A Model-Based Approach to the Definition of Collaborative Processes in Supply Chain Environments

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Abstract: Global supply chains involve multiple actors and complex interactions, often spanning multiple organizations and geographic regions. However, issues such as limited process automation, coordination gaps, and concerns about data security and integrity continue to hinder collaboration in these networks. This paper addresses these challenges by presenting a metamodel to support secure and seamless collaboration in the diamond jewelry supply chain in Spain. Based on business process management standards, the metamodel improves traceability, coordination, and automation across organizational boundaries. The metamodel includes mechanisms for hash-based certification, certificate of origin, and shared traceability rules that facilitate the exchange of transparent information while maintaining data integrity. A case study focused on diamond certification from Lesotho to Spain demonstrates the feasibility and benefits of this approach. The results show improvements in process efficiency, fraud reduction, and stakeholder trust, especially in high-value and highly regulated supply chains.

1 INTRODUCTION

Global supply chains are complex, fragmented ecosystems that involve diverse actors across geographic and organizational boundaries. The growing demands of international trade have exposed significant challenges in the management of these networks, including limited integration, coordination gaps, lack of cross-organizational automation, and the reluctance to share sensitive information (Garcia-Garcia et al., 2020; Shen, 2007).

These issues are especially critical in collaborative supply chain (CSC) environments, where coordination and information exchange are vital (Han and Fang, 2024). Although business process management (BPM) has matured within organizations, its application in inter-organizational contexts remains scarce, constrained by the absence of frameworks and tools to support collaboration (Szelkagowski and Berniak-Woźny, 2024).

Concerns over data privacy and manipulation further hinder the adoption of BPM in supply chains, limiting the realization of its full potential benefits—such as transparency, efficiency, and accountability—in collaborative scenarios (Akinsola and Akinde, 2024).

In response to the identified limitations in current supply chain systems, this study proposes a metamodel designed to facilitate secure and integrated collaboration among stakeholders in the diamond jewelry supply chain in Spain. The metamodel is developed with the goal of improving process traceability, coordination, and automation by using established BPM standards. By leveraging this integrated supply chain, all stakeholders within the supply chain and logistics network can benefit from unrestricted information sharing facilitated by secure data exchange mechanisms that eliminate data tampering concerns. This enhanced transparency contributes to improved production efficiency, faster customer service, greater process synchronization, cost reduction, higher product quality, and a significant decrease in fraudulent activities (Esan et al., 2024; Kalla et al., 2025). These capabilities are particularly critical in high-value, high-regulation sectors, such as the diamond industry, where authenticity and origin issues pose significant challenges (Dasaklis et al., 2019). For

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example, a diamond claimed to have been manufactured in Lesotho (South Africa) may, in reality, originate from a less expensive source, undermining both consumer trust and market transparency. Therefore, ensuring product integrity requires the ability to trace the journey of a diamond from the mine to the end customer.

To address this issue, in addition to proposing an integrated supply chain with traceability of goods, payments, and all processes, we proposed a Certificate of Origin [1] capable of verifying the provenance of diamonds extracted from mines and transported to Spain. This approach is reinforced by the growing economic importance of the diamond market, which was valued at 80 billion USD in 2017 and is projected to exceed 123 billion by 2030 (Thakker et al., 2020).

The effectiveness of the proposed metamodel is demonstrated through a case study incorporating hash-based certification, shared Objectives and Key Results (OKRs) [2]and traceability rules to ensure secure verification and transparent collaboration. The meta-model also supports auxiliary components, such as insurance integration, payment gateways, and specialized monitoring mechanisms tailored for handling high-value goods in regulated markets.

The rest of this paper is structured as follows. Section 2 reviews the most relevant literature. Section 3 details our proposed metamodel and its implementation, focusing on how it enhances supply chain modeling. Section 4 presents a case study to validate the model in the international diamond industry. Finally, Section 5 summarizes our findings and outlines future research directions.

2 RELATED WORK

Recently, blockchain and model-based approaches in BPM and supply chains have been explored. However, most studies focus on technological implementation rather than on modeling collaborative business processes.

For example, (Dasaklis et al., 2019) highlights the challenge of limited monitoring and tracking of goods, proposing a blockchain-based framework to improve transparency and auditing. Similarly, (Li et al., 2022) emphasizes the role of end-to-end visibility in enhancing supply chain resilience (SCR), showing that blockchain-supported business model designs (BMDs) significantly improve SCR and firm performance. Trust issues in data sharing are addressed in (Kamble et al., 2020), which proposes blockchain to enhance traceability, data integrity, and auditability. Additionally, (Shi et al., 2022) introduces a Blockchain-Based Service Modeling (BOSM) approach to improve quality management through business and technical domain alignment, as demonstrated in the dairy industry.

Despite these advances, current literature presents several limitations. First, insurance visibility and management are rarely integrated into supply chain models. Second, many approaches lack a unified, end-to-end view, focusing instead on isolated components. Third, the use of OKRs with measurable indicators for service provider evaluation and risk management is underexplored. Fourth, decision-making processes are often absent in existing metamodels. Fifth, while tracking is widely discussed, it is seldom implemented via a dynamic, integrated platform. Sixth, contracts are typically treated as secondary elements rather than central entities. Lastly, mechanisms ensuring goods authenticity and compatibility with blockchain technologies are largely overlooked.

These gaps underscore the need for a comprehensive metamodel that addresses these shortcomings through a more integrated and functional approach. To address these gaps, our study proposes a technology-independent metamodel for collaborative supply chains, supported by a BPMN-based modeling approach. This framework integrates traceability, risk management, contract handling, and evaluation mechanisms based on OKRs. It also supports transparency, service quality validation, and secure collaboration among stakeholders—without dependence on specific platforms or technologies.

3 PROPOSAL FOR SUPPLY CHAIN PROCESS MODELLING

This section presents the technical details of the proposed metamodel (cf. Figure 1) and its defining characteristics. As previously mentioned, the primary objective of our metamodel is to offer an integrated approach to a CSC to facilitate efficient information exchange, data sharing, and synchronization among participants. Our approach provides a realistic yet simplified metamodel that can be valuable for both industrial and academic applications.

The **Process metaclass** is the core metaclass in

[1]A Certificate of Origin or Declaration of Origin (often abbreviated to C/O, CO, or DOO) is a document widely used in international trade transactions that attests that the product listed therein has met certain criteria to be considered as originating in a particular country.

[2]Objectives and Key Results (OKRs) is a goal-setting framework used by individuals, teams, and organizations to define measurable goals and track their outcomes.

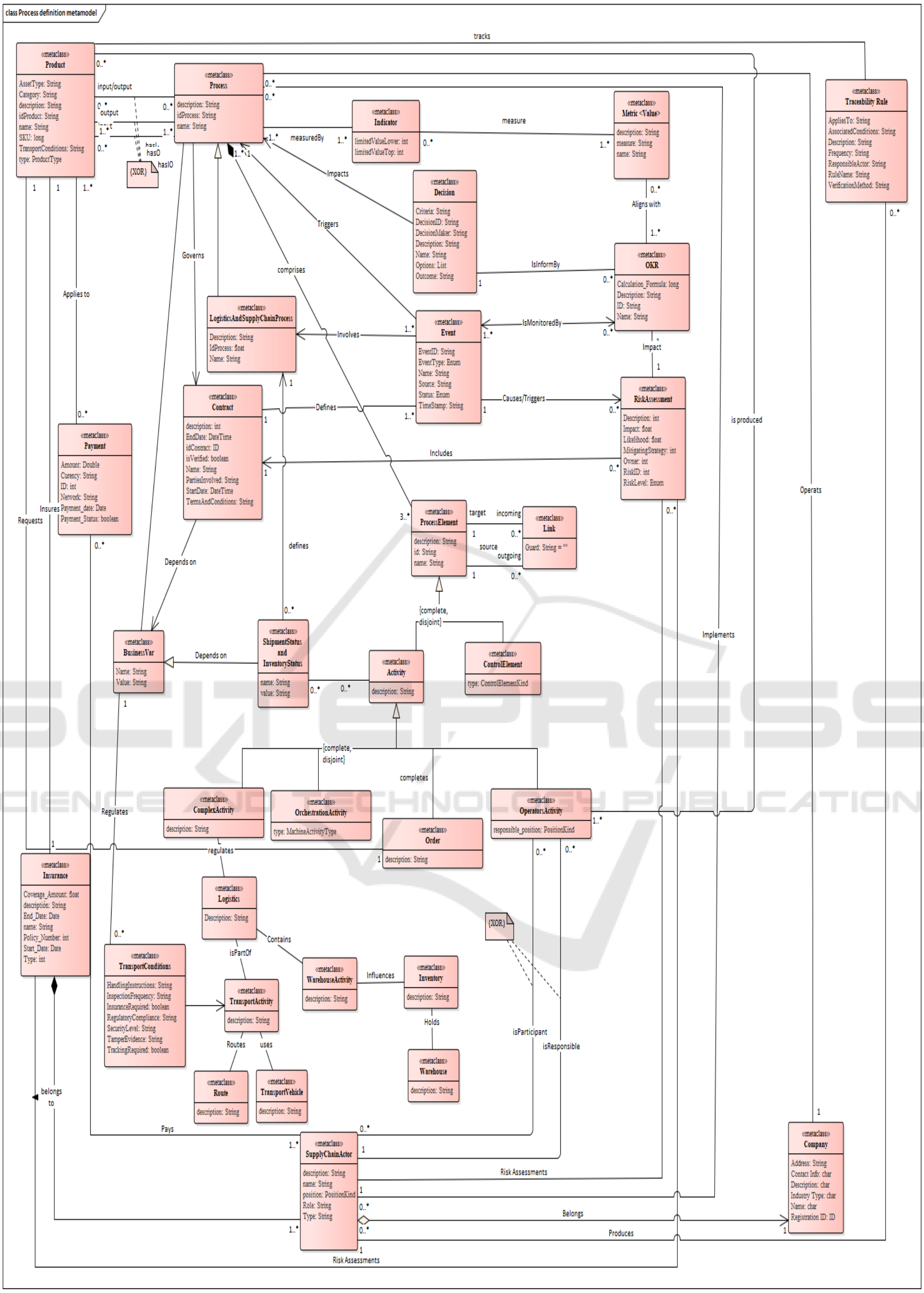

Figure 1: Integrated Collaborative Supply Chain Process Meta-Model.

our metamodel. In fact, it has been connected to some metaclasses to produce result, product, and update the measurments for the metamodel. **Contract** is the most important metaclass connected to the Process metaclass. It serves as a pivotal control layer that guarantees and verifies workflow execution defined within the Process metaclass. In supply chain contexts, actors and organizations establish formal agreements, which are represented and validated by this metaclass.

The Contract metaclass is immutable; once finalized and loaded, it prohibits any modifications, ensuring a unidirectional execution flow that preserves the integrity of contractual agreements. It acts as a ledger, managing, guiding, and enforcing all contract clauses to ensure compliance throughout the supply chain. This addresses a key challenge in reliably executing complex supply chain processes. This metaclass is influenced by the **BusinessVar and Event metaclasses**, enabling it to dynamically reflect business conditions and respond to specific triggers. As such, contracts can adapt to real-time events while maintaining enforcement of business rules.

Additionally, it is linked to the **RiskAssessment metaclass**, which provides metrics for evaluating actors and processes. These assessments are supported by historical data from OKR metaclasses, aligning risk evaluation with strategic objectives and performance metrics. This integration allows the Contract metaclass to contribute to proactive risk management and greater consistency with business goals.

Furthermore, the Contract metaclass is directly linked to both **SupplychainActor and Company metaclasses**, enabling the formalization and enforcement of agreements at the individual and organizational levels. This ensures that obligations and compliance are clearly defined and governed across the supply chain. Additionally, OKR data support the evaluation and selection of reliable partners, reinforcing trust within the network.

The **Product metaclass** represents either inputs or outputs of a Process, or both. Its role is defined by an XOR constraint among hasI, hasO, and hasIO, ensuring it assumes only one type within a process. Every Process must involve at least one Product, as enforced by cardinality rules, aligning with the core principles of process-product relationships defined in (Garcia-Garcia et al., 2020).

The **Decision metaclass** plays a strategic role by guiding the Process based on OKRs, which are linked to **Metrics and Indicators**. Indicators provide real-time data that influence process execution, whereas Metrics measure progress toward objectives. The Decision metaclass ensures that the actions taken during the process align with organizational goals, creating a feedback loop that fosters data-driven and goal-oriented execution.

The **LogisticsAndSupplyChainProcess metaclass** plays a crucial role in managing and overseeing supply chain operations, relying on ShipmentStatusAndInventoryStatus for real-time tracking of shipments and stock. The Event metaclass, which is closely linked to this process and other key metaclasses like RiskAssessment, OKR, and Contract, drives dynamic responses to triggers, enabling proactive risk management, contract enforcement, and alignment with strategic goals within the supply chain.

The **Event metaclass** plays a crucial role in collaborative business and supply chain contexts by serving as a trigger for processes, workflows, and decision-making. It is directly linked to LogisticsAndSupplyChainProcess, Process, RiskAssessment, OKR, and Contract metaclasses. Events represent both external conditions (e.g., supplier delivery delays) and internal changes (e.g., stock reaching critical levels), initiating actions such as order reception or risk detection, defining process preconditions, and influencing performance goals and contractual terms.

Also, the **BusinessVar** is another metaclass that has a direct association with the Process metaclass. In fact, the BusinessVar metaclass defines dynamic variables associated with a single process, enabling adaptability and decision-making. Linked to the Process metaclass through aggregation, these variables drive conditional logic, helping determine the next activity based on their values. Acting as building blocks for business rules, they ensure processes are flexible and context-aware.

The **ProcessElement metaclass**, directly associated with the Process metaclass, forms the fundamental building block of workflows. It encapsulates all elements within a process, serving as the backbone for constructing interconnected and dynamic sequences. This metaclass branches into two specialized types: **ControlElement** and **Activity**, each shaping the workflow's structure and intent. The **Link metaclass** connects ProcessElements, establishing logical pathways that ensure seamless transitions and coherent process flow.

The **Activity metaclass** defines the executable tasks within a process, bridging intent and action. As a specialization of ProcessElement, it not only performs work but also updates business variables upon completion. It includes four specialized subtypes: (i) **Order**, representing commands that trigger activities; (ii) **OrchestrationActivity**, for automated system tasks; (iii) **ComplexActivity**, enabling subprocess integration for hierarchical process design; and (iv) **OperatorsActivity** or HumanActivity, involving tasks performed by individuals, highlighting human roles in workflows. ComplexActivity is key in supply chain and logistics, encapsulating logistics, transport conditions, and inventory management subprocesses.

This allows hierarchical workflow modeling and ensures efficient coordination of transportation, warehousing, and resource allocation, thus improving the effectiveness of the supply chain process.

In addition, the **SupplyChainActors** would formulate the Insurance and Payment metaclasses, with a tangible association to the Company metaclasses, reflecting their roles in managing financial and risk-related aspects of the supply chain process. Specifically, the Insurance metaclass would be associated with SupplyChainActors that manage risk, while the Payment metaclass would be linked to financial transactions between SupplyChainActors and Companies, ensuring that the contractual and financial obligations within the supply chain are met efficiently.

4 VALIDATION

This section presents a use-case model based on the previously described metamodel. It assumes an ideal scenario without constraints to demonstrate the metamodel's flexibility and effectiveness. To highlight traceability, origin assurance, and fraud prevention, diamonds—a highly valuable commodity—are used as the focus. The model follows the BPMN 2.0 standard, enabling comprehensive representation of the main process and its subprocesses.

4.1 General Overview

This case study describes a jewelry store in Spain working with a hub in South Africa to procure diamonds directly from a mine in Lesotho. It illustrates a complex supply chain involving multiple actors: buyer, shippers (land and sea), customs, mining company, South African partner, insurers, and payment systems.

Through a secure and integrated platform, or cross-platform communication system, these actors exchange data in a manner that ensures data integrity and security at every step of the process. Real-time OKR updates keep all actors informed of the goods' status, promoting transparency and efficiency. This coordinated communication enhances the reliability and security of the diamond procurement process, aligning all stakeholders across the transaction.

The process model (cf. Figure 2) depicts the lifecycle of order processing, logistics coordination, and product delivery within a supply chain. Its goal is to improve operational efficiency, reduce delays, and ensure stakeholder integration. The model emphasizes automation, data-driven decisions, and inter-system communication, reflecting modern BPM practices. Activities are segmented by roles such as customers, payment systems, logistics managers, and storage facilities, ensuring clear accountability and highlighting cross-department collaboration.

4.2 Mapping Metamodel Elements to BPMN Constructs

The BPMN model (cf. Figure 2) reflects key concepts from our metamodel. Each BPMN element maps to one or more metaclasses, ensuring alignment between process representation and model structure. For example, the BPMN Pool for "Logistics and Supply Chain Coordinator" corresponds to the Process metaclass. Tasks like "Send Invoice" and "Transport" align with the Activity metaclass, while Events such as "Payment Received" map to the Event metaclass, which triggers actions and transitions. Data Objects and Messages (e.g., "Order Approval," "Purchase Contract") correspond to Order, Contract, and Payment metaclasses. Decision Gateways like "Is available in stock?" relate to Decision and RiskAssessment metaclasses. Data Stores such as "Warehouse" match InventoryData and Warehouse metaclasses. Strategic goals and performance metrics represented as Artifacts or Annotations correspond to OKR and Metric metaclasses, linking performance targets with risk management. This alignment allows the BPMN model to serve as an executable representation of the metamodel's structured concepts.

4.3 Process Phases

This section models the complete diamond purchasing process involving a jeweler in Spain and partners in South Africa and Lesotho. The approach follows the previously described metamodel and uses the BPMN 2.0 standard for process representation.

Figure 2 shows the main diamond purchasing workflow. Figure 4 details the integrated payment process, enabling transparent and secure transactions among stakeholders. Figure 5 illustrates the insurance process, protecting goods during transit and enforcing liabilities through contracts. These subprocesses ensure trust, automation, and compliance across legal and logistical boundaries. Figure 3 depicts the generation and engraving of a cryptographic hash on the diamond to guarantee authenticity and contractual integrity. Buyer-specific data (name, confidential password) is combined with diamond attributes (size, weight, color, clarity) and salted to enhance security. This data is salted [3] and used to calculate a

[3]In cryptography, a salt is random data added before

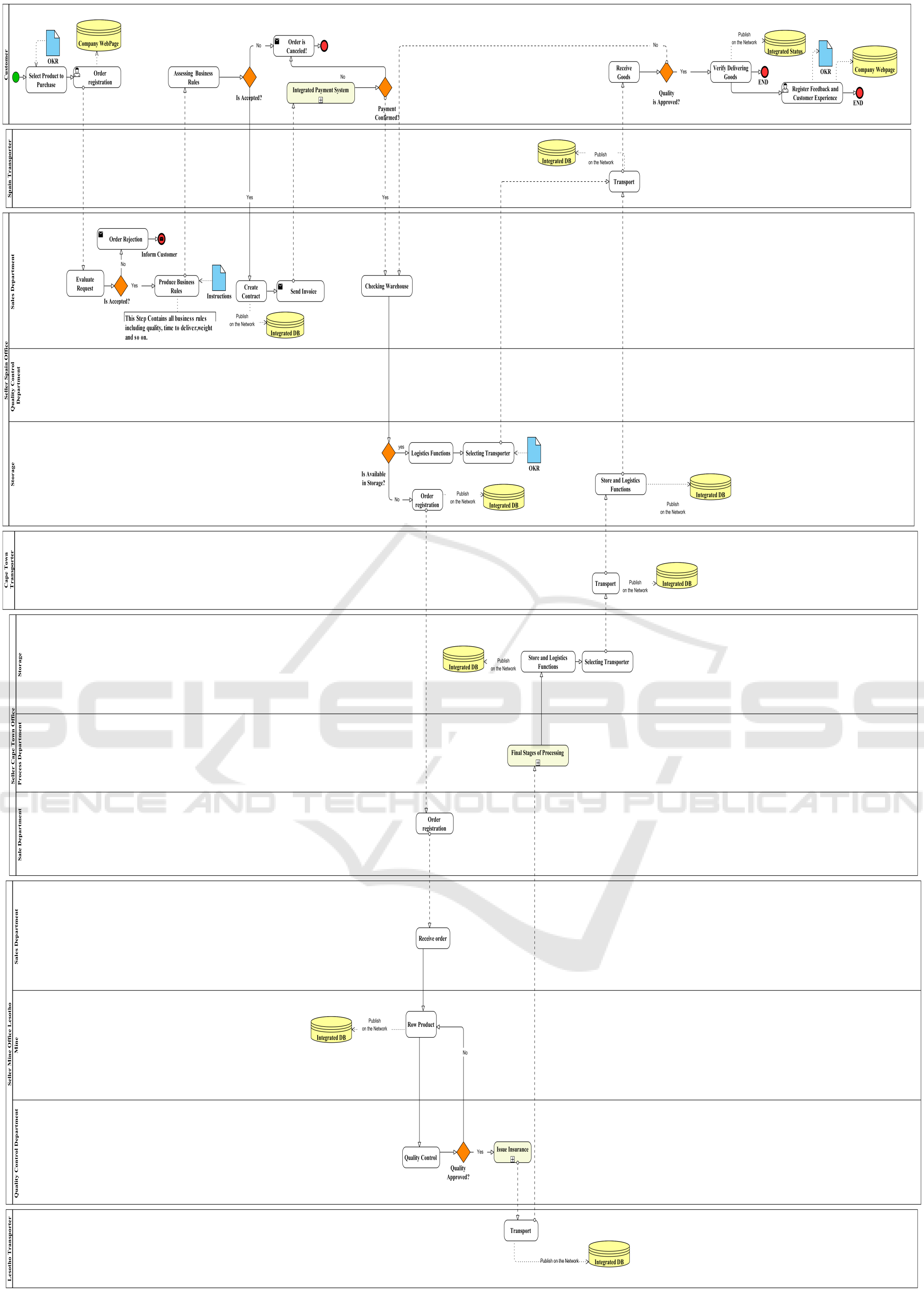

Figure 2: Diamond Purchasing Main Process.

unique hash, which is engraved onto the diamond and published on a secure network. The resulting hash is cryptographically linked to the contract, enabling a verifiable connection between the physical asset and

hashing to increase resistance against precomputed attacks such as rainbow tables (Mustafa, 2024).

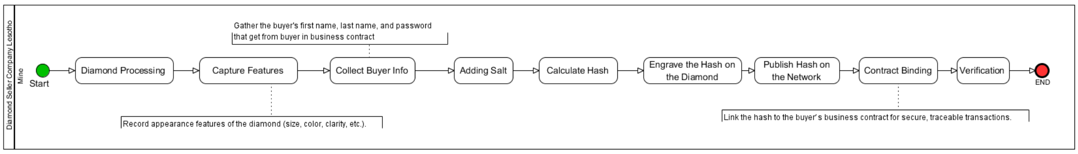

Figure 3: Diamond Hash Processing.

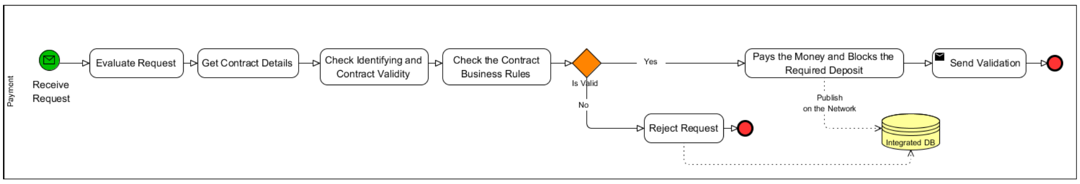

Figure 4: Integrated Payment System.

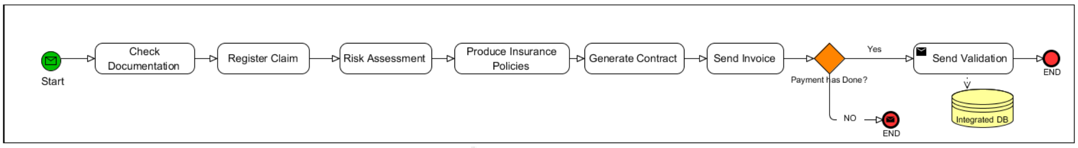

Figure 5: Integrated Issue Insurance Process.

its digital record.

This approach enables the original buyer, possessing the correct input data, to regenerate and verify the hash, confirming ownership. Future buyers and sellers can similarly validate the diamond's authenticity and transaction history on a tamper-resistant platform. Due to space limitations, technical details like hashing algorithms, encryption, and system integration will be covered in a separate article focused on implementation.

- **Order Registration:** The process starts with the customer submitting the product order, followed by validation of order details to ensure compliance with business rules. This step integrates with the Integrated Payment System shown in Figure 4 for invoicing.
- **Logistics Coordination:** After successful payment, warehouse availability is checked and transport resources are allocated. Decision gateways manage process flow based on inventory status and transport options. Advanced transport scheduling algorithms are implied to reduce lead times and optimize resource use.
- **Product Processing:** As illustrated in Figure 3, once produced at the mine, the diamond is transported to the South African partner for final processing. This critical stage ensures quality standards and verifies the diamond's authenticity and origin.
- **Insurance and Payment:** The supply chain supports autonomous, comprehensive payment execution without external approval, exemplified in the subprocess of Figure 4. Additionally, insurance issuance is integrated, enabling risk assessment reviews for each actor and stage throughout the product lifecycle.
- **Quality Control and Storage:** Products undergo inspection before storage or dispatch. Data feedback loops update the inventory system in real-time for accurate stock management.
- **Final Transport and Delivery:** Products are loaded and shipped according to predefined schedules, with monitoring mechanisms ensuring secure and timely delivery.
- **Traceability and Integrated Database:** Throughout the process, actors update and record progress in a comprehensive database, accessible to all stakeholders for real-time tracking of both the process and the product status.

5 CONCLUSIONS AND FUTURE WORKS

This study presented a technology-independent metamodel and a BPMN-based modeling approach that enhances transparency, traceability, and coordination in collaborative supply chains. The emphasis has been placed on conceptual clarity, process integrity, and stakeholder alignment, without dependence on a specific technological platform.

The proposed model is designed to facilitate seamless and reliable data exchange across organizational boundaries, addressing common concerns related to data manipulation or misuse. One of its core strengths lies in improving traceability, allowing buyers to verify the authenticity and origin of goods at each step of the chain. A key differentiator of the model is the integration of risk management as a continuous process, enabling structured and objective evaluation of each actor and service provider involved. The use of Objectives and Key Results (OKRs) as a decision-making framework empowers participants to assess and select trusted business partners based on transparent and measurable performance indicators.

As future work, we plan to implement the proposed model and its underlying metamodel on a blockchain-based platform to evaluate its practical viability and performance —focusing especially on synchronization, security, and decentralized trust mechanisms. We plan to integrate these technological aspects into our methodological framework to enhance its practical applicability. We also intend to develop the concept of a certificate of origin based on the proposed “Engraving Hash on Diamond” mechanism in a practical and detailed manner. Additionally, a comparative and quantitative evaluation will be designed to assess the impact of our approach against existing methods, providing stronger empirical support. These extensions aim to validate and refine the proposed concepts in real-world collaborative environments and further strengthen both their theoretical and operational contributions.

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