Organizational Interoperability: Strengthening Collaboration in Systems of Information Systems

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*Abstract. **Research Context**: Collaborative System of Information Systems (SoIS) involve multiple independent organizations that must interact dynamically, without centralized control, to achieve both collective and individual objectives. Organizational interoperability is crucial in this context but still lacks adequate solutions when participants frequently join or leave the collaboration. **Scientific and/or Practical Problem**: Current BPM and SOA approaches were designed for static intra or inter-organizational contexts and do not handle the dynamic nature of SoIS. This limitation creates difficulties in maintaining process continuity when participants enter or exit, compromising global objectives. **Proposed Solution and/or Analysis**: This research proposes a solution for organizational interoperability in collaborative SoIS comprising a metamodel and a semi-automated simulation environment. The metamodel specifies key concepts, properties, and relationships for modeling collaborative SoIS, while the simulation environment enables the specification and enactment of model instances according to the metamodel. **Related IS Theory**: Research on organizational interoperability is associated with organizational information processing theory and the complexity of information systems. **Research Method**: The Design Science Research (DSR) approach was adopted, following the steps of investigation, design, validation, implementation and evaluation. **Summary of Results**: The metamodel was applied in an e-commerce scenario, showing it to be consistent, expressive, and able to represent domain concepts through models adhering to its rules and structure. The simulation environment executed these models, enabling analysis of participant entry and exit dynamics and demonstrating process continuity despite organizational changes. **Contributions and Impact to IS area**: The approach provide both a conceptual foundation and a means for analyzing and improving collaboration in dynamic interorganizational contexts. The impact lies in enabling more resilient and adaptive SoIS, capable of maintaining continuity and interoperability even under frequent organizational changes.*

1. Introduction

Systems of Systems (SoS) consist of independent, heterogeneous constituent systems collaborating for common global missions [Maier 1998]. Interactions among participants enables the SoS to provide new functionalities that are not offered by any of the systems individually, which is known as emergent behavior [Mendes et al. 2018]. System of Information Systems (SoIS) add a sociotechnical nature to SoS, addressing both system and organizational levels [Saleh et al. 2015].

SoIS may involve constituent systems of different organizations that should collaborate. In this context, organizational interoperability issues are common. The diversity of parties may also generate organizational conflicts, that is, each organization may have its own interests and regulations and may diverge from each other [Cavalcante et al. 2016].

In SoS, Service-Oriented Architecture (SOA) has been used to provide certain types of technological interoperability, such as technical, syntactic, and semantic interoperability [Nakagawa et al. 2013]. SOA works well in an SoS context when only software is taken into consideration [Salgado et al. 2015]. However, due to its sociotechnical particularities of SoIS, merely adopting a set of technological interoperability standards provided by SOA is not sufficient to interoperate its constituents. A SoIS needs to consider the business aspects that constitute an organization, and thus the organizational level must be addressed in the interoperability architecture [Simanta et al. 2010] [Fernandes et al. 2021]. If business processes are not aligned, SoIS mission may not be achieved. Organizational interoperability enable the communication, integration, and interaction between organizations with different organizational structures that align their heterogeneous business processes to achieve agreed objectives of collaboration among efficient, integrated, and transparent interorganizational services [Proencia et al. 2025].

One way to achieve organizational interoperability is through Business Process Management (BPM), which enables organizations to define, manage, and monitor their processes efficiently and effectively. However, according to [Graciano Neto et al. 2017], [Santos et al. 2020], [Oliveira et al. 2022], [Cordeiro et al. 2022] and [Proencia et al. 2025], current approaches used to support business processes are still not adequate to meet SoIS needs. According to these works, these approaches were developed to support intra-organizational contexts or inter-organizational contexts in which participants and their processes are known in advance and do not change frequently. In the case of SoIS, where participants may change over time, these approaches are unable to represent the interactions among them and, consequently, fail to represent emergent behaviors.

Therefore, this paper proposes a solution to support organizational interoperability aiming to guide the entry and exit of participants in collaborative SoIS. Our solution is based on a metamodel that represents the structure for collaborative SoISs, and a semi-automated simulation environment that allows for dynamic evaluation of this metamodel. The solution goal is to connect process models and software architecture, enabling the understanding of the mission in a collaborative SoIS based on the design of the processes and the connections between them (interoperability links).

Metamodel instances allow the understanding of business processes related to participants roles that make up the SoIS. This way, they are aware of their role and the

activities they need to perform to collaborate. Furthermore, if a participant leaves, the others know which participants they should contact to continue collaborating to fulfill the overall SoIS mission. Currently, if a participant leaves, this reconnection must be performed manually by the SoIS participant manager, may be resulting in SoIS execution being momentarily interrupted until the reconnections between participants are restarted. By promoting mechanisms for adaptive collaboration and resilient interoperability, this research aims to contribute to the development of more sustainable and enduring SoIS.

1.1. Research Method

The proposed solution was developed following the Design Science Research (DSR) methodology guided by the logical structure proposed by [Wieringa 2009], known as the regulatory cycle, composed of the stages: Problem Investigation, Solution Design, Design Validation, Solution Implementation and Implementation Evaluation.

In the Problem Investigation stage, we sought to obtain an overview of the use of business processes in the context of SoIS and an overview of organizational interoperability current understanding [Proencia et al. 2025]. In the Solution Design stage, we developed the proposed metamodel, building on the related work found in the previous stage. In the Design Validation stage, we instantiated the metamodel with a BPMN model of an e-commerce scenario, which allowed us to verify its consistency and expressiveness in representing domain concepts. In the Solution Implementation stage, we developed a semi-automated simulation environment to dynamically analyze the metamodel instance. Finally, in the Implementation Evaluation stage, the e-commerce model was simulated in three scenarios, demonstrating the dynamics of SoIS in the face of changing scenarios (entry and exit of participants).

The achieved results demonstrate that the metamodel and the simulation environment provide a conceptual foundation and a means for analysis to achieve more resilient and adaptive collaboration among interorganizational systems. The simulation confirmed the solution's ability to manage the entry of new participants and perform the automatic rerouting of activities upon a constituent's exit, minimizing the impact on the global SoIS objective and ensuring process continuity, even in environments with high organizational dynamism.

In this context, enabling developers of participating systems to design solutions that support the entry and exit of organizations without breaking interoperability links becomes essential. Such capability ensures the continuity of collaborative processes and prevents interruptions in the overall functioning of the SoIS.

The remaining sections are structured as follows: Section 2 presents the main concepts associated with this work and discusses existing studies in the literature related to the research objective. Section 3 specifies the proposed solution. Section 4 presents the validation of the proposed solution, and finally, Section 6 provides the conclusion and directions for future work.

2. Background and Related Works

Interoperability is the ability of diverse systems and organizations to work together (interoperate) in a way that ensures people, organizations, and computer systems can interact to exchange information effectively and efficiently [European Commission 2017].

Several frameworks classifies interoperability types or levels [European Commission 2017], [Maciel et al. 2024]. Usually the most basic type of interoperability corresponds to the technical or syntatic levels, beying semantic the second one. Other intermediate interoperability levels may exist [Ribeiro et al. 2019], such as the pragmatic level [Asuncion et al. 2010]. Among types on top level is organizational, which focuses on aligning processes, communication flows, and policies between organizations, ensuring that the exchanged data can be used meaningfully in their operations to achieve common goals [Proencia et al. 2025]. To achieve organizational interoperability, all the previous levels must be attained [Maciel et al. 2017].

Furthermore, our approach is grounded in the Organizational Information Processing Theory (OIPT), which posits that organizations must increase their information processing capabilities to reduce uncertainty in complex environments. In dynamic SoIS, the proposed metamodel serves as a mechanism to manage this uncertainty, providing structured information to maintain coordination despite frequent participant changes.

According to [Proencia et al. 2025], organizational interoperability can be structured into multiple dimensions, each addressing specific aspects of integration and collaboration, for instance:enterprise, business and finally process as organizational interoperability subtypes.

Several proposals address interoperability issues in complex systems, with a particular focus on SoIS and the use of business processes to achieve organizational interoperability. Concerning the adoption of business processes, [Neto et al. 2017] explore the relationship between business process modeling and SoIS missions, highlighting a gap in existing engineering approaches, that fail to adequately support mission modeling. The use of business processes makes the mission of SoIS clear to all participants.

In the same vein, [Oliveira et al. 2022] propose a systematic method to transition from the business level to the architectural level in SoIS. The study aims to bridge the gap between high-level business process models (e.g., BPMN) and concrete architectural models, ensuring that the system architecture is aligned with business needs.

Complementing this view, [Cen et al. 2017] explore the use of shared ledgers to enhance organizational interoperability. Their research argues that this approach fosters transparency, trust, and data consistency, thereby optimizing inter-organizational workflows.

Finally, [Fernandes et al. 2021] emphasize conceptual modeling to address the technical, human and organizational factors that influence interoperability in SoIS. The study highlights the importance of planning and orchestrating systems for effective data exchange and the mediation of heterogeneity, noting that new technical connections also impact organizational and human dimensions.

Business process modeling, especially using Business Process Model and Notation (BPMN), is a consensus among these studies as an effective tool to describe organizational operations and interactions among constituent systems. There is a common understanding that interoperability goes beyond the technical level, requiring consideration of organizational and human aspects. While existing studies address specific challenges like shared records or abstraction levels, an integrated approach linking process modeling, collaboration, and simulation is still missing.

Our research works differs from the previous ones as it lies in proposing a solution that address organizational interoperability in collaborative SoIS by explicitly linking business process modeling with mechanisms to represent and evaluate the dynamics of participant entry and exit. Our solution presents a metamodel that represents the structure for collaborative SoISs. Furthermore, we propose and implement a semi-automated simulation environment which allows for the validation of our metamodel, simulating the dynamics of real-world SoIS.

3. Proposed Solution

This section presents the proposed solution to enhance organizational interoperability in collaborative SoIS by minimizing the impacts caused by the dynamic entry and exit of participants. In this context, the global objectives of the SoIS can be impacted when a participant leaves, especially if no other is available to assume its role. The metamodel and the simulation environment together provide a conceptual foundation and a means of analysis to address this challenge, enabling participants to be aware of their roles before joining, and to automatically assume or reroute activities when another participant leaves. The achieved results demonstrate that the solution supports more resilient and adaptive collaboration by preserving participants' autonomy to join or leave at any time, while at the same time ensuring process continuity and reducing disruptions to the global SoIS mission.

The solution consists of a metamodel (Section 3.1), with the fundamental concepts for modeling collaborative SoIS, their properties and relationships, as well as a semi-automated simulation environment (Section 3.2), which enables the specification and enactment of model instances according to the metamodel. The solution was grounded in the challenges identified in SoIS and in the solutions proposed in the literature, seeking to integrate and enhance existing concepts for the collaborative and dynamic context.

3.1. Metamodel

The specification of the metamodel (Figure 1) followed the methodology proposed in [Magalhães et al. 2015], which assumes the analysis of existing models in the domain. Therefore, our metamodel proposal was based on the solutions proposed by [Neto et al. 2017], [Cen et al. 2017], [Fernandes et al. 2021] and [Oliveira et al. 2022], which already use concepts of SoIS, Business Process, Activity, Interoperability Link, and Link Type.

Our proposal enhanced these concepts by explicitly adding the Sending and Receiving Activities, which are part of the Business Process Modeling approach. We also included the concepts of Interaction and Communication, which use Interoperability Links (Technological or Sociotechnical) to connect activities across roles specifying dependencies. In the same way, the Link Type has been expanded to Technological and Sociotechnical, with the aim of specifying the types of interoperability required in each Interaction or Communication. Furthermore, we also propose the concept of Role and Participant, where Role is responsible for a Business Process and Participant plays a Role.

According to [Neto et al. 2017], an SoIS has missions derived from the specification of different business processes. Aligned with these concepts, in our proposal (see the metamodel in Figure 1) a SoIS (*SoIS*) is formed by multiple *Business Processes* belong
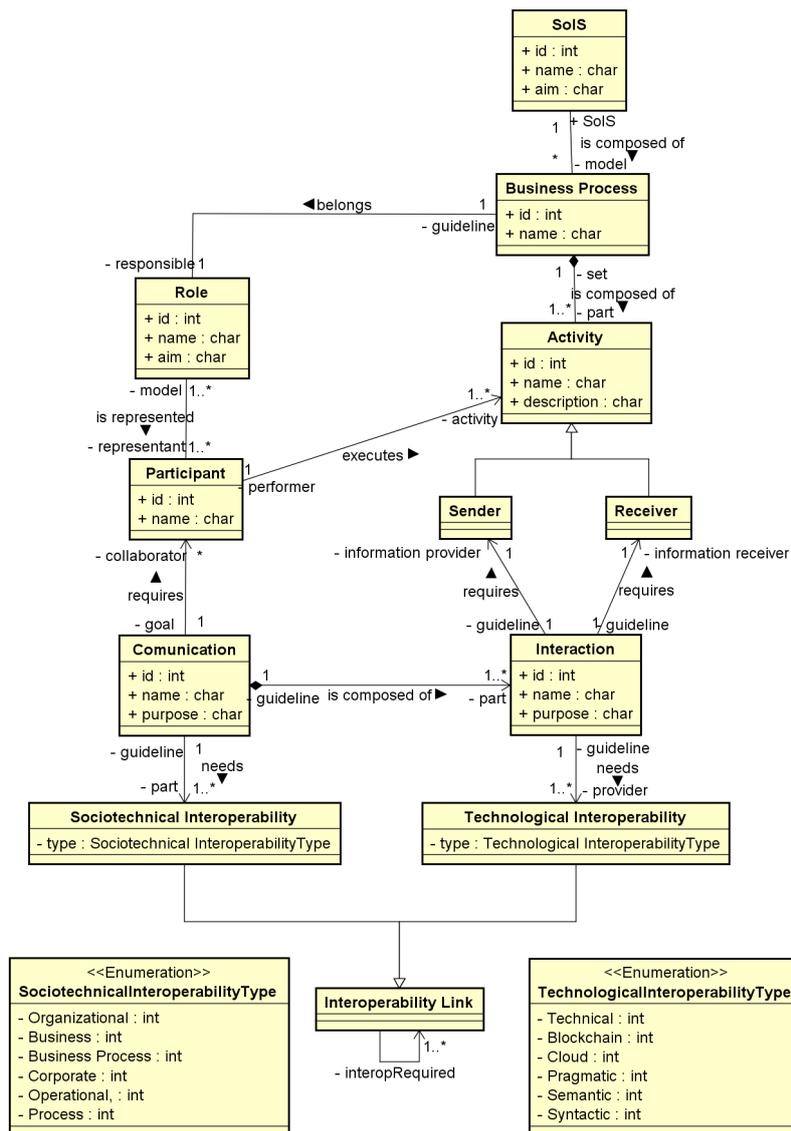
Figure 1. SoIS Metamodel

to *Roles* that contribute to its objective. The SoIS has an ID, a name and a goal. To illustrate the concepts of the metamodel, we will use an example of SoIS for E-commerce. Considering this example, the SoIS goal could be defined as "Product Sale and Delivery".

Each *Business Processes* is composed of one or more activities and has an ID and a name. An activity (*Activity*) is the fundamental component of a business process and has an ID, a name and a description. For the example of the E-commerce SoIS, "Receive Delivery Data" is an activity from business process of the Carrier *Role*.

A *Role* describes a generic function or responsibility that an organization (*Participant*) plays within the SoIS. Each *Role* has a name and an goal that defines its purpose. In the E-Commerce example, the goal of "Carrier" *Role* is "Perform Product Delivery". In our metamodel, a Role (e.g., Carrier) maps to a BPMN Participant (Pool) at design time, while a Participant (e.g., Correios) represents a concrete instance of that role at runtime.

A *Participant* is the concrete instance of an organization that takes on *Role*. While

a *Role* is the abstract function, a *Participant* is the actual entity performing it. For example, the company "Amazon" is a *Participant* that takes on the "Online Store" *Role* on the E-Commerce SoIS.

The *Activity* is specialized into *Sender* class or *Receiver* class. A *Sender Activity* initiates an *Interaction*, while a *Receiver Activity* receives it. In the E-commerce SoIS example, "Send Delivery Data", in the "Online Store" *Role*, is a *Sender Activity*, while "Receive Delivery Data", in a "Carrier" *Role*, is a *Receiver Activity*.

An *Interaction* represents the relationship between a *Sender Activity* and a *Receiver Activity* belonging to distinct *Role*s, performed by different *Participant*s. Each *Interaction* describes links, which may involve data exchanges, service requests, or the execution of dependent tasks between systems.

A *Communication* corresponds to a structured set of *Interaction*s that express the cooperation necessary to achieve a specific business objective between *Participant*s. However, *Communication* is not simply the sum of *Interaction*s, it reflects the sociotechnical aspect of collaboration, incorporating rules, responsibilities, and agreements that guide the joint behavior of participants.

Thus, while *Interaction*s address the technical and functional mechanisms of interoperability, *Communication*s capture the organizational and coordinating level of cooperation, reflecting how organizations articulate to achieve the overall objectives of the SoIS. These *Communications* are governed by business rules and constraints (e.g., participation agreements and service level requirements) which, although simplified in this paper for brevity, are fully detailed in our complete metamodel specification to ensure the alignment of independent organizational policies.

The *Interaction* and *Communication* classes are conceived to be enhanced in future implementations to include shared ledger mechanisms [Cen et al. 2017], thereby ensuring traceability and immutability of interactions among participants, even without a central orchestrator.

The connection between interoperability requirements to establish an *Interaction* or *Communication* between *Participant*s is called *Interoperability Link* and was inspired by the works of [Fernandes et al. 2021] and [Oliveira et al. 2022]. It is specialized into *SociotechnicalInteroperability* or *TechnologicalInteroperability*. Each *Interoperability Link* requires one or more types of both *Sociotechnical* and *Technological Interoperability* (described in [Santos et al. 2021] and [Maciel et al. 2024]).

*Interoperability Link*s may break when *Participant*s are unaware of their *Role*s or when all *Participant*s of a given *Role* leave the collaboration. While traditional approaches require manual restoration by the SoIS participant manager, our solution supports a participant to recognize their *Role* and the *Role* of other SoIS *Participant*s and possibilite the automatic reassignment of activities whenever *Participant*s of the same *Role* remain, thus minimizing disruptions. Only the complete absence of a role still demands manual intervention.

TechnologicalInteroperability represents the technical aspects that enable the connection and exchange of information between systems and services, such as data formats and communication protocols. *SociotechnicalInteroperability* refers to the need for mu-

tual understanding and alignment between organizations and their business processes for effective collaboration. A *Interaction* requires one or more *Technological Interoperability Link* and a *Communication* requires one or more *Sociotechnical Interoperability Link*. Some types of *Technological Interoperability Link*s are Technical, Syntactic, Semantic and Pragmatic [Maciel et al. 2024]. Some types of *Sociotechnical Interoperability Link*s are Process, Business and Organizational [Maciel et al. 2024].

An example of *TechnologicalInteroperability* can be observed in the *Interaction* between the "Send delivery data" (from the Online Store) and "Receive delivery data" (from the Carrier) activities. For example, there is technical interoperability when the systems communicate through a compatible channel, such as a REST API over the HTTPS protocol.

An example of *SociotechnicalInteroperability*, specifically organizational interoperability, can be observed in the *Communication* between participants representing the Online Store and Carrier roles. For the delivery process to function seamlessly, organizations need to share business rules and agreements, such as the maximum order delivery deadline, the delivery status update policy, and liability in case of loss. These rules depend not only on technical compatibility but also on alignment between organizational policies, responsibilities, and commitments. Thus, organizational interoperability ensures that, despite being independent, participants can collaborate in a coordinated and predictable manner.

Representing these concepts in the metamodel is essential because it allows for the explicit definition of the dependencies that support collaboration between participants. By modeling the different levels of interoperability, it becomes possible to identify which connections are purely technical and which require organizational agreements, facilitating both compatibility verification and automatic link restoration in the event of failures. Furthermore, this representation supports the analysis of SoIS resilience, allowing us to understand how the departure of one participant can impact service continuity and under what conditions another participant can assume their functions without compromising the overall system objectives.

Process synchronization is essential to ensure interoperability in integrated management systems. Although process synchronization is not explicitly modeled as a class in our metamodel, the concept of *Interaction* and *Communication*, together with the requirement for *Interoperability Link*s, inherently implies the need for alignment in information exchanges.

3.2. Simulation Strategy

While the metamodel allows modeling SoIS static structures, the simulation strategy aims to demonstrate the dynamic nature of participant input and output, enabling validation of the completeness and viability of a SoIS. The strategy is implemented as a semi-automated simulation environment, detailed in this section. It manages the metamodel's structured data and simulates the flow of events in dynamic scenarios.
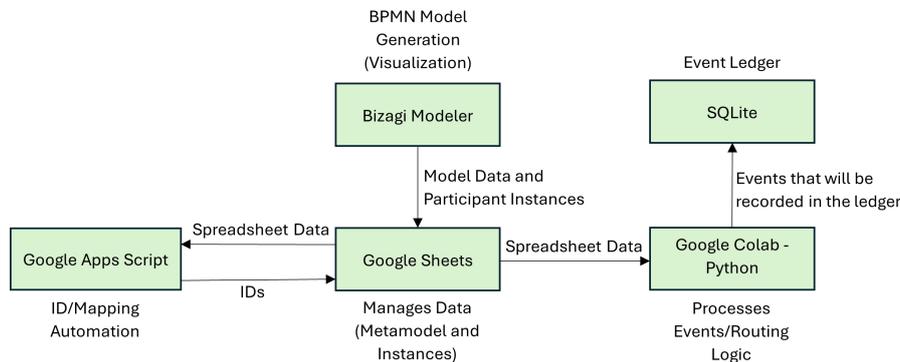
Figure 2 presents the environment architecture. The **Bizagi Modeler**[1] is used for the visual creation of process models in BPMN. **Google Sheets**[2] serves as the main model

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[1]https://www.bizagi.com/pt/plataforma/modeler
[2]https://docs.google.com/spreadsheets/

data repository. Each tab of the spreadsheet is manually filled with information related to instantiated BPMN model and with data from the Participants. **Google Apps Script**[3] operates directly on the spreadsheets, automating the management of IDs and mappings (script is available at https://tinyurl.com/yhc7ra59). As data is populated in the spreadsheet, **Google Colab**[4], running Python script (available at https://tinyurl.com/5ezd7ktk) captures each modification, such as participant entry/exit, interactions, and communications as events, and interacts with **SQLite**[5] Database (Event Ledger) which is used to chronologically record all actions and states of the simulated SoIS, ensuring the immutability of events. The data and control flow among these components demonstrates the integration required for simulating the collaborative dynamics of SoIS.

Figure 2. Implementation and Simulation Environment Architecture

Each tab of the spreadsheet represents an element of the metamodel and contains the data related to that element. The identifier (ID) columns are automatically populated by Google Apps Script and hidden to protected from manual editing, ensuring data integrity. The foreign key columns that reference other tabs use dynamic drop-down lists filled with user-friendly names to facilitate selection. Date columns allow selection via calendar input. As an example, the spreadsheet containing all information related to the e-commerce scenario, is available at https://tinyurl.com/336fehnw (in portuguese).

The SQLite database is configured with two main tables: eventsLedger, which stores the complete history of all events that occur during the SoIS simulation, enabling traceability and auditing; and roleRoutingState, which is used to manage the sticky routing state for participant selection.

The sticky routing strategy by role is employed to simulate continuity of collaboration among SoIS participants. Once an active participant is chosen to perform a role, they become the preferred participant for all future interactions involving that role, simulating an established working relationship. The Round-Robin (RR) strategy is triggered when a role requires a new assignment, either because it is the first time this role is involved in an interaction or because the previously assigned participant (the "sticky") has become inactive (left the SoIS). In this case, RR selects the next available active participant in the predefined sequence (e.g., alphabetical order of IDs), who then becomes the new "sticky" participant for that role. This combined mechanism significantly contributes

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[3]https://script.google.com/
[4]https://colab.google/
[5]https://sqlite.org/

to simulating the adaptability and resilience of the SoIS in response to the dynamism of its constituents.

In Figure 3, it is possible to see two events that were recorded in the ledger representing the simulation output. In event ID 1, the first participant joined the SoIS. In this case, the previous event hash is "None," since nothing occurred before this event. Starting from the second event (event ID 2), the ledger stores both the hash of the previous event and the hash of the current event. In this example, the previous hash for event ID 2 corresponds to the current hash of event ID 1. This mechanism allows tracking the chronological order of events. Additionally, other information can be identified, such as the event type, which in this case, was the participant's entry—the participant's name, and their current status. The simulation data, related to the e-commerce scenario, recorded in the ledger are available at https://tinyurl.com/2tbevcsa.

{'id_evento': 1, 'timestamp': '2025-06-26 16:14:47', 'user_id': 'analista_x', 'tipo_evento': 'Participante_Entrou', 'origem_dado': 'Planilha_Participantes', 'id_elemento_afetado': '1', 'tipo_elemento_afetado': 'Participante', 'detalhes_evento': '{"status_atual": "ATIVO", "nome": "Amazon"}', 'hash_evento_anterior': None, 'hash_evento_atual': 'a3b75425060e4b8171f1431a6564d8b688828291e4f6f64ad71a2f9bbcbca0c4'}
{'id_evento': 2, 'timestamp': '2025-06-26 16:15:13', 'user_id': 'analista_x', 'tipo_evento': 'Participante_Entrou', 'origem_dado': 'Planilha_Participantes', 'id_elemento_afetado': '2', 'tipo_elemento_afetado': 'Participante', 'detalhes_evento': '{"status_atual": "ATIVO", "nome": "PagSeguro"}', 'hash_evento_anterior': 'a3b75425060e4b8171f1431a6564d8b688828291e4f6f64ad71a2f9bbcbca0c4', 'hash_evento_atual': '8af2bcc416ef2e4e8aa5ea7f4de3f9042b9e191d54bb2bc1a69a39bc73d5a9a7'}

Figure 3. Example of Data Stored in the Event Ledger

4. Initial Evaluation and Validation

Regarding SoIS enviroments, real-world validation poses a particular challenge due to the socio-technical and inter-organizational nature of the systems in question. Participants tend to be autonomous and heterogeneous, and are often resistant to the idea of coordinating controlled activities [Maier 1998, Mendes et al. 2018]. Following the DSR cycle, instantiation of a metamodel and simulation-based evaluation are appropriate validation strategies [Wieringa 2009].

Our initial validation strategy started with metamodel instantiation in a scenario focused on e-commerce payment and delivery processes. The objective was to evaluate metamodel concerning its expressiveness and accuracy in representing domain concepts by creating models that adhere to its rules and structure. Following the DSR approach, this step was essential to identify possible ambiguities, inconsistencies, or gaps in the metamodel that might not be apparent from its abstract definition alone.

The metrics used in this evaluation were quantitatives. This allows distinguishing partial from full adherence to the metamodel rules and concepts. Table 1 presents the metrics adopted. These metrics were specifically defined for this research following the Design Science Research (DSR) approach, grounded in established conceptual evaluation criteria such as metamodel expressiveness and the specific resilience requirements for dynamic participant behavior in SoIS.

Table 1. Metrics for Metamodel Instantiation

Quality	What it Measures	How the Result is Measured
Expressiveness	The metamodel's ability to accurately represent all fundamental concepts of the Collaborative SoIS domain.	$\dfrac{\text{Concepts Represented}}{\text{Concepts Required}}$
Syntax Adherence	The ability to map the Abstract Syntax (metamodel) to the Concrete Syntax (BPMN).	$\dfrac{\text{Correct Mappings}}{\text{Total Mappings}}$

Expressiveness evaluates the proportion of domain concepts represented by the instantiated model in relation to the total required concepts. *Syntax Adherence* measures how many abstract elements of the metamodel were correctly mapped to their corresponding BPMN elements.

For analysis and comparison purposes, all metrics were normalized to a continuous range of $[0, 1]$, where 1 represents the reference or ideal value. Thus, the closer a metric result is to 1, the better the performance of the metamodel or the simulated model regarding the evaluated aspect. This normalization allows different metrics to be compared on the same scale and facilitates interpretation, as deviations from the reference value highlight weaknesses or improvement opportunities in the model.

The evaluation continued with simulation, which allowed us to assess the metamodel's feasibility, adaptability and resilience in controlled yet realistic scenarios, reproducing key collaborative SoIS phenomena such as participant entry/exit, rerouting, and interoperability disruption.

Due to the practical difficulty of engaging real organizations at this stage, simulation is a scientifically sound and widely adopted method of providing initial feasibility evidence before moving on to field validation.

The simulation was also evaluated through quantitative metrics that capture *viability*, *adaptability*, *resilience*, and *transparency* of the collaborative SoIS (Table 2). These simulation metrics were tailored to evaluate the viability and resilience of the collaborative process under the dynamic scenarios of participant entry and exit.

Table 2. Metrics for Model Simulation

| Metric	What it Measures	How the Result is Measured
Flow Viability	The ability to complete the SoIS's global objective in the Base Scenario of Normal Operation.	$\dfrac{\text{Successful Flows}}{\text{Total Flows}}$
Adaptability to Entry	The SoIS's ability to incorporate a new participant without interruption.	$\dfrac{\text{Entries Successfully Incorporated}}{\text{Total Entries Attempted}}$
Resilience to Rerouting	The ability to maintain the global objective after the exit of a critical participant.	$\dfrac{\text{Interactions Rerouted Successfully}}{\text{Total Interactions Affected}}$
Transparency and Immutability	The simulation environment's ability to provide traceability and an auditable record of actions.	$\dfrac{\text{Events with Valid Hash}}{\text{Total Events}}$

Flow Viability corresponds to the proportion of planned execution flows that were successfully completed in the base scenario. *Adaptability to Entry* measures the proportion of new participants that were incorporated without disrupting the global SoIS objective. *Resilience to Rerouting* evaluates the proportion of affected interactions that were successfully reassigned after the exit of a participant. Finally, *Transparency and Immutability* assess whether all registered events maintain valid cryptographic hashes, ensuring chronological integrity of the ledger.

All metrics were normalized to a continuous range of $[0, 1]$, where 1 represents the ideal reference value.

4.1. Metamodel Instantiation

To achieve the objective of validation first stage we instantiated the metamodel in an e-commerce payment and delivery scenario (Figure 4), characterized by its multi-organizational dynamism and clear interoperability requirements, in order to verify if

the metamodel is able to represent the concepts of: SoIS, Business Process, Sending Activity, Receiving Activity, Role, Participant, Interaction, Communication, Technological Interoperability Link, and Sociotechnical Interoperability Link.
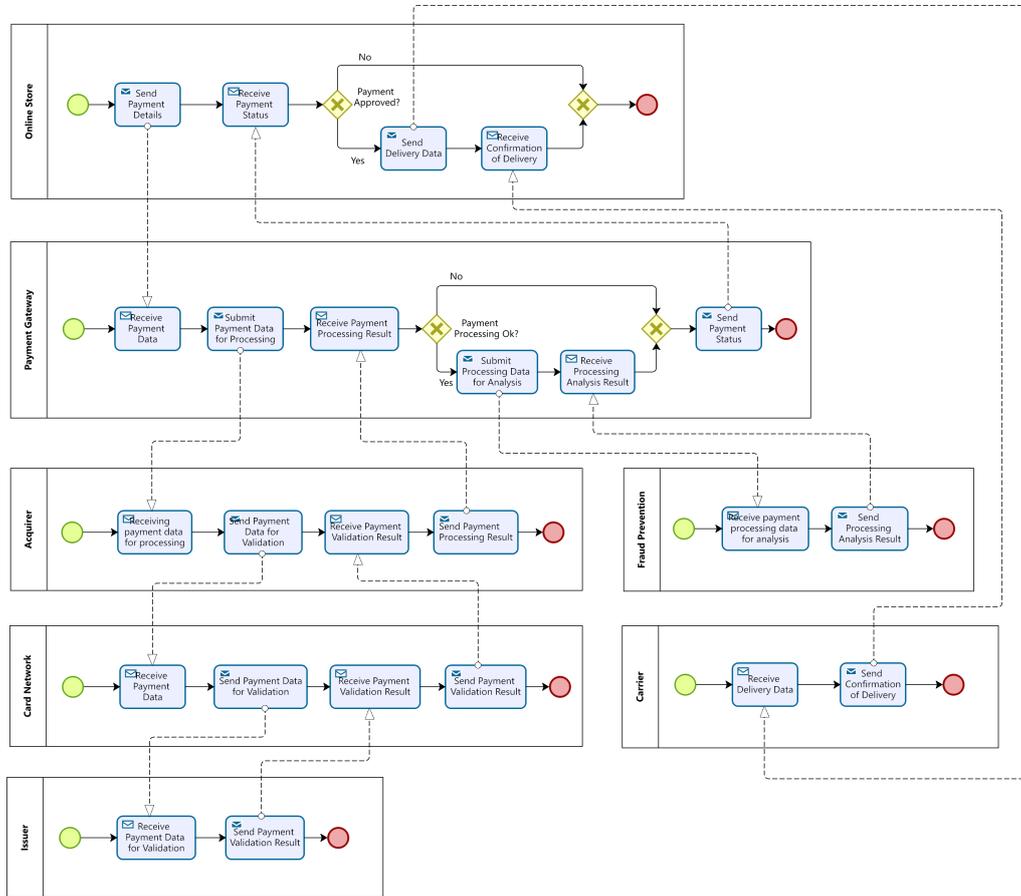
Figure 4. SoIS Collaboration Diagram - e-Commerce

The metamodel instantiation was carried out iteratively through three refinement cycles. The goal of these iterations was to verify, in each attempt, whether the elements and relationships defined in the metamodel were sufficient to represent the concepts and interactions of a SoIS within the e-commerce domain. In each cycle, the results of the previous instantiation were analyzed by the first and second authors — the latter acting as a metamodeling specialist — and reviewed by the last author, who assessed the conceptual consistency of the resulting model.

In the first iteration, the metamodel included the elements *SoIS*, *Business Process*, *Activity*, *Participant*, *Role*, and *Interoperability Link*. The interoperability types — Syntactic, Semantic, and Organizational — were represented as independent classes. This structure provided an initial understanding of the relationships between processes and participants but proved limited for expressing the dependencies between activities belonging to different roles.

In the second iteration, the metamodel was improved with the inclusion of the Interaction and *Communication* elements, which made it possible to explicitly represent exchanges between activities of different roles. Additionally, the *Activity* element was specialized into *Sender* and *Receiver*, allowing the direction of information flow to be

identified. In this version, the interoperability types ceased to be separate classes and became an attribute of the *Interoperability Link*, simplifying the structure and reducing redundancy.

In the third iteration, the *Interoperability Link* was specialized into *Technological Interoperability* Link and *Sociotechnical Interoperability* Link. The first includes the attribute *Technological Interoperability Type*, associated with the technical, syntactic, semantic, among others technological interoperability levels; the latter includes the attribute *Sociotechnical Interoperability Type*, associated with business, process, organizational, among others sociotechnical interoperability levels. The relationships between elements were also refined to better reflect hierarchy and dependency direction, and some attributes were renamed or expanded to improve semantic clarity.

The process was concluded after the third iteration, as the resulting structure proved capable of representing all relevant concepts and interactions required for the collaborative functioning of a SoIS. At this stage, the metamodel achieved internal consistency and conceptual completeness, with no remaining gaps or ambiguities that would justify additional iterations.

The instantiation in BPMN successfully represented the core elements of the metamodel - *SoIS*, *Business Process*, the general *Activity*, the specialization *Sender Activity* and *Receiver Activity*, *Role*, *Interaction*, *Communication*, and the general *Interoperability Link*. Although the *Participant* element and the specialization of *Interoperability Link*s (*Technological* and *Sociotechnical*) were not explicitly represented, the instantiated model was sufficient to validate the conceptual soundness of the metamodel.

The metamodel instantiation metrics were evaluated according to the criteria summarized in Table 1. The results indicate high syntactic adherence and a satisfactory level of expressiveness. The expressiveness metric obtained a value of 0.75, calculated by comparing the number of metamodel concepts represented in the BPMN instantiation (9) with the total number of concepts defined in the metamodel (12), demonstrating that the metamodel is sufficiently expressive to represent collaborative SoISs in the e-commerce domain. The syntactic adherence metric reached the reference value of 1.0, confirming that the mapping between BPMN constructs and metamodel elements was correctly applied.

Next, we detail how the elements of the metamodel (abstract syntax) are materialized and represented in this context using the BPMN (concrete syntax). These elements are shown in Figure 5.

SoIS is the sales and delivery ecosystem itself and it is visually represented by the set of *Pools* that represent the **Roles** (Online Store, Payment Gateway, Acquirer, Card Netwaork, Issuer, Fraud Prevention and Carrier). **Business Process** is visually represented by the set of **Activities**, represented as *Tasks*, contained in a *Pool*. The nature of an Activity as a **Sender** or **Receiver** is inferred from the direction of the *Message Flows* connected to it and can also be explicitly defined by the type of *Task* used, such as *Send Task* or *Receive Task*. In Figure 5, **Sender Activities** are marked in red, while **Receiver Activities** are marked in green.

Participant is not explicitly represented by a specific BPMN graphical component. This occurs because the Participant is considered an instance management element,

which is handled in the simulation layer (implemented via Google Sheets and Python) rather than within the abstract business process model. Some examples of **Participants** for each **Role** are as follows: Online Store ("Amazon", "Mercado Livre"), Payment Gateway ("PagSeguro", "BrasPag"), Acquirer ("Cielo", "Rede"), Card Network ("Visa", "Mastercard"), Issuer ("Banco do Brasil", "Santander"), Fraud Prevention ("ClearSale", "CyberSource") and Carrier ("Correios", "Loggi").

Interoperability Links are represented by *Message Flows*, but the specific interoperability type are not directly visualized as graphical elements; instead, they are semantic attributes that enrich the description of the modeled **Interactions** and **Communications** and materializes in the simulation environment. **Interaction** is represented by *Tasks* together with *Message Flows* and **Communication** is represented visually by is the set of **Interactions** between **Roles**.
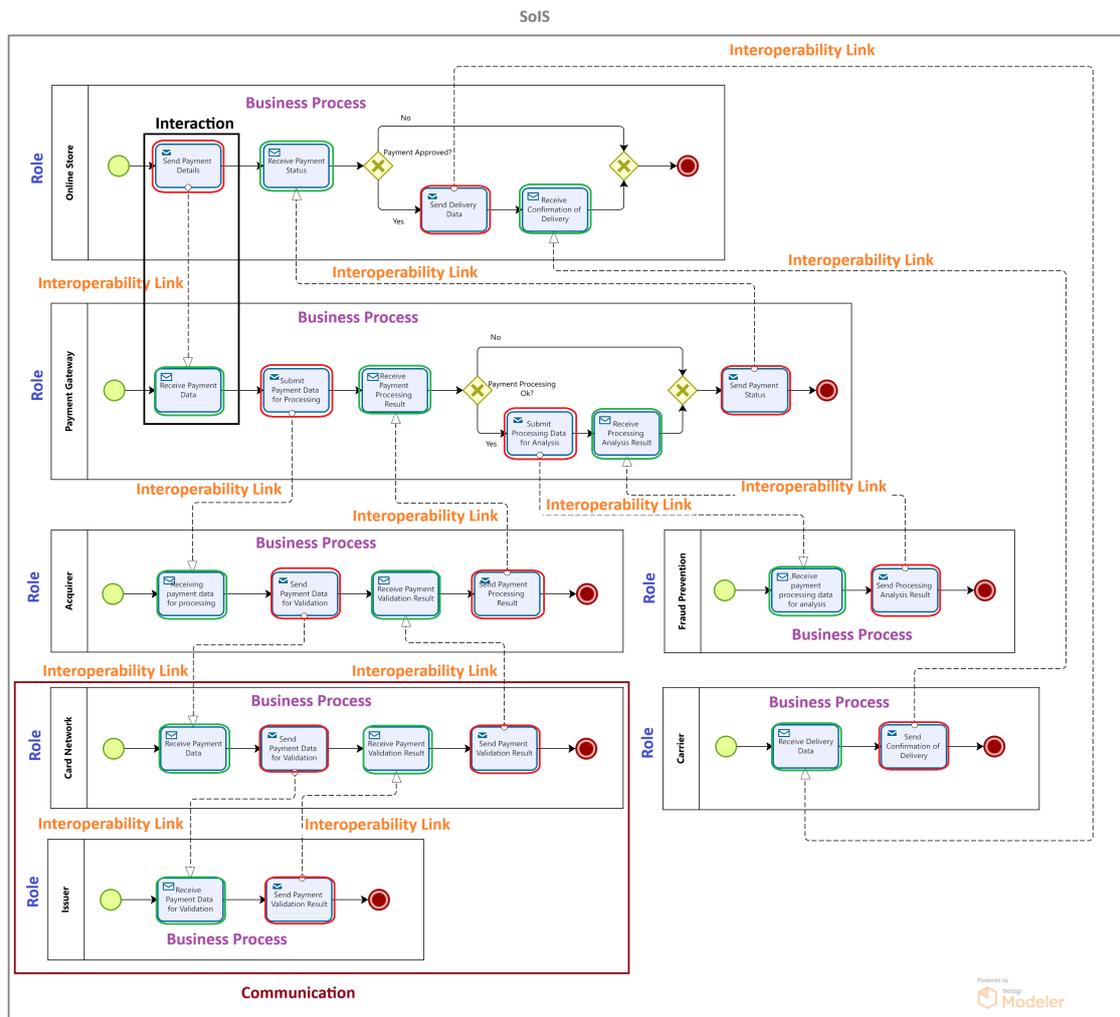

Figure 5. SoIS Collaboration Diagram - e-Commerce - Metamodel Elements

4.2. Metamodel Instance Simulation

To achieve the objective of the second stage of validation (simulation), three dynamic scenarios were simulated within the scope of e-commerce payment and delivery, in order

to verify if the planned execution flows were successfully completed in all scenarios and whether the recorded events can be consulted in order to identify all the steps of the executed flow.

Initially, detailed information about the SoIS, Role, Business Process and Activity elements was recorded in the corresponding Google Sheets tabs. This ensured that all attributes defined in the metamodel were properly associated with each element of the test scenario. Google Apps Script automatically populated the primary IDs in the tabs (e.g., IdRole in Roles) and performed the mappings from names to IDs in the foreign key columns (e.g., IdRoleResponsible in BusinessProcesses).

To evaluate the behavior of the proposed solution, three simulation scenarios were defined, each representing a specific situation involving the entry or exit of participants in the collaborative SoIS. For each scenario, an objective, initial state, and expected final state were established, as described below.

Scenario 1 – Normal Operation

- **Objective:** To simulate the normal execution of the collaborative SoIS in the e-commerce domain, validating that the information flow and collaboration between participants occur as expected when all roles are present and functioning. This scenario serves as a baseline for the analysis of dynamic behavior in the subsequent simulations.
- **Initial State:** The initial participants for each role in the e-commerce SoIS were entered in the Participants tab of Google Sheets. During monitoring, the Python script logged a *ParticipantJoined* event in the ledger for each active participant, simulating the entry of participants.
- **Final State:** The complete execution flow of the successful purchase was simulated. For this, the necessary interactions to complete this flow were recorded in the Interactions tab of Google Sheets along with information on the types of technological interoperability required to complete the interaction. The Python script automatically retrieved the interaction details and selected the participants responsible for each sender and receiver activity. The script then logged *InteractionStarted* and *InteractionCompleted* events in the ledger, computing hashes to ensure immutability. Similarly to interactions, the Python script automatically retrieved the communication details from the Communications tab and logged a *CommunicationStarted* event in the ledger. This scenario establishes the baseline for comparison with subsequent tests.
  Flow viability metric was verified in this Scenario by simulating a complete and successful process execution, which was fully traceable through the sequenced hashes in the immutable event ledger.

**Scenario 2 – Entry of a new participant**

- **Objective:** To evaluate the SoIS's capacity to dynamically integrate a new participant during execution, verifying whether the system can establish the necessary interoperability links without interrupting ongoing processes.
- **Initial State:** The SoIS starts in a stable configuration with the participants active and collaborating normally. During execution, a new participant joins the system assuming the Carrier role, which is already represented by another participant. The new Participant's data ("Loggi") was added to the Participants tab in Google

Sheets and the Python script logged a *ParticipantJoined* event in the ledger, simulating the entry of a new participant.

- **Final State:** The SoIS successfully incorporates the new Carrier participant. The overall process continues without interruption, demonstrating how multiple participants can perform the same role, expanding the collaboration options and adaptability of the SoIS without the need for a central orchestrator.

The initial and final state of this scenario is represented in Figure 6.

Adaptability to entry metric was proven in this Scenario by successfully logging a "ParticipantJoined" event, making the new participant available for routing.
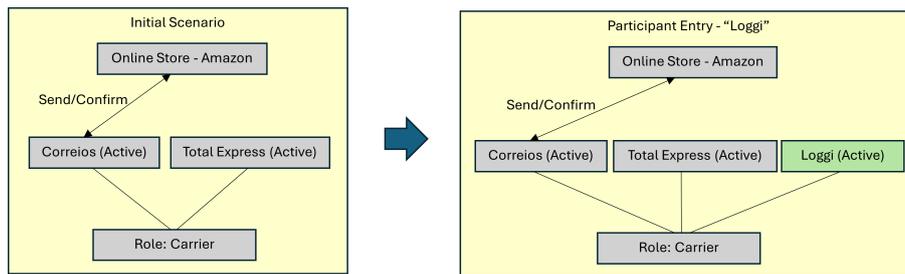
Figure 6. Participant Entry Dynamic in a Collaborative SoIS

### Scenario 3 – Participant exit and automatic rerouting

- **Objective:** To assess the SoIS's ability to maintain continuity when a participant leaves the collaboration, verifying the solution's capability to reroute activities automatically and restore interoperability links.
- **Initial State:** The SoIS starts with all participants active. During execution, one participant performing the Carrier role leaves the system, interrupting the delivery process. However, another participant remains in the same role and is capable of taking over the pending activities. The status of "Correios" was changed to "Inactive" in the Google Sheets tab and the Python script logged a *ParticipantExited* event in the ledger.
- **Final State:** The script Python automatically identified the next active participant available for the Carrier role and a *SoISRerouteCompleted* event was recorded in the ledger, simulating the SoIS adaptation. The interoperability links are reestablished, and the process execution reaches completion without manual intervention. This confirms the solution's ability to adapt dynamically to participant changes, maintaining the SoIS's operational flow and achieving its global objective despite organizational variation.

The initial and final state of this scenario is represented in Figure 7.

Resilience to Rerouting metric was confirmed in this Scenario when the script automatically managed the exit of a participant, logging a "ParticipantExited" event followed by the "SoISRerouteCompleted" event, thereby maintaining the Global SoIS Objective of "Product Sale and Delivery".

The chaining of event hashes throughout the three scenarios confirmed the Transparency and Immutability metric of the record, simulating the auditability capabilities of a shared ledger.

In the Scenario 3, if no active substitutes were available, the crucial interoperability link for delivery is broken, and the Online Store can no longer perform the necessary
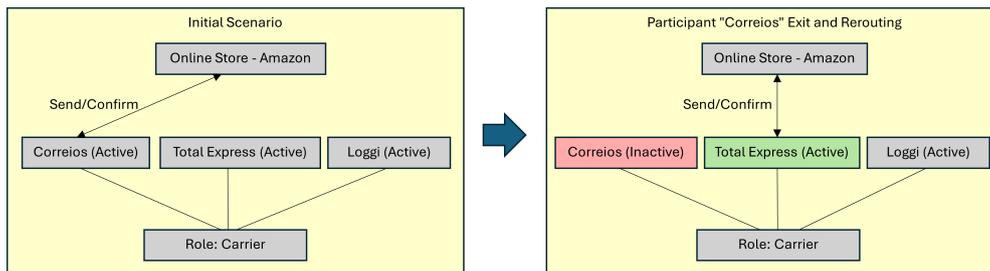
Figure 7. Participant Exit and Rerouting Dynamics in a Collaborative SoIS

interaction. This scenario results in the inability to achieve the SoIS's global objective of "Product Sale and Delivery," demonstrating a critical failure in service continuity. In this case, the script Python would be record a *SoISCriticalImpact* event in the ledger. The initial and final state of this scenario is represented in Figure 8.
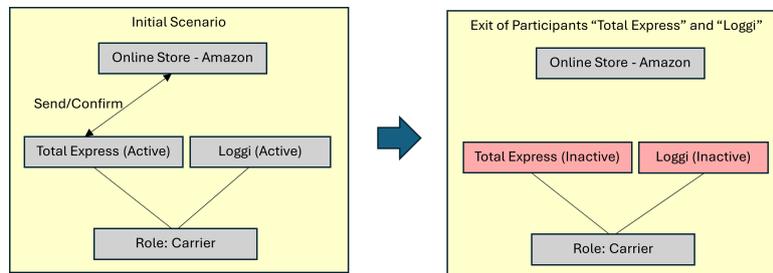
Figure 8. Interoperability Breakdown - Critical Impact due to Total Participant Exit

In a real collaborative SoIS, the total absence of providers for a critical service would require manual intervention, the search for new external partners, or the redefinition of the SoIS objectives. In this case, the autonomy of the constituents alone is insufficient to mitigate the impact. This scenario highlights an inherent limitation of collaborative SoIS without central orchestration: resilience to complete failures in critical roles depends on the prior availability of substitutes or the system's ability to attract new participants quickly. The proposed approach, while optimizing rerouting among existing participants, cannot create new participants or functionalities when no options are available.

In all three simulated scenarios, the overall SoIS process reaches a conclusion; no instance is "stuck" without a result. Therefore, the Flow Viability metric reached the maximum value (1.0). Regarding the Adaptability to Entry metric, in Scenario 2, a new participant joins, and the SoIS continues to function as expected. Therefore, the metric reached the maximum value (1.0). Regarding the Resilience to Rerouting metric, in Scenario 3, when one participant left the SoIS, all interactions associated with the Carrier role were automatically rerouted to another available participant with the same role. Therefore, the metric reached the maximum value (1.0). The Transparency and Immutability metric reached the ideal value (1.0), confirming that all configuration changes performed during the simulations were correctly recorded and made visible to the participants involved.

The simulation of the e-commerce scenario successfully demonstrated the model's feasibility, adaptability, and resilience in a dynamic environment, validating the achievement of the second set of objectives. The simulation confirmed the adherence to the metrics presented in Table 2.

By instantiating the metamodel in a semi-automated environment and exploring three representative collaborative scenarios, the study demonstrated its capacity to describe and sustain interoperability among autonomous systems under different configurations. The simulation enabled the observation of how the approach should supports collaboration continuity and mitigates the effects of participant entry and exit, without the practical constraints of real-world implementation. Therefore representing a necessary grounded step providing evidence of the approach feasibility and establishing a foundation for subsequent empirical validation in realistic environments.

The results obtained confirmed the feasibility, adaptability, and resilience of the metamodel in an SoIS environment, especially in the dynamics of participants joining and leaving with automatic flow rerouting. The evaluation was conducted using a well-known scenario,an e-commerce environment, which proved suitable for illustrating the interactions and interoperability links among heterogeneous participants. However, additional simulations using other collaborative contexts are required to verify whether the behavior of the metrics remains consistent across different domains and levels of organizational complexity. Moreover, to increase the robustness of the evaluation, it is suggested that in future simulations the scenarios be executed with a greater number of participants joining and leaving the SoIS. This increase will allow for a more comprehensive evaluation of the adaptability and resilience metrics, testing the system's performance in a context of higher complexity. A notable difficulty in the simulation was the visualization and analysis of the event logs, given that consulting the Event Ledger was carried out through a direct SQL query to the SQLite database. This approach hindered the user-friendly comparison of the cryptographic hashes and the visual and chronological recreation of the execution flow from the log, limiting the clarity and efficiency of the simulation audit.

5. Threats to Validity and Limitations

This initial evaluation has limitations that must be acknowledged. Regarding external validity, results are limited to an e-commerce scenario; future studies should explore more complex domains like healthcare to test generalization. Concerning conclusion validity, the small participant set and simple scenarios resulted in several 1.0 metrics, representing a functional proof-of-concept rather than performance under stress. Lastly, the current simulation is sequential; handling parallel events, high concurrency, and non-functional requirements (e.g., encryption, scalability) is required for real-world production environments.

6. Conclusion and Future Works

This work presented an approach to strengthen organizational interoperability in collaborative SoIS, grounded in Organizational Information Processing Theory to mitigate uncertainty in dynamic contexts. Our main contribution is the integration of a formally defined metamodel with a simulation environment that implements an automatic rerouting mechanism (using sticky and round-robin logic). This combination enables autonomous organizations to maintain process continuity and global objectives without central orchestration, addressing a gap in traditional BPM/SOA approaches.

The simulation results in the e-commerce domain demonstrate that the approach effectively reduces the impact of participant entry and exit. Future work will focus on: (i) evolving the simulation environment into a user-friendly graphical interface; (ii) integrating business rules and constraints into interaction links; (iii) exploring AI and Large

Language Models (LLM) to identify and raise emergent behaviors at runtime; and (iv) validating the solution with real-world organizations in production environments. Overall, this research contributes to the design of more resilient and adaptive SoIS capable of sustaining long-lived collaborations.

Acknowledgments

References

Asuncion, C. H., Iacob, M. E., and van Sinderen, M. J. (2010). Towards a flexible service integration through separation of business rules. In *Proceedings of the 14th IEEE International EDOC Enterprise Distributed Object Computing Conference (EDOC 2010)*, pages 184–193, Vitória, Brazil. IEEE.

Cavalcante, E., Cacho, N., Lopes, F., Batista, T., and Oquendo, F. (2016). Thinking smart cities as systems-of-systems: A perspective study. In *Proceedings of the 2nd International Workshop on Smart*, SmartCities '16, New York, NY, USA. Association for Computing Machinery.

Cen, Y., Wang, H., and Li, X. (2017). Improving business process interoperability by shared ledgers. In *Proceedings of the 6th International Conference on Informatics, Environment, Energy and Applications*, IEEA '17, page 89–93, New York, NY, USA. Association for Computing Machinery.

Cordeiro, F., de Vasconcelos, A. P. V., and dos Santos, R. P. (2022). Accountability evaluation in systems-of-information systems based on systems thinking. In *Anais Estendidos do XVIII Simpósio Brasileiro de Sistemas de Informação*, pages 127–129. SBC.

European Commission (2017). New european interoperability framework – promoting seamless services and data flows for european public administrations. European Union. European Commission, Directorate-General for Informatics.

Fernandes, J., Graciano Neto, V. V., and Santos, R. P. d. (2021). An approach based on conceptual modeling to understand factors that influence interoperability in systems-of-information systems. In *Proceedings of the XX Brazilian Symposium on Software Quality*, SBQS '21, New York, NY, USA. Association for Computing Machinery.

Graciano Neto, V., dos Santos, R., and Araujo, R. (2017). *Sistemas de Sistemas de Informação e Ecossistemas de Software: Conceitos e Aplicações*, pages 22–41.

Maciel, R. S. P., David, J. M. N., Claro, D. B., and Braga, R. (2017). Full interoperability: Challenges and opportunities for future information systems. In de Computação, S. . B., editor, *GranDSI–BR: Grandes Desafios da Pesquisa em Sistemas de Informação no Brasil para o período de 2016 a 2026*, pages 107–116. SBC. Chapter 9.

Maciel, R. S. P., Valle, P. H. D., Santos, K. S., and Nakagawa, E. Y. (2024). Systems interoperability types: A tertiary study. *ACM Comput. Surv.*, 56(10).

Magalhães, A. P., Maciel, R. S. P., and Andrade, A. (2015). Towards a metamodel design methodology: Experiences from a model transformation metamodel design. In *Proceedings of the International Conference on Software Engineering and Knowledge Engineering (SEKE)*, pages 625–630, USA. Knowledge Systems Institute Graduate School.

Maier, M. W. (1998). Architecting principles for systems-of-systems. *Systems Engineering*, 1(4):267–284.

Mendes, A., Loss, S., Cavalcante, E., Lopes, F., and Batista, T. (2018). Mandala: An agent-based platform to support interoperability in systems-of-systems. In *2018 IEEE/ACM 6th International Workshop on Software Engineering for Systems-of-Systems (SESoS)*, pages 21–28.

Nakagawa, E. Y., Gonçalves, M., Guessi, M., Oliveira, L. B. R., and Oquendo, F. (2013). The state of the art and future perspectives in systems of systems software architectures. SESoS '13, page 13–20, New York, NY, USA. Association for Computing Machinery.

Neto, V. V. G., Cavalcante, E., El Hachem, J., and Santos, D. S. (2017). On the interplay of business process modeling and missions in systems-of-information systems. In *2017 IEEE/ACM Joint 5th International Workshop on Software Engineering for Systems-of-Systems and 11th Workshop on Distributed Software Development, Software Ecosystems and Systems-of-Systems (JSOS)*, pages 72–73.

Oliveira, L. d. S., de Vasconcelos, A. P. V., and dos Santos, R. P. (2022). Um método para geração de modelo arquitetural de sistemas-de-sistemas de informação apartir da análise de modelos de processos de negócio. In *Anais Estendidos do XVIII Simpósio Brasileiro de Sistemas de Informação*. SBC.

Proencia, E., Mascarenhas, A., Mane, B., Claro, D., and Maciel, R. (2025). Organizational interoperability: A systematic mapping study. In *Anais do XXI Simpósio Brasileiro de Sistemas de Informação*, pages 280–289, Porto Alegre, RS, Brasil. SBC.

Ribeiro, E. L. F., Monteiro, E. L., Claro, D. B., and Maciel, R. S. P. (2019). A conceptual framework for pragmatic interoperability. In *Proceedings of the XV Brazilian Symposium on Information Systems*, SBSI '19, New York, NY, USA. Association for Computing Machinery.

Saleh, M., Abel, M.-H., and Mishra, A. (2015). An architectural model for system of information systems. In Ciuciu, I. and et al., editors, *On the Move to Meaningful Internet Systems: OTM 2015 Workshops*, volume 9416 of *Lecture Notes in Computer Science*, pages 411–420. Springer, Cham.

Salgado, C. E., Teixeira, J., Santos, N., Machado, R. J., and Maciel, R. S. P. (2015). A soaml approach for derivation of a process-oriented logical architecture from use cases. In *International Conference on Exploring Services Science*, pages 80–94. Springer.

Santos, J. M., Neto, V. V. G., and Nakagawa, E. Y. (2020). Business process modeling in systems of systems. In *Anais do II Workshop em Modelagem e Simulação de Sistemas Intensivos em Software*, pages 26–35. SBC.

Santos, K. S. S., Pinheiro, L. B. L., and Maciel, R. S. P. (2021). Interoperability types classifications: A tertiary study. In *Proceedings of the XVII Brazilian Symposium on Information Systems*, SBSI '21, New York, NY, USA. Association for Computing Machinery.

Simanta, S., Morris, E., Lewis, G. A., and Smith, D. B. (2010). Engineering lessons for systems of systems learned from service-oriented systems. In *2010 IEEE International Systems Conference*, pages 634–639.

Wieringa, R. J. (2009). Design science as nested problem solving. In *Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology (DESRIST '09)*, pages 1–12, Philadelphia, PA, USA. Association for Computing Machinery.