the incentives of the buyers and sellers and improve the efficiency of the supply chain. For instance, the platform could offer different types of contracts, such as revenue-sharing or quantity discounts, and analyze the impact of these contracts on the behavior of the buyers and sellers. The platform could also use game theory to determine the optimal contract terms that maximize the profits of both parties while promoting sustainability and corporate social responsibility initiatives.

Another example could be a logistics company that uses game theory-based contract design to incentivize its suppliers to provide high-quality raw materials at a reasonable cost. The company could design a contract that aligns the incentives of the suppliers with its own goals, such as minimizing transportation costs and reducing the risk of disruptions in the supply chain. The company could also use game theory to analyze the impact of various contract types, such as penalty clauses or performance-based incentives, and determine the optimal terms that will maximize its profits while ensuring the quality and reliability of the raw materials.

2.6 Evolutionary game theory:

This approach investigates how strategies evolve over time as firms learn from one another's actions. By observing the behavior of other firms in the same market, evolutionary game theory can assist firms in identifying optimal strategies.

For example, if a company notices that a competitor is employing a profitable strategy, it may choose to use a similar strategy in order to remain competitive. Over time, the firm population may converge on a set of dominant strategies that are stable and effective for all players. Evolutionary game theory can also be used to model the effects of external factors on the evolution of supply chain strategies, such as changes in market conditions or government regulations. This approach can provide valuable insights into how firms can adapt their strategies to changing circumstances while maintaining a long-term competitive advantage.

Overall, the state of the art for game theory in supply chain management is defined by a diverse set of research topics and applications, with new models and techniques being developed and refined on a regular basis. As a result, there are numerous opportunities for future research in this area, especially as businesses continue to face complex challenges in managing global supply chains.

The state of the art for game theory in supply chain management encompasses a broad range of research topics and applications. Ongoing research aims to refine existing models and techniques and develop new ones, creating numerous opportunities for future research. With businesses facing increasingly complex challenges in managing global supply chains, game theory offers a valuable tool for improving coordination, efficiency, and profitability.

The real-time application of evolutionary game theory in supply chain management is in the study of supplier selection. When a buyer is looking for a new supplier, they may use evolutionary game theory to evaluate the strategies of potential suppliers based on their past behavior and performance. By analyzing the suppliers' history and observing how they have adapted to changes in market conditions or regulations, the buyer can make a more informed decision about which supplier to select.

In this scenario, the buyer can view the suppliers as players in a game, where each supplier has its own set of strategies and actions. By modeling the supplier selection process as an evolutionary game, the buyer can identify the most successful strategies and choose a supplier based on their ability to adapt and thrive in the market. This approach can lead to more efficient and effective supplier selection, ultimately improving the buyer's supply chain performance.

[12] Paper provides a comprehensive review of the literature on the application of evolutionary game theory in supply chain management. The authors discuss the basic concepts of evolutionary game theory and how it has been applied in the context of supply chain management. They also identify the major research themes and methodologies used in the existing literature, as well as the limitations and future research directions for this field.

The authors review various research topics, including supplier selection, pricing, coordination, and sustainability. They highlight the importance of incorporating behavioral factors and social norms into the analysis, as well as the need for a more realistic representation of supply chain dynamics. The paper also discusses the potential for using big data and machine learning techniques to enhance the accuracy and validity of the models.

The authors conclude that evolutionary game theory has significant potential to contribute to the development of effective supply chain strategies. However, they note that the research in this field is still in its infancy, and there is much work to be done to overcome the limitations and challenges of using this approach in practice. They suggest several future research directions, including the integration of multiple game-theoretic models, the development of new optimization algorithms, and the validation of the models through empirical studies.

Overall, this paper provides a useful overview of the current state of research on evolutionary game theory in supply chain management and identifies several promising avenues for future research.

3 Implementation

3.1 Shapley Value: its Algorithms and Application to Supply Chains

Because of free trade, companies around the world have to compete with bigger and stronger organizations, which makes it hard for smaller companies to survive. To overcome this, many companies are forming groups or alliances to work together and become more competitive. However, working together can bring new challenges, like figuring out how to coordinate and share profits fairly.

One way to do this is through cooperative game theory, where all players work together to achieve a common goal without affecting their own benefits. To figure out how to fairly distribute profits among the players, researchers use a concept called the Shapley Value. This value helps to attribute the economic output of a team to individual members.

The Shapley Value has been studied a lot and many researchers have developed methods to boost cooperation within alliances. This paper focuses on how to calculate the Shapley Value in supply chain management, and reviews different methods for doing so. The paper also includes a numerical example and proposes a new algorithm for calculating the Shapley Value.

The Shapley Value is a precise method for calculating each player's contribution, but it has a high computational complexity because it requires calculating all possible coalitions, which can be up to 2^n - 1 for n players. Therefore, several research papers that propose modifications and improvements to the Shapley Value algorithm to reduce its computational complexity and improve its accuracy.The Shapley value is a method to calculate how much each player contributes to a group in a precise way. However, some experts have pointed out that it can be difficult to calculate because you have to consider all possible groups that can be formed, which can be a lot of calculations, especially for larger groups of players. For example, for a group of n players, the number of possible coalitions is 2n-1.

$$\emptyset_i(v) = \sum_{S \in N: i \in S} \frac{(S - 1)!(n - S)!}{n!} (S) - v(S - \{i\})$$

Researchers proposed new algorithms or modified existing algorithms to improve the Shapley value calculation method

[13] Fatima et al.developed a new algorithm that uses randomization to calculate the Shapley value in a computationally efficient way. [14] Hong & Yanhong improved the Shapley value algorithm by ensuring that the benefits of participants are not reduced, maintaining the stability of the alliance, and reaching the whole optimum.

[15] Kim proposed an online wireless network routing algorithm based on a cooperative game model, which maintains energy efficiency, responds to network conditions, and achieves load balancing. Chao-hui [16] developed a revenue allocation strategy based on the Shapley method principle, considering a risk coefficient and investment to improve the effects of the profit's allocation, ensuring the persistence of the alliance and stability in the supply chain cooperation.

[17] Cui et al. presented a palliative algorithm to improve the Shapley value in concurrent delay claim, which allots time delay responsibility to each single responsible activity by Shapley Value. [18] Xu et al. raised a modification of the classical Shapley algorithm to find equal benefits under generated alliances, mainly in RFID technology.

[19] Muros et al. presented an alternative way to consider constraints on the Shapley value by using a computationally efficient one-step design algorithm. Castro et al. [20] proposed a refinement of the polynomial method based on sampling theory to estimate the Shapley value for cooperative games, reducing the variance in situations where the marginal contributions of each player vary greatly.

TABLE 2. BASIC DATA OF COMPANIES IN THE COALITION.

Companies	Net Profit inU$	% tolerable price reduction	Expected Profit in U$
PC1	25000	0,03	10000
PC2	15000	0,1	5000
PC3	20000	0,2	8000
PC4	14000	0,05	5000
PC5	22000	0,1	7000
PC6	24000	0,1	9000

3.2 Proposed Algorithm Applicable to Supply Chains

This algorithm to calculate the Shapley Value, which improves efficiency by reducing the complexity of forming all possible coalitions in the game. In supply chains, the structure of these chains is known beforehand, and a set of feasible coalitions is obtained, significantly reducing the number of coalitions.

A case study that applies this general characterization to the furniture business supply chain was developed by Ramirez-Rios et al. The algorithm's output can provide valuable insights into the relative contributions of each player in the coalition

Shapley value.py > players

```python
from itertools import combinations
from math import factorial

# Define the data for the players
player_data = {
    "PC1": {"profit": 25000, "tolerable_reduction": 0.03, "expected_profit": 10000},
    "PC2": {"profit": 15000, "tolerable_reduction": 0.1, "expected_profit": 5000},
    "PC3": {"profit": 20000, "tolerable_reduction": 0.2, "expected_profit": 8000},
    "PC4": {"profit": 14000, "tolerable_reduction": 0.05, "expected_profit": 5000},
    "PC5": {"profit": 22000, "tolerable_reduction": 0.1, "expected_profit": 7000},
    "PC6": {"profit": 24000, "tolerable_reduction": 0.1, "expected_profit": 9000},
}

# Define a function to calculate the value of a coalition
def coalition_value(coalition):
    total_profit = sum(player_data[player]["profit"] for player in coalition)
    if len(coalition) > 0:
        total_tolerable_reduction = min(player_data[player]["tolerable_reduction"] for player in coalition)
    else:
        total_tolerable_reduction = 0
    total_expected_profit = sum(player_data[player]["expected_profit"] for player in coalition)
    return total_profit - total_tolerable_reduction * total_profit + total_expected_profit

# Define a function to calculate the Shapley value
def shapley_value(players):
    n = len(players)
    shapley_values = {player: 0 for player in players}

    # Define the number of players
    print(f"Number of players: {n}")

    # Define the set of possible coalitions
    coalitions = [set(), *[set(comb) for i in range(1, n+1) for comb in combinations(players, i)]]
    print(f"Possible coalitions: {coalitions}")

    # Determine the value of each coalition
    coalition_values = {tuple(c): coalition_value(c) for c in coalitions}
    print(f"Coalition values: {coalition_values}")

    for coalition_size in range(1, n+1):
        for coalition in combinations(players, coalition_size):
            for player in coalition:
                coalition_value_diff = coalition_value(coalition) - coalition_value(set(coalition) - {player})
                shapley_values[player] += coalition_value_diff * factorial(len(coalition) - 1) * factorial(n - len(coalition)) / factorial(n)

    # Print the Shapley values for each player
    print("Shapley values:")
    for player, value in shapley_values.items():
        print(f"{player}: {value}")


players = list(player_data.keys())
shapley_value(players)
```

We demonstrate the proposed algorithm's functionality. The scenario is a hypothetical case provided in a field survey conducted on a group of furniture industry businesses in Barranquilla, Colombia. The survey asked the businesses how much they were willing to reduce their product prices to gain access to new high-volume markets. To test the scenario, the proposed algorithm, was used, which is a game theory-based approach that calculates the Shapley value of each player in the game.

The businesses were classified into three echelons: suppliers, producers, and marketers. The scenario assumed intraechelon cooperation, where actors within the same echelon collaborate with each other. Six companies participated in the simulation.

Table 2 provides important information on the six companies in the simulated scenario, including their current profit, expected profit, and acceptable price reduction. This data is essential to determine the potential benefits for each company under different coalition scenarios. For instance, PC1 can form a coalition with PC2 and together they can achieve a higher game value. The coalition's game value depends on the total expected profit and price reduction that the two companies can offer.

3.3 Results:

All Possible coalitions

```
Possible coalitions: [set(), {'PC1'}, {'PC2'}, {'PC3'}, {'PC4'}, {'PC5'}, {'PC6'}, {'PC1', 'PC2'}, {'PC3', 'PC1'}, {'PC1', 'PC4'}, {'PC1', 'PC5'}
, {'PC6', 'PC1'}, {'PC3', 'PC2'}, {'PC4', 'PC2'}, {'PC2', 'PC5'}, {'PC6', 'PC2'}, {'PC3', 'PC4'}, {'PC3', 'PC5'}, {'PC3', 'PC6'}, {'PC4', 'PC5'},
 {'PC6', 'PC4'}, {'PC6', 'PC5'}, {'PC3', 'PC1', 'PC2'}, {'PC1', 'PC2', 'PC4'}, {'PC1', 'PC2', 'PC5'}, {'PC6', 'PC1', 'PC2'}, {'PC3', 'PC1', 'PC4'
}, {'PC3', 'PC1', 'PC5'}, {'PC3', 'PC6', 'PC1'}, {'PC1', 'PC5', 'PC4'}, {'PC6', 'PC1', 'PC4'}, {'PC6', 'PC1', 'PC5'}, {'PC3', 'PC4', 'PC2'}, {'PC
3', 'PC2', 'PC5'}, {'PC3', 'PC6', 'PC2'}, {'PC4', 'PC2', 'PC5'}, {'PC6', 'PC4', 'PC2'}, {'PC6', 'PC2', 'PC5'}, {'PC3', 'PC4', 'PC5'}, {'PC3', 'PC
6', 'PC4'}, {'PC3', 'PC6', 'PC5'}, {'PC6', 'PC4', 'PC5'}, {'PC3', 'PC1', 'PC2', 'PC4'}, {'PC3', 'PC1', 'PC2', 'PC5'}, {'PC3', 'PC6', 'PC1', 'PC2'
}, {'PC1', 'PC2', 'PC4', 'PC5'}, {'PC6', 'PC1', 'PC2', 'PC4'}, {'PC6', 'PC1', 'PC2', 'PC5'}, {'PC3', 'PC1', 'PC5', 'PC4'}, {'PC3', 'PC6', 'PC1',
'PC4'}, {'PC3', 'PC6', 'PC1', 'PC5'}, {'PC6', 'PC1', 'PC5', 'PC4'}, {'PC3', 'PC4', 'PC2', 'PC5'}, {'PC3', 'PC6', 'PC4', 'PC2'}, {'PC3', 'PC6', 'P
C2', 'PC5'}, {'PC6', 'PC4', 'PC2', 'PC5'}, {'PC3', 'PC6', 'PC4', 'PC5'}, {'PC3', 'PC1', 'PC2', 'PC4', 'PC5'}, {'PC3', 'PC1', 'PC2', 'PC4', 'PC6'}
, {'PC3', 'PC1', 'PC2', 'PC5', 'PC6'}, {'PC1', 'PC2', 'PC4', 'PC5', 'PC6'}, {'PC3', 'PC1', 'PC4', 'PC5', 'PC6'}, {'PC3', 'PC2', 'PC4', 'PC5', 'PC
6'}, {'PC3', 'PC1', 'PC2', 'PC4', 'PC5', 'PC6'}]
```

Value of Each possible coalition

GAME CHARACTERISTIC FUNCTION RESULTS (n_1, v)					
COALITION	**GAME VALUE**	**COALITION**	**GAME VALUE**	**COALITION**	**GAME VALUE**
v({P1})	25000	v({P1,P2,P3})	81200	v({P1,P2,P3,P5})	109540
v({P2})	15000	v({P1,P2,P4})	72380	v({P1,P2,P3,P6})	113480
v({P3})	20000	v({P1,P2,P5})	82140	v({P1,P2,P4,P5})	100720
v({P4})	14000	v({P1,P2,P6})	86080	v({P1,P2,P4,P6})	104660
v({P5})	22000	v({P1,P3,P4})	80230	v({P1,P2,P5,P6})	114420
v({P6})	24000	v({P1,P3,P5})	89990	v({P1,P3,P4,P5})	108570
v({P1,P2})	53800	v({P1,P3,P6})	93930	v({P1,P3,P4,P6})	112510
v({P1,P3})	61650	v({P1,P4,P5})	81170	v({P1,P3,P5,P6})	122270
v({P1,P4})	52830	v({P1,P4,P6})	85110	v({P1,P4,P5,P6})	113450
v({P1,P5})	62590	v({P1,P5,P6})	94870	v({P2,P3,P4,P5})	92450
v({P1,P6})	66530	v({P2,P3,P4})	64550	v({P2,P3,P4,P6})	96350
v({P2,P3})	44500	v({P2,P3,P5})	71300	v({P2,P3,P5,P6})	101900
v({P2,P4})	37550	v({P2,P3,P6})	75100	v({P2,P4,P5,P6})	97250
v({P2,P5})	45300	v({P2,P4,P5})	65450	v({P3,P4,P5,P6})	105000
v({P2,P6})	49100	v({P2,P4,P6})	69350	v({P1,P2,P3,P4,P5})	128120
v({P3,P4})	45300	v({P2,P5,P6})	75900	v({P1,P2,P3,P4,P6})	132060
v({P3,P5})	52800	v({P3,P4,P5})	73200	v({P1,P2,P3,P5,P6})	141820
v({P3,P6})	56600	v({P3,P4,P6})	77100	v({P1,P2,P4,P5,P6})	133000
v({P4,P5})	46200	v({P3,P5,P6})	83400	v({P1,P3,P4,P5,P6})	140850
v({P4,P6})	50100	v({P4,P5,P6})	78000	v({P2,P3,P4,P5,P6})	124250
v({P5,P6})	57400	v({P1,P2,P3,P4})	99780	v({P1,P2,P3,P4,P5,P6})	160400

```
Coalition values: {(): 0, ('PC1',): 34250.0, ('PC2',): 18500.0, ('PC3',): 24000.0, ('PC4',): 18300.0, ('PC5',): 26800.0, ('PC6',): 30600.0, ('PC1
', 'PC2'): 53800.0, ('PC3', 'PC1'): 61650.0, ('PC1', 'PC4'): 52830.0, ('PC1', 'PC5'): 62590.0, ('PC6', 'PC1'): 66530.0, ('PC3', 'PC2'): 44500.0,
PC3', 'PC6', 'PC4', 'PC2'): 96350.0, ('PC3', 'PC6', 'PC2', 'PC5'): 101900.0, ('PC6', 'PC4', 'PC2', 'PC5'): 97250.0, ('PC3', 'PC6', 'PC4', 'PC5'):
 105000.0, ('PC3', 'PC1', 'PC2', 'PC4', 'PC5'): 128120.0, ('PC3', 'PC1', 'PC2', 'PC4', 'PC6'): 132060.0, ('PC3', 'PC1', 'PC2', 'PC5', 'PC6'): 141
820.0, ('PC1', 'PC2', 'PC4', 'PC5', 'PC6'): 133000.0, ('PC3', 'PC1', 'PC4', 'PC5', 'PC6'): 140850.0, ('PC3', 'PC2', 'PC4', 'PC5', 'PC6'): 124250.
0, ('PC3', 'PC1', 'PC2', 'PC4', 'PC5', 'PC6'): 160400.0}
```

The game characteristic function of the scenario was calculated. Each coalition, or group of companies, was evaluated based on their tolerable price reduction and their current net profit. For example, the coalition between companies CP1 and CP2 was evaluated by determining the lesser tolerable price reduction for the sum of their present profits US 25000 for CP1 and US 15000 for CP2, which in this case was 3%. This value was then added to the expected additional profit for both companies, resulting in a game value of US 53800. Similar calculations were made for each coalition, regardless of the number of companies involved.

```
Shapley values:
PC1: 35941.666666666664
PC2: 19216.66666666667
PC3: 26533.333333333325
PC4: 19181.666666666668
PC5: 27820.00000000001
PC6: 31706.666666666664
```

Contribution coalitions formed by j palyers							
Player i in each coalition	1	2	3	4	5	6	ji(v)
1	$25.000,00	$202.400,00	$362.250,00	$366.050,00	$182.900,00	$ 36.150,00	**$ 35.173,33**
2	$15.000,00	$125.250,00	$191.450,00	$193.550,00	$ 97.450,00	$ 19.550,00	**$ 19.598,33**
3	$20.000,00	$160.850,00	$268.600,00	$271.400,00	$136.600,00	$ 27.400,00	**$ 26.815,00**
4	$14.000,00	$125.980,00	$196.270,00	$196.830,00	$ 96.670,00	$ 18.580,00	**$ 9.403,33**
5	$22.000,00	$166.290,00	$277.460,00	$280.540,00	$141.260,00	$ 28.340,00	**$ 27.941,67**
6	$24.000,00	$183.730,00	$316.320,00	$319.680,00	$160.920,00	$ 32.280,00	**$ 31.468,33**
P(j)	0,166666667	0,033333333	0,016666667	0,016666667	0,033333333	0,016666667	$ 160.400

In above table each player contributes to different coalitions of varying sizes. The rows represent players and the columns represent coalition sizes. The value in each cell is calculated by adding up the game values of all coalitions in which the player is included, subtracting the game values of other players, and obtaining the total contribution of that player to that coalition size.

The row labeled P(j) shows the probability of forming coalitions of a particular size. To obtain the value of the game for each player, we multiply their row with P(j) row. This gives the expected value of all the possibilities, which can help in deciding how to split the benefits of coalitions between its members, based on the proportion of participation of each player in the total value.

The final value obtained is the value of the great coalition, which is the expected value of all possible coalitions. While this value represents all possibilities, it is still useful for making decisions about dividing the benefits of coalitions among the players.

3.4 Critiques of a Paper on Coalition Formation and Decision-Making

Assumptions: The paper may rely on assumptions that are unrealistic or do not accurately reflect the real-world context. For instance, the paper may assume that all players have equal bargaining power, when in reality, this may not be the case. Such assumptions can weaken the validity of the findings and reduce their applicability to real-world situations.

Data and methodology: The data used in the paper may be incomplete or inaccurate, or the methodology used to analyze the data may be flawed. For example, the paper may use a model that is too simplistic to capture the complexities of coalition formation and decision-making. These issues can lead to unreliable or misleading results.

Generalizability: The paper's findings may not be generalizable to other contexts or populations. For instance, the paper may focus on a specific industry or region and fail to consider how the results would apply to other industries or regions. This can limit the usefulness and relevance of the findings.

Lack of innovation: The paper may fail to make a significant contribution to the existing literature on coalitions and their values. The paper may simply replicate existing findings or fail to offer any new insights or perspectives. This can make the paper less interesting and impactful to readers.

Lack of clarity: The paper may be poorly written or unclear, making it difficult for readers to understand the methods, results, and conclusions. The paper may also fail to define key terms or provide sufficient background information for readers who are not familiar with the topic. This can hinder the dissemination of the paper's findings and reduce its impact.

3.5 CONCLUSIONS

Cooperative game theory can provide tools for managers and governments to make decisions in this regard. The Shapley value, a concept from cooperative game theory, is discussed as a way of calculating the benefits of cooperation in supply chains. The use of efficient algorithms can help reduce the effort required. The trend towards cooperation and sharing economies has forced companies to make changes in their business models and organizational structures, and it is important for them to preserve their know-how while also sharing information with their supply chain actors

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