
# Designing a Collaboration Model Among Supply Chain Members to Reduce External Supply Risk in the Oil and Petrochemical Industry Using Game Theory

Parisa Agha Babaeipour[1], Mahmoud Mohammadi[2]*, Mohammad Ali Afshar Kazemi[1]

[1] Department of Industrial Management, Central Tehran Branch, Islamic Azad University, Tehran, Iran.
[2] Department of Industrial Management, Central Tehran Branch, Islamic Azad University, Tehran, Iran (Corresponding Author).

*** Corresponding author email address**: mahmoodmohammadi525@yahoo.com

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**Abstract**

The goal of supply chain management is to improve various activities of the components and levels of a supply chain to enhance the overall condition of the supply chain system. During this process, numerous conflicts and contradictions may arise between the objectives of different components and levels in achieving the overall goals of the supply chain. These disruptions and inconsistencies may gradually lead to a decline in the supply chain's strength and competitiveness. Conflicts may include issues related to pricing, inventory costs, and marketing disagreements. Given its characteristics, game theory is an appropriate tool to create collaboration within supply chains. In recent years, supply chain management has gained significant importance due to the globalization of business markets. A supply chain is a collection of facilities, suppliers, customers, products, and methods of inventory, supply, and distribution control. Supply chain management is the process of effectively planning, implementing, and controlling supply chain operations and is an effective method for maintaining a competitive advantage and improving organizational performance. The shorter product life cycle, the emergence of new technologies, and the expansion of supplier relationships and product development push the supply chain toward increased complexity. With rising complexity, the level of uncertainty and risk within the supply chain also increases. Supply chain risk is a potential event that disrupts the natural flow of materials and information in the chain, leading to disturbances. This article addresses the topic of designing a collaboration model among supply chain members to reduce external supply risk in the oil and petrochemical industry using game theory. Initially, by analyzing relevant data and outputs, the technical efficiency of domestic supplier companies was obtained using Data Envelopment Analysis (DEA) under the assumptions of constant and variable returns to scale. A statistical sample of 15 experts, with both academic and practical knowledge in financial management and experience in stock market operations, was selected for this purpose. Subsequently, game theory was utilized to design a collaboration model among supply chain members aimed at reducing external supply risk in the oil and petrochemical industry. The analysis focuses on selecting the best cooperative coalition and presenting a collaboration model based on the Shapley value. The findings indicate that this cooperative game model provides a structured approach for forming alliances among supply chain partners based on their contributions. By following the specified steps, companies can maximize their profits while enhancing supply chain collaboration.

***Keywords:*** *Collaboration model, supply chain, external supply risk, oil and petrochemical industry, game theory*.

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## 1. Introduction

The objective of supply chain management is to improve various activities of the components and levels of a supply chain to enhance the overall state of the supply chain system. During this process, numerous conflicts and contradictions may emerge between the goals of different components and levels in achieving the overall objectives of the supply chain. These disruptions and inconsistencies can, over time, lead to a reduction in the strength and competitiveness of the supply chain. Conflicts may include issues related to pricing, inventory costs, and marketing disagreements. Given its characteristics, game theory is an appropriate tool for creating collaboration within supply chains [1]. Nix, Zachary, and Lach argue that management collaboration involves interdependencies aimed at maximizing common objectives and enhancing secondary goals. "Collaboration" in supply chains is recognized as a cooperative strategy where one or more companies or business units create mutual benefits. This strategy has shifted from the traditional paradigm of bargaining based on the lowest possible price to increase profit to a new paradigm that focuses on cohesive solutions centered on a shared product for end customers [2].

In collaboration, a collective agreement is formed among business partners, based on which they share information and cooperate mutually to achieve a set of shared and collective goals. Collaboration is an appropriate approach when supply chain partners face opportunities or issues that are difficult or complex to resolve individually and when there is a need for joint decision-making, open information sharing, free flow of creative ideas, and rich communication through face-to-face meetings. Accordingly, inter-organizational collaboration can be viewed as a series of shared actions through which organizations work together to solve issues that fall within the inter-organizational domain and cannot be addressed or exploited individually. Collaboration becomes particularly beneficial when business partners face a highly complex and interdependent issue or opportunity. Highly complex issues are those that are difficult to solve and require significant effort. Interdependent opportunities or issues are those where effective resolution or exploitation depends on other companies, meaning that there is a need for the knowledge or skills of other companies [3].

"The numerous benefits of implementing collaboration include economies of scale, access to specific resources, cost and risk-sharing, learning, and flexibility. Nix and his colleagues found in their research that companies with high levels of collaborative capabilities experienced a 40% improvement in work performance and a 55% improvement in the quality of their relationships. Generally, the level of collaboration in the supply chain among partners is influenced by various factors. Organizational strategy involves decisions that indicate which industries and businesses are targeted by the company, what position the company holds in the value system, and how overall company resources are allocated to different businesses. Various classifications of strategy exist, with one of the most well-known being Miles and Snow's typology, which categorizes organizations based on differences in their strategies into four groups: defenders, analyzers, explorers, and reactors. Defenders remain within their current domain and maintain a steady market share. For these companies, product development is limited to improving existing products. These organizations tend to ignore developments outside their domain. The supply chain structure for organizations with a defensive strategy requires a high level of formality, centralization, cost efficiency, standardization, and a lower level of innovation, risk, flexibility, and delivery operations. These objectives are achieved through a mechanistic supply chain management structure [4].

Organizations, as systems, consist of interdependent subsystems interacting as a cohesive whole. From a holistic perspective, supply chain companies can be viewed as subsystems that interact and collaborate to maintain the integrity of the network. By considering the supply chain as a system, business partners need to collaborate on tasks and use shared input resources such as skilled human capital through joint hiring systems, shared information, and common raw materials. This perspective provides a comprehensive view of the supply chain as an integrated and cohesive unit. Companies within a supply chain operate in a shared field and collaborate in the production of common products [5].

The outputs of the supply chain can include products, services, knowledge and information, and shared quantitative and qualitative standards, as well as specialized human resources. The strategy that organizations pursue in the supply chain impacts the level of collaboration among partners. Strategy determines the direction of an organization, and therefore, alignment of strategies within the supply chain influences the orientation of the network. A demand-driven strategy increases the focus on customers and the need for collaboration throughout the chain. Technology has recently become a significant factor impacting relationships within the supply chain. The infrastructure that supply chain organizations have can influence communication methods and, consequently, the level of collaboration and participation among members. The advent of the internet has expanded online communication, enhancing IT's role in supporting not only data systems but also group conversations. The development of such technologies has facilitated the formation of online communities, thereby promoting inter-organizational collaboration. Additionally, collaboration on securing input resources, such as information, raw materials, and human resources, further necessitates cooperation. Aligning supply chain efforts to secure necessary inputs results in collective actions, thereby enhancing collaboration [6].

In recent years, supply chain risk and uncertainty have become a significant focus of research among scholars. Supply chain risk is defined as a potential event that disrupts the natural flow of materials and information, causing chain disturbances [7, 8]. For instance, the bankruptcy of a supplier not only impacts the subsequent link but also affects the entire chain. Supply chain risk is generally described as "events or uncertain conditions that, if they occur, may have positive or negative consequences for organizational objectives." Despite the significant impact of supply chain risk, it has historically received limited attention. Given the wide range of risks that exist, organizations must use appropriate strategies for managing and controlling them [9]. This emphasizes the need for risk management in supply chains.

Today, due to increasing uncertainty in product supply chains, organizations are investing more resources in demand forecasting and mitigating internal uncertainties to reduce vulnerability and enhance supply chain resilience. Addressing these uncertainties has led to the emergence of supply chain risk management as a crucial concept. The presence of risks can have a significant impact on short-term performance and negatively affect long-term financial performance. Therefore, supply chain risk management is essential for mitigating failures caused by various risks, such as economic cycles, uncertain customer demand, and unpredictable natural or human events. Effective risk management requires identifying, evaluating, and ranking risks based on criteria like impact and likelihood. The accuracy of this assessment stage determines the reliability of the overall risk management process. Ranking risks is crucial because it reveals the relative importance of each risk, enabling decision-makers to allocate resources accordingly [10].

The literature review examines various aspects of supply chain and risk management in industries like oil, gas, and petrochemicals. For example, Karimi et al. (2022) investigated strategic supply chain management's impact on orientation and performance, highlighting the mediating roles of agility and resilience [11]; and Ziegenbein and Nienhaus (2021) categorized supply chain risks and highlighted sanctions as a major political risk [5].

The article's structure is organized as follows: The second section provides a theoretical background, including relevant theories and empirical study results. The third section outlines the model, research methodology, and tests used. The fourth section presents the results and model estimation. The fifth section provides a summary and conclusion.

## 2. Methodology

In this article, effective data and outputs are analyzed, beginning with the technical efficiency assessment of domestic supplier companies using Data Envelopment Analysis (DEA) under the assumptions of constant and variable returns to scale. A statistical sample of 15 experts, familiar with financial management and stock exchange operations and with practical experience in financial management, was selected. Based on the information available in the previous articles as well as the website of the Iranian Stock Exchange, companies with a green supply chain were identified. The research sample includes Bistoon, Pack House, Metasan, Rash Polymer, Kimia Tamin Azar, Keyhan Baspar Nik Andishan, Mahak Azma, Resin Baher, Mana Sanat Tejarat, Petro Octane Isatis, Bonyan Kala Shimi, Basa Polymer, Houpad, Imen Sabz Persia, Covestro Iran, Jahan Shimi Baspar, Oxin Shimi Tous, Tavan, Ava Shimi, and Polymer Iran. The data for this research were extracted from reports provided by these companies on the stock exchange and their websites. One of the most well-known and foundational DEA models is the CCR model. As previously mentioned, the Farrell method resolved the issue related to selecting the production function but still faced challenges regarding the number of inputs and outputs. This method was only applicable in cases of two inputs and one output or one input and two outputs. In an attempt to address this issue, Charnes, Cooper, and Rhodes generalized the Farrell method to multiple inputs and outputs in 1978, leading to the development of the CCR model, named after the initials of its creators.

**Technical Efficiency Analysis**

Assessing the sources of inefficiency in a unit under evaluation is a topic worth investigating. It is important to determine whether inefficiency is due to the unit's own poor performance or is caused by the conditions in which the unit operates. Therefore, comparing the CCR and BCC efficiency scores is essential. The CCR model assumes constant returns to scale in the production possibility set, allowing for proportional expansion and contraction of all units, including non-negative combinations. Consequently, the CCR score is referred to as overall technical efficiency. In contrast, the BCC model assumes a convex combination of units as the production possibility set, and the BCC score is termed pure technical efficiency. If a unit is efficient under the BCC model but has a lower efficiency score under the CCR model, the unit is considered locally efficient but not globally efficient due to its scale. Hence, it is logical to determine a unit's scale efficiency using the ratio of these two scores.

**Scale Efficiency Calculation**

Scale efficiency (SE) of a unit is obtained by the ratio of efficiency under optimal scale. The objective is to produce at the optimal scale. Scale efficiency represents the extent to which an organization can achieve optimal scale by adjusting its size. In fact, the size or scale of a company's operations can impact efficiency in two ways: First, if a company's size can enhance its market influence, it may obtain inputs at lower costs. Second, increasing the company's size can result in economies of scale, meaning the output-to-input ratio can improve with a larger company size, and vice versa.

The assumption of constant returns to scale in a model implies that organizational size is not a factor in determining relative efficiency. A small organization can achieve the same output-to-input ratio as a larger organization. By solving the CCR model, we calculate the technical efficiency of the unit under evaluation. This efficiency is divided into pure technical efficiency and scale efficiency. Pure technical efficiency is also known as managerial efficiency. Any resource wastage or suboptimal use of resources and an inappropriate structure reduces efficiency. Technical inefficiency reflects performance losses and poor management. If the calculated efficiencies differ between the CCR and BCC models, it indicates that the unit under study has scale inefficiency, which can be determined from the difference between the two calculated efficiency scores. The scale efficiency is derived from the ratio of the efficiency scores under constant returns to scale (CRS) to variable returns to scale (VRS), as shown below:

$$SE = \frac{\varphi^*_{CCR}}{\varphi^*_{BCC}}$$

**Table 1.** Average Scale Efficiency of Companies

| Average Efficiency | Company Name | Rank |
|---|---|---|
| 99% | Bistoon | 1 |
| 96% | Pack House | 2 |
| 97% | Rash Polymer | 3 |
| 100% | Metasan | 4 |
| 100% | Bonyan Kala Shimi | 5 |
| 100% | Keyhan Baspar Nik Andishan | 6 |
| 100% | Imen Sabz Persia | 7 |
| 94% | Resin Baher | 8 |
| 100% | Mana Sanat Tejarat | 9 |
| 93% | Petro Octane Isatis | 10 |
| 99% | Kimia Tamin Azar | 11 |
| 95% | Basa Polymer | 12 |
| 99% | Tavan | 13 |
| 97% | Mahak Azma | 14 |
| 98% | Covestro Iran | 15 |
| 96% | Jahan Shimi Baspar | 16 |
| 97% | Oxin Shimi Tous | 17 |
| 100% | Houpad | 18 |
| 97% | Ava Shimi | 19 |
| 96% | Polymer Iran | 20 |

Technical efficiency and pure technical efficiency are directly obtained from the CCR and BCC models, respectively. Scale efficiency is also calculable. Under the CRS assumption, the average efficiency of the companies studied is 88.45%. Geometrically, under this assumption, the production frontier is a straight line on which efficient units lie or form. Under the VRS assumption, efficiency is 90.88%, indicating that companies produce 9.12% less than the optimal output level with their current inputs. The production frontier under this assumption is concave, with each efficient unit positioned on its respective frontier point. The average scale efficiency is 97.17%, implying that the actual production scale differs by 2.83% from the most productive scale. If pure technical efficiency (PTE) exceeds scale efficiency, scale inefficiency occurs. Conversely, if the situation is reversed, the primary source of inefficiency is pure technical inefficiency or managerial (operational) inefficiency.

**Creating Cooperative Coalitions Using Game Theory**

Game theory, a branch of applied mathematics, is used in social sciences, including politics, economics, and sociology. It models decision-makers' behavior in strategic situations, where the outcome for each player depends on the strategy choices of other players, aiming to identify the best strategy for all involved. In essence, game theory provides analytical tools to understand phenomena involving mutual influence and explores how decisions are made in interactive settings. A game comprises a set of rules, arrangements, and mechanisms known to all players, outlining their choices and the consequences of each decision. The goal of game theory is to provide a method for rational decision-making and preference-based choices to maximize individual benefits.

**Game Elements are as follows:**

**Players:** Each decision-maker in the game is considered a player who makes decisions in the strategic game environment based on rational behavior. The player seeks to achieve the best possible outcome by considering the actions of other competitors and aims to maximize their own benefits. Games are categorized by the number of players into two-player, three-player, and n-player games.

**Strategies:** This term refers to an action or set of actions that a player chooses based on the available information. In a strategic environment, individuals are influenced by the mutual interaction between their own decisions and those of others. Games are divided into two types based on the number of strategies: games with a finite strategy set (such as a coin toss or chess with a fixed number of moves) and games with an infinite strategy set (such as Cournot models with two firms that can choose from an infinite range of production levels).

**Payoff:** The amount of utility, profit, or benefit that a player receives from selecting a particular strategy in the game is referred to as the payoff. The total payoff for all players at the end of the game constitutes the overall payoff. Based on the nature of the payoffs, games can be divided into zero-sum games (win-lose) and non-zero-sum games (win-win).

**Equilibrium:** Equilibrium is a situation where players select strategies based on their preferences and predictions and in response to the behavior of other players, with no incentive to change their chosen strategy. In equilibrium, each player's strategy represents the best response to the strategies selected by other players. It is important to note that in equilibrium, not all players necessarily achieve the highest possible outcome, and conditions may not be optimal for everyone.

**Cooperative Game Theory:**

Unlike non-cooperative games, where players act rationally, focus solely on their own interests, and do not cooperate or reach agreements, in cooperative games, players can collaborate and work together. In other words, players have the opportunity to agree on certain strategies to achieve greater benefits. This agreement may include all or only some of the participants and is referred to as a coalition. Participation in these coalitions is voluntary, with no coercion, and players must receive at least as much benefit from cooperation as they would from acting alone. The primary goal of these games is to provide a method for the fair division of the benefits derived from cooperation. Cooperative games are usually analyzed statically, and players’ utility functions can be deterministic or expected.

**Shapley Value in Cooperative Games:**

One of the proposed solutions for finding a unique rational allocation is the use of the Shapley value. This method assigns values to players based on their role and impact in generating coalition outcomes, using axiomatic principles. These values, which are real numbers, can be represented by a value function vector:

In this equation, Q denotes the value of a player in the cooperative game.

**Efficiency, Group Rationality:**

$$\Sigma \varphi_í(V) = V(N) \ (i \varepsilon N)$$

$$V(SU\{i\}) = V(SU\{j\}) = Q(v) = Q\ (v)$$

If a player contributes nothing to the coalition, meaning their presence or absence makes no difference to the coalition, they should not receive any share from it.

V (SU{i}) = V(S) - Qi(v)=0
Q (U +V) >= Q (V) + Q (U)

If a function satisfies these conditions, the value allocated to player i is determined using this relationship. In this method, a specific amount of profit is assigned to each player proportional to their economic impact across different coalitions. In other words, this method calculates the average marginal contribution, obtained by averaging over all n! permutations.

**Marginal Contribution:** This represents the increase in utility that a coalition experiences when an external player joins. The mathematical expression for this method is:

$$\varphi_k(C) = \sum_{k \epsilon S, S \subseteq E*} \frac{(p-1)!\,(q-p)!}{q!} \left[ C(s) - C\left(\frac{S}{\{k\}}\right) \right]$$

- P: Number of members in S
- q: Total number of efficient units in subset E*
- C(S): Payoff from forming coalition S
- C(S\{K}): Payoff from coalition S without unit K

It should be noted that S cannot be equivalent to E when there are no inefficient units in N.

## 3. Findings

Among the companies examined, six—Houpad, Mana Sanat Tejarat, Imen Sabz Persia, Keyhan Baspar Nik Andishan, Bonyan Kala Shimi, and Metasan—demonstrated positive efficiency and were identified as top suppliers in the oil and petrochemical supply chain in Iran. Subsequently, game theory was used to create collaboration among these top suppliers and develop a cooperative game model, which identified and compared the cooperative game strategies based on market share and industry metrics.

To calculate the Shapley value for each company in the supply chain using the provided formula, the revenue generated from various coalitions must first be determined, after which the formula can be applied. The following is a step-by-step process to accomplish this:

Step 1: First, identify the pairwise coalitions based on the cooperative game model for analysis. The pairwise games are presented in Table 2.

**Table 2.** Pairwise Cooperative Games of Suppliers

| No. | Collaboration |
|---|---|
| 1 | Houpad - Mana Sanat Tejarat |
| 2 | Houpad - Imen Sabz Persia |
| 3 | Houpad - Keyhan Baspar Nik Andishan |
| 4 | Houpad - Bonyan Kala Shimi |
| 5 | Houpad - Metasan |
| 6 | Mana Sanat Tejarat - Imen Sabz Persia |
| 7 | Mana Sanat Tejarat - Keyhan Baspar Nik Andishan |
| 8 | Mana Sanat Tejarat - Bonyan Kala Shimi |
| 9 | Mana Sanat Tejarat - Metasan |
| 10 | Imen Sabz Persia - Keyhan Baspar Nik Andishan |
| 11 | Imen Sabz Persia - Bonyan Kala Shimi |
| 12 | Imen Sabz Persia - Metasan |
| 13 | Keyhan Baspar Nik Andishan - Bonyan Kala Shimi |
| 14 | Keyhan Baspar Nik Andishan - Metasan |
| 15 | Bonyan Kala Shimi - Metasan |

Next, the additional revenue generated by each company's presence in each coalition is calculated, as shown in Table 3.

**Table 3.** Revenue from Pairwise Cooperative Games

| No. | Pairwise Collaboration | Final Contribution (C) (in billion rials) |
|---|---|---|
| 1 | Houpad - Mana Sanat Tejarat | 90 |
| 2 | Houpad - Imen Sabz Persia | 110 |
| 3 | Houpad - Keyhan Baspar Nik Andishan | 70 |
| 4 | Houpad - Bonyan Kala Shimi | 120 |
| 5 | Houpad - Metasan | 110 |
| 6 | Mana Sanat Tejarat - Imen Sabz Persia | 110 |
| 7 | Mana Sanat Tejarat - Keyhan Baspar Nik Andishan | 60 |
| 8 | Mana Sanat Tejarat - Bonyan Kala Shimi | 120 |
| 9 | Mana Sanat Tejarat - Metasan | 100 |
| 10 | Imen Sabz Persia - Keyhan Baspar Nik Andishan | 90 |
| 11 | Imen Sabz Persia - Bonyan Kala Shimi | 100 |
| 12 | Imen Sabz Persia - Metasan | 130 |
| 13 | Keyhan Baspar Nik Andishan - Bonyan Kala Shimi | 100 |
| 14 | Keyhan Baspar Nik Andishan - Metasan | 80 |
| 15 | Bonyan Kala Shimi - Metasan | 140 |

Based on the calculated values $C$, the Shapley value for each company can be determined. Using the Shapley value formula, the contribution of each supplier was computed and presented in Table 4.

**Table 4.** Shapley Value for Each Supplier

| No. | Company | Shapley Value |
|---|---|---|
| 1 | Houpad | 31.667 |
| 2 | Mana Sanat Tejarat | 30.644 |
| 3 | Imen Sabz Persia | 40.833 |
| 4 | Keyhan Baspar Nik Andishan | 25.001 |
| 5 | Bonyan Kala Shimi | 41.66 |
| 6 | Metasan | 41.886 |

These Shapley values indicate the extent to which each company contributes to the overall revenue in the supply chain while considering collaboration among participants. As expected, due to the symmetrical nature of the input data, the values are relatively close. However, some differences arise from varying collaboration benefits when combining different pairwise games and company groups.

Choosing the Best Pairwise Coalition and Developing a Cooperative Model for the Supply Chain Based on Shapley Value

After calculating the approximate values for each supply chain partner, the rankings are as follows:

- Imen Sabz Persia: 40.833
- Metasan and Bonyan Kala Shimi: both around 41
- Houpad and Mana: both around 30

Based on these Shapley values, the best cooperation in the supply chain involves partnering with the top contributors first to maximize mutual benefits. Starting with Bonyan Kala Shimi and Metasan makes sense, as they are equally significant and substantially higher than the others in the initial stages of collaboration. Subsequently, incorporating Imen Sabz Persia, Houpad, or Mana appears logical given their similar contribution levels.

To construct the final cooperative game model, the benefits of each coalition are calculated:

- Coalition 1: Metasan + Bonyan Kala Shimi (41 + 41 = 82)
- Coalition 2: Imen Sabz Persia + Metasan + Bonyan Kala Shimi (40.833 + 41 + 41 = 122.833)
- Coalition 3: Houpad + Mana (30 + 30 = 60)
- Coalition 4: Imen Sabz Persia + Houpad + Mana (40.833 + 30 + 30 = 100.833)

Step 4: Visual Representation

We can visualize this cooperative game using a model where the nodes represent the companies and the edges represent potential coalitions.

1. Cooperative Game Model

- Initial Collaboration: The first step should be a coalition between Metasan and Bonyan Kala Shimi, as they have equal contributions and can maximize their combined output.

- Subsequent Collaboration: Once the initial coalition is established, the logical next step is to include Imen Sabz Persia to maximize overall revenue. This coalition significantly increases total value.
- Final Coalition: Once the initial coalition is stable, integrate Houpad and Mana as a secondary coalition to further enhance supply chain efficiency.

Step 6: Collaboration Model

- Phase 1: Form a coalition between Metasan and Bonyan Kala Shimi.
- Phase 2: Integrate Imen Sabz Persia into the coalition.
- Phase 3: Form a secondary coalition with Houpad and Mana.

Step 7: Considerations and Trade-offs

- Benefits of Collaboration: Each coalition should be evaluated based on Shapley values and potential revenue increases.
- Risks: Consider risks such as dependency on partners and potential conflicts of interest.
- Flexibility: The model should allow for adjustments based on changing market conditions or partner performance.

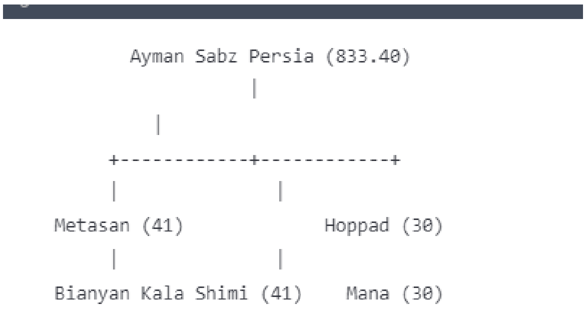


**Figure 1.** Cooperative Game Model

## 4. Discussion and Conclusion

Identifying uncertainties, particularly their sources, leads to understanding effective strategies for redesigning the supply chain. According to previous studies, supply chain risk management comprises four main stages: risk source assessment, risk concept identification, trigger tracking, and risk mitigation. Since the core of risk management involves activities related to identifying, analyzing, and responding to risks, the first stage of risk management is recognizing the factors that influence risk. This recognition aids in understanding uncertainties that may impact the supply chain in the future. Risk identification is a key activity upon which the other stages of the supply chain risk management process are built. It involves listing risks that could potentially affect the supply chain. Given the impracticality of listing all possible risks, the identification phase focuses on the most significant risks based on their impact on the supply chain. In summary, the goal of risk identification is to create a list of the most critical supply chain risks [1, 4, 10, 11].

Identifying risks in the supply chain is not simple due to the complexity and interdependence between internal and external networks. A company should be able to formally identify any risk that could arise from any activity or interaction within the supply chain using tools and techniques. This includes all members of the internal supply chain network, such as suppliers, manufacturers, distributors, retailers, end consumers, and logistics providers, as well as the external environment of the supply chain. Supply chain risks are interconnected and should not be identified as isolated events. Since efforts to reduce one risk event can lead to either reducing or increasing other risk events, understanding the interrelationships between potential supply chain risks allows for balancing different strategies [12-14].

Therefore, achieving a comprehensive understanding of supply chain risks and their relationships is essential for developing a more effective and integrated risk reduction strategy. However, this has often been overlooked in prior research, with only a few studies providing limited attention to this issue. Organizations cannot rely on personal information and informal procedures for risk identification but require formal procedures. The risk identification process involves collecting inputs, such as product details, operations, business environment, financial suppliers, and any other elements needed to fully describe the supply chain, using tools for these inputs, and producing outputs, such as lists of risks, risk sources, indicators, triggers, and documented consequences. A range of formal tools has been developed for risk identification. Some of these tools are general and can be used to identify any type of risk, such as historical data analysis, brainstorming, cause-and-effect analysis, fault trees, process mapping, probability-impact matrices, and scenario planning. Others are specific to the supply chain, such as supply chain audit mapping, critical path identification, supplier-relative importance, and customer-relative importance.

Some tools are based on analyzing past events (e.g., five whys, cause-and-effect diagrams, Pareto analysis, checklists), others on idea generation (e.g., interviews, group meetings, Delphi method), and some directly on operational analysis (e.g., process diagrams, process control). The second stage of supply chain risk management is risk analysis, which involves evaluating and assessing risks. Analyzing supply chain risks is crucial to reduce the likelihood of their impact and prevent occurrences.

A review of various literature indicates that both qualitative and quantitative approaches are used for risk analysis and assessment in the supply chain, and sometimes a combination of the two approaches is employed. These projects largely reflect the rational allocation of risk among public and private participants. Private financial suppliers and lenders generally consider the risks associated with project completion and performance, while the government accounts for significant risks in almost all projects under its jurisdiction, such as operational performance, currency conversion, fuel costs, inflation, and political events.

During project development, the main risk is the project's potential rejection by the government or financial suppliers. Reasons for rejection could include business weaknesses or failure to obtain permits, agreements, and certifications. During the construction phase, the primary risk is the project not being completed at an acceptable performance level or within the scheduled timeframe and budget. This risk mainly falls on the project implementing company and its stakeholders, who, in turn, mitigate these risks through insurance policies and contractor bonds.

Post-construction, the concern is that the project may not operate continuously within acceptable economic and technical parameters. Although there are many operational risks, they are generally not very large. These risks include technical failures, inadequate fuel access, market demand, and pricing, government fiscal policies (such as taxes and subsidies), currency exchange rates, and environmental issues [11]. The project implementing company bears these risks.

Krista et al. explored risk allocation rules in project finance, noting that finance involves a risk-sharing commitment, and conflicts arise if risks are allocated improperly. Effective risk allocation positively impacts project performance by reducing costs, shortening contract execution duration, improving project quality, and fostering active working relationships. However, optimal risk allocation is challenging in practice [15]. Kripa et al., analyzing investment in Iran's oil and gas industry from a legal and commercial perspective, reviewed foreign investment opportunities in Iran's oil and energy sectors. They conducted an in-depth analysis of Iran's oil and gas reserves and the legal restrictions that may affect foreign investment, such as constitutional provisions and insurance and tax system weaknesses.

Their comprehensive analysis of buy-back contracts in Iran's oil industry revealed legal barriers to foreign investment and issues stemming from Iran's weak insurance and tax systems. The researchers also analyzed production-sharing contracts, yielding significant insights for foreign oil companies and the host government. They found that a major risk for foreign oil companies is reservoir non-commerciality. If a contract never reaches the production stage, the foreign company cannot recover its costs. However, if production is achieved and reserves are commercial, the foreign company seeks to recover its costs as quickly as possible per the contract terms. The host government's concern is whether the foreign company will use the best practices in both exploration and production to maximize total output or prioritize short-term cost recovery at the expense of sustainable extraction. Government oversight or participation in the production process can partially alleviate this concern. Another mutual concern is oil price fluctuations, which may render production in many oil fields uneconomical. Other risks include changes in production costs over time and infrastructure and transportation system weaknesses, which pose threats only to the foreign company and not to the host government [1, 5, 16].

This cooperative game model provides a structured approach for forming alliances among supply chain partners based on their contributions. By following the outlined steps, companies can maximize their profits while enhancing collaboration within the supply chain.

## Authors' Contributions

Authors equally contributed to this article.

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## Declaration of Interest

The authors report no conflict of interest.

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## Ethical Considerations

All procedures performed in this study were under the ethical standards.

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