Intelligent Mediator for Supply Chain Coordination: Overcoming Information Asymmetry

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Abstract: This work addresses the critical challenge of coordinating complex supply chain networks, where aligning the interests of diverse stakeholders is essential for achieving shared goals. The complexity of supply chain coordination increases when different parties have varying levels of information, leading to unequal bargaining power and bilateral information asymmetry. To address this issue, an intelligent intermediator leveraging modern technologies is introduced to enhance effective supply chain coordination, aiming to overcome information asymmetry and reduce misreporting behavior. Key operational levers susceptible to informational asymmetry are identified, and an innovative approach that provides customized plans and recommendations tailored to the specific needs of individual actors is proposed. This strategy addresses the core issue of trust deficits, often influenced by both strategic and operational motivations. By implementing a dynamic framework, localized perspectives are integrated into a broader context, thus promoting global optimization. This not only enhances trust among supply chain participants but also positively impacts overall supply chain performance.

Keywords: Supply Chain; bilateral; asymmetric information; mediator; Intelligent

1.Introduction

In today's dynamic manufacturing landscape, characterized by an increasing variability of demand and tight response times, supply chains face unprecedented challenges. To meet these challenges in an increasingly competitive and dynamic environment, it is crucial to understand that supply chains are not merely linear sequences of processes. They are complex networks where every activity and component is closely connected, mutually influencing the overall performance (Dallasega, Rauch and Linder, 2018) (Converso et al. 2015). However, these interdependencies also heighten overall risks, jeopardizing the achievement of common objectives (Christopher and Holweg, 2011). In the context of supply chain management, the advent of Industry 4.0 plays a pivotal role by radically transforming how processes are monitored and managed. This new era has introduced real-time monitoring and online control, enabling instant feedback based on critical parameters, thus ensuring optimal performance across the system. By centralizing and analyzing data from every phase of the supply chain, Industry 4.0 transforms information into valuable resources. The use of cutting-edge technologies such as Digital Twins and Cyber-Physical Systems enables accurate and dynamic simulation of each phase of the process, allowing for the anticipation and resolution of potential issues before they occur. Thanks to these advancements in monitoring and control, companies can optimize not only their own production but also every stage of the supply chain, resulting in greater operational efficiency, improved risk management, and enhanced adaptability to changing market demands (Marchesano et al., 2022 ; Improta et al., 2014; Morra et al., 2019)

While Industry 4.0 has revolutionized supply chain management through enhanced real-time monitoring and control, these advancements alone cannot ensure widespread efficiency across the entire supply chain. The transformation brought about by Industry 4.0 requires not only technological integration but also strategic and tactical coordination among all members of the supply chain. This need becomes increasingly critical as the volume of information that different stakeholders must share grows.

Indeed, the competitive environment often impedes collaborative efforts, resulting in optimizations that are confined to localized levels. Such fragmentation undermines the achievement of global efficiency, highlighting the necessity for robust supply chain coordination. This area of research is dedicated to finding optimal solutions that encompass the entire system, thus addressing the key challenges posed by information asymmetry. Information asymmetry occurs when one party in a transaction possesses more or superior information than the other, leading to an imbalance of power and potentially unfair advantages. Within supply chains, this asymmetry can confer competitive advantages to the actor with greater bargaining power, facilitating the development of diverse commercial and negotiation strategies. However, against the backdrop of an increasingly uncertain market and rising capacity costs, even coordinated inventory management across various actors can significantly reduce costs and enhance the overall performance of the supply chain (Vosooghidizaji, Taghipour and Canel-depitre, 2019). As a result, effective coordination not only boosts bargaining power but also supports the development of varied commercial and negotiation strategies, which are crucial in an uncertain market environment. The exchange of information among various stakeholders is fundamental for supply chain coordination. However, a frequent misalignment between the individual goals of these stakeholders and those of the overall supply chain often undermines the honest exchange of information and fosters the emergence of misreporting. This is a behavior where actors within the supply chain may deliberately choose to report partial or incorrect data concerning their sensitive information. Recent literature has increasingly focused on analyzing this phenomenon of information asymmetry, the ways it manifests within supply chains, and the attempts to mitigate its effects through various coordination mechanisms (Vosooghidizaji, Taghipour and Canel-depitre, 2019). These mechanisms, ranging from monetary compensations to shared costs and pricing incentives, aim to encourage actors to disclose accurate information and thus align as closely as possible with the outcomes of complete collaboration (Shen, 2016). The primary challenge in identifying effective coordination mechanisms in supply chains with information asymmetry involves addressing the misreporting behaviors of individual actors, which significantly hamper negotiations. As result, the introduction of a governance element or mediator, tasked with optimizing the performance of the supply chain while safeguarding the objectives of each participant, may serve as a trust-building approach to mitigate misreporting behaviors (Salatiello et al., 2023). Some authors propose innovative governance structures or mediators that can reduce information manipulation, thus promoting trust among supply chain actors and facilitating better coordination (Zissis, 2022a). However, these entities often act more like external coordinators, not directly involved in overcoming misreporting behaviors in information exchange and not aligned with the dynamism required by current supply chains. For this reason, this work proposes an intelligent intermediator whose goal is to overcome information asymmetry by minimizing misreporting behaviors and enhancing coordination across the entire supply chain. Serving as a conduit between various actors, the Intelligent Mediator facilitates the rapid transmission and validation of information. Its ability to analyze and interpret data in real time boosts responsiveness to unforeseen events and strengthens the resilience of the supply chain against emerging challenges

Furthermore, while most studies focus on the strategic and cost management aspects of supply chains, this work aims to model the interactions between actors by exploring multiple factors involved in operational planning. It identifies key decision-making levers, analyzes how information asymmetry can manifest at this planning level, and assesses its impact on both local and global optimization processes.

2. Theoretical background

To establish a theoretical framework for understanding coordination mechanisms in decentralized supply chains, it is essential to address the distinctions between scenarios characterized by perfect informational symmetry and those marred by asymmetry. In symmetric scenarios, all operational parameters are fixed and known in advance to all participants, fostering a transparent and predictable environment. In contrast, asymmetrical environments feature estimable parameters that are susceptible to misreporting by individual actors, complicating the coordination and operational efficiency of the supply chain.

Research in this area has been robust, with significant contributions aimed at addressing the challenges posed by information asymmetry. (Qin and Shao, 2019) introduced a mathematical model to mitigate misreporting behaviors, while (Fu and Zhu, 2019) proposed a blockchain-based approach to diminish the subjectivity in information reporting, thus enhancing reliability. Moreover, the mediator model suggested by (Zissis, Ioannou and Burnetas, 2020) offers a strategy to improve supply chain outcomes by assessing reports from individual actors and proposing optimized alternatives.

However, these models often face challenges related to the verifiability of information. As highlighted by (Huang, Ho and Kao, 2022a), while the reliability and availability of information are critical, these aspects have been predominantly explored from a technological perspective, often neglecting the actors' motivation to share truthful and complete data. This oversight underscores the persistent trust issues that can undermine collaborative efforts within the supply chain.

In most literature, studies tend to focus on a dyadic type of supply chain model involving vendor and buyer relationships. This framework simplifies the complex interactions typically seen in broader supply networks, thereby providing a clearer understanding of the direct exchange dynamics between two parties. In practical applications, particularly in these vendor-buyer models, the dual roles of actors—as vendors downstream and buyers upstream—provide a crucial framework for analyzing the strategic interactions that influence supply chain dynamics. This approach helps to dissect how decisions at one level affect operations at another, offering insights into the interconnected nature of supply chains. Studies focusing on this model typically aim to optimize variables such as order quantities and production cycles to maximize cost efficiency and profitability for all parties involved (Sucky, 2005; Chan and Kingsman, 2007; Esmaeili and Zeephongsekul, 2010; Mobini, van den Heuvel and Wagelmans, 2019) . These interactions highlight the complex interplay between individual profit maximization and the broader operational goals of the supply chain.

Thus, this theoretical backdrop sets the stage for understanding how coordination mechanisms can be designed and implemented to address the inherent challenges of information asymmetry in supply chains. It also prepares the reader for a deeper exploration of specific mechanisms and strategies that can facilitate more effective collaboration and negotiation among disparate actors, ultimately leading to a more cohesive and efficient supply chain network.

3. The Intelligent Mediator

The primary aim of this work lies in the definition of an intelligent mediator aimed at overcoming informational asymmetry by mitigating misreporting behaviour. The mediator, depicted in Figure 1, is characterized by four main elements.

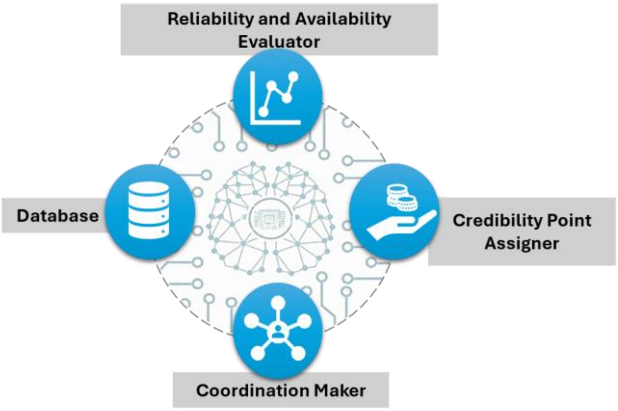

Figure 1: The Intelligent Mediator

- Database:

The Database (DB) constitutes a foundational element within the supply chain ecosystem, serving as a centralized repository for aggregating and organizing diverse inputs from various stakeholders. It functions as a comprehensive data node, housing critical information essential for orchestrating effective coordination across the supply chain network. Notably, access to and manipulation of this repository are exclusively granted to the Intelligent Mediator. By confining access privileges solely to the Intelligent Mediator, the database ensures stringent control over sensitive data, mitigating the risks associated with unauthorized access or tampering. This controlled access mechanism aligns with contemporary data privacy and security standards, safeguarding the confidentiality and integrity of the information contained within the database (Zissis, 2022b).

- Reliability and Availability Evaluator:

The Reliability and Availability Evaluator (RAE) plays a pivotal role in discerning and rectifying misreporting phenomena within the supply chain. A central function of the RAE is the evaluation of data reliability (R) and availability (A) metrics, as delineated in extant literature (Huang, Ho and Kao, 2022b). Reliability (R) refers to the condition in which shared information may be distorted during the information-sharing process. R is a value between 0 and 1, with 1 indicating a perfectly reliable transmission of information. Availability (A) indicates if the information is fully transmitted, rated from 0 to 1, with 1 meaning complete transmission. The application of these metrics empowers the RAE to proactively identify instances of data distortion or omission, thereby fortifying the foundations of trust and transparency essential for seamless supply chain coordination.

- Credibility Points Assignment:

The Credibility Points Assigner (CPA) stands as a fundamental component within the intelligent mediator. Its primary functionality revolves around the allocation of credibility scores and the dynamic adaptation of credibility plans, leveraging the reliability and availability metrics provided by the REA.

These scores serve as quantitative representations of the perceived trust and reliability of each actor in sharing their information. By leveraging insights gleaned from the REA metrics over time, the CPA assigns credibility scores to each actor according to a monotonically increasing function.

$$CP = F(R)$$

This function must be adaptable, allowing for customization in how the credibility score responds to updated reliability values over time according to specific system requirements. Furthermore, another distinctive feature of the CPA is its dynamic nature, wherein credibility plans are continually updated and refined in response to evolving circumstances and feedback. This dynamism not only enhances the accuracy of credibility assessments but also instils a sense of adaptability and resilience within the trust framework. Credibility points represent, to some extent, the weights with which the information of individual actors is considered by the intelligent mediator. The objective of individual actors, leveraging their natural tendency for local optimization, is thus to increase their weight, achievable by sharing increasingly reliable information.

- Coordination Maker

The Coordination Maker assumes a pivotal role within the Intelligent Mediator framework. Serving as the primary decision-making entity, the Coordination Maker orchestrates contributions from both the database and the credibility points assigned to each actor, aiming to devise synchronized strategies to optimize the effectiveness of the supply chain. The CM, as defined, leverages existing mechanisms applied in literature but innovatively developed. Consequently, the CM is capable of dynamically responding to the supply chain's needs. This can be achieved through the utilization of cutting-edge Industry 4.0 technologies, such as Artificial Intelligence (AI) and Machine Learning (ML), to enhance the decision-making capability and operational resilience of the system.

4. Vendor-Buyer Operational Formulation

The supply chain analyzed consists of a single vendor and a single buyer exchanging a specific product. This system is examined to understand how market demand D influences the vendor's production organization, pricing dynamics between the two actors, and how these are related to the vendor's operational specifics in a context of information asymmetry.

The main hypotheses are as follows:

- The market demand D, as perceived by the buyer, is a function of the selling price P and marketing expenses M, according to the law $D = kP^{-\alpha}M^{\beta}$. Market demand is private information of the buyer, through α and β, which are not known to the vendor (specifically, the vendor does not know β, and after estimating it, can obtain an estimate of α through the value of the ratio $L = {}^{\alpha}/_{\beta}$. L is a constant that depends on several factors, including the product lifecycle, whether the product is perishable or not, and is known to both actors.

- The production cost C_s and the setup cost A_s are private information exclusively of the vendor, not known to the buyer.

- The vendor's daily production rate, r, is calculated based on the ability to complete production batches within a defined time, while the daily demand rate d is expressed as the ratio ${}^{(D + Q_{wip})}/_{N}$, where N represents the number of working days in a week, and Q_{wip} represents the vendor's order portfolio at the time of negotiation. The importance of Q_{wip} emerges from the fact that the vendor may be involved simultaneously in multiple supply chains, each involving various actors, including different buyers, located at different levels of the supply chain.

- It is assumed that the two rates, d and r, are linearly correlated by the following relationship: $\rho = d/r$such that $\rho < 1$, where ρ represents the vendor's productive saturation coefficient.

- The lead time (LT), i.e., the waiting time the buyer must sustain from the order to the delivery of the batch, it depend by the vendor's current order portfolio, Q_{wip}, and its demand rate d. This lead time can be expressed by the following relation:

$$LT = \tau \left(\frac{D + Q_{wip}}{d}\right)$$

where τ represents a safety factor introduced to mitigate variability and provide a more reliable estimate of the average lead time.

In response to the market demand D that occurs weekly, the vendor organizes its daily production according to the demand rate d. To meet the weekly demand, the vendor produces the batch Q^* that optimizes its profit. If the lead time LT required by the buyer is less than the LT proposed by the vendor, according to the expression of LT. Assuming that an order with greater urgency, i.e., requiring a reduction of the LT, entails an increase in d (more orders to be completed in less time). This leads to an increase in ρ as ρ approaches 1, there is a greater likelihood of system saturation, and this translates into an increase in costs that the vendor imposes on the buyer., According to the following relationship:

$$V = V_0 + V_{LT} \quad \text{with} \quad V_{LT} = \frac{f}{LT+1}$$

where:

- V_0, is the price obtained corresponding to the vendor's profit annulment, $\Pi_V(V_0,\ Q) = 0$

- f, is the coefficient expressing the relationship between the price V and the lead time LT (the lower the waiting time required, the higher the price to be paid)

- LT, waiting time, i.e., lead time expected by the buyer from the order to the delivery of the batch.

This pricing model reflects the intrinsic uncertainty in estimating delivery time and ensures that the supplier's pricing strategy is aligned with prevailing market conditions and operational constraints. The tighter the delivery time required by the buyer, the higher the price proposed by the supplier. At this stage, the supplier does not have visibility into market demand but only into orders coming from the buyer.

From all these definitions, the equations for the average weekly profit of both the vendor (Π_V) and the buyer (Π_B) are subsequently expressed.

$$\Pi_V(V,Q) = VD - C_S D - A_s \frac{D}{Q} - \frac{1}{2} i C_S Q \frac{d}{r}$$

$$\Pi_B(P,M) = PD - VD - MD - A_B \frac{D}{Q} - \frac{1}{2} i V Q$$

Where, A_B is the buyer's ordering cost (\$/order) and *i* is the percentage of holding cost per unit per week.

As result, the profit of the entire supply chain under analysis is expressed as: $\Pi_{tot} = \Pi_V + \Pi_B$.

These levers are commonly susceptible to misreporting, as vendors often tend to propose higher mark-up prices V to buyers. This tendency is primarily driven by the buyer's lack of awareness regarding the vendor's orders portfolio Q_{wip}. Conversely, any increment in the mark-up price V adversely affects the buyer's profit Π_B, to some extent mirroring the vendor's operational capabilities. This situation underscores the complex interplay between the actors and the pricing dynamics within supply chains, highlighting the critical need to consider a variety of factors when evaluating supply chain performance.

4.1 Intelligent Mediator Theoretical Implication

The mediator is responsible for evaluating the integrity of information sharing put forth by both parties and assessing the reliability and availability of information shared by actors through the REA. This evaluation involves assigning credibility points to individual actors via the CPA and devising a coordination mechanism aimed at optimizing the coordination of the chain, following the flow outlined in Figure 2.

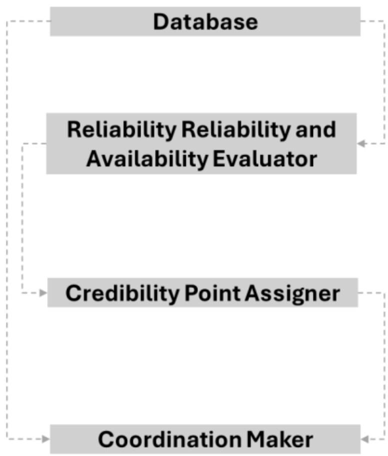

Figure 2: The flow of the Intelligent Mediator

Once the actors exchange their information, as previously discussed, the reliability and availability of the shared information are evaluated for each actor, according to (Huang, Ho and Kao, 2022c) within the REA. The defined values of *R* e *A* are then used to assess the credibility score of the actors through the CPA. A possible example of a monotonically increasing function lies in the logistic function, where, considering the generic actor *i*, the credibility point at time *t* is defined as:

$$CP_{i_t} = \frac{1}{1 + e^{-k(R-R_0)} + CP_{i_{(t-1)}}}$$

The CPs thus defined represent a score ranging from 0 to 1, where *R* represents the reliability, also varying between 0 and 1. The coefficient *k* determines the slope of the logistic function, representing the rate at which CP changes with *R*. R_0 is the inflexion point of the logistic function: when $R > R_0$, the credibility score CP tends to 1; when $R < R_0$, it tends to 0.

Once the credibility points (CPs) of the vendor and the buyer are calculated, the CM uses these values to weigh the information from each actor and evaluate the optimal Q^* to be assigned for defining V, P, M and Lead Time (LT) to maximize the overall profit of the supply chain.

Defined Q^* as the optimal quantity to be inserted into the total profit equation, this will be obtained through a linear combination of the units optimizing the production of the vendor Q_v and the units requested by the buyer D, with normalized credibility points as follows:

$$Q^* = \frac{CP_V}{CP_V + CP_B} * Q_V += \frac{CP_B}{CP_V + CP_B} * D$$

This equation essentially calculates the optimal quantity Q^* by weighting the individual quantities Q_V and D based on their respective credibility points CP_V and CP_B. The weights are determined by dividing each actor's credibility points by the sum of all actors' credibility points involved. This ensures that each actor's contribution to the optimal quantity is proportional to their perceived credibility within the supply chain.

In the case of perfect information symmetry, the optimal batch size obtained is the one that, when substituted into the total profit equation, yields the best possible profit $\Pi_{tot}{}^*$. On the other hand, in the case of information asymmetry, let Π_{tot} represent the profit achievable in the absence of any coordination mechanisms. It has been demonstrated in the literature that the application of a coordination mechanism allows obtaining a $\Pi_{tot} > \Pi_{tot}{}'$ but still a $\Pi_{tot}{}' < \Pi_{tot}{}^*$, as depicted in Figure 3. The intelligent mediator, with its four logical elements, leverages coordination mechanisms while directly addressing misreporting behaviour, promoting the process whereby, as R approach 1, the Q^* released by the CM tends to converge towards Q^* achievable in the case of information symmetry, thus fostering the optimization of the global supply chain.

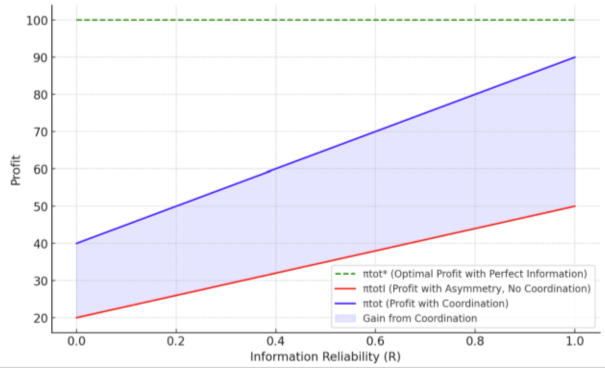

Figure 3: Profit Variation Relative to Information Reliability

The shaded area between the $\Pi_{tot}{}'$ and Π_{tot} lines represents the gain from coordination as information reliability increases. This visual representation clearly demonstrates the benefits of coordination mechanisms in improving profits under conditions of varying information reliability, highlighting the effectiveness of such mechanisms in approaching the optimal profit scenario.

In summary, once the reliability of the information shared by the actors is assessed through the CPA, the supply chain optimization process relies on determining the optimal quantity Q^*. This value is calculated by weighing the individual quantities of suppliers and buyers based on their respective credibility points, ensuring a proportional contribution to their perceived reliability within the chain. In conclusion, this approach aims to maximize the efficiency and effectiveness of the overall supply chain, promoting optimized resource and process management.

5. Conclusion

This study marks an advancement in the realm of effective supply chain coordination within Industry 4.0, addressing crucial gaps associated with misreporting behavior and the prevailing focus on strategic rather than tactical aspects of supply chains. By integrating reliability and availability metrics, and sophisticated coordination mechanisms approach, the proposed framework addresses the challenges modern supply chains face, particularly in handling information asymmetry.

A key contribution of this research is the introduction of an intelligent mediator, which innovatively incorporates operational levers into the profit equations of vendor-buyer supply chains. This operational formulation allows for both short-term and long-term definitions of how the intelligent mediator can affect supply chains and the actors involved, considering their primary operational levers.

However, the study is not without its limitations. One of the main challenges is the difficulty in obtaining practical data for validating the framework, which could impact the robustness of the proposed solutions. Future developments should include an extensive campaign of experiments to validate the proposed model and further research on different methods for analyzing and assessing reliability compared to known or innovative methods using artificial intelligence or machine learning. Additionally, the effects of the intelligent mediator on a more extended supply chain warrant further exploration.

By addressing these aspects, the research moves forward in understanding and improving supply chain coordination through a comprehensive and innovative approach that spans both theoretical and practical dimensions.

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