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RESEARCH ARTICLE

RESOURCE CONSUMPTION OPTIMIZATION MODEL FOR INTER-ORGANIZATIONAL BUSINESS PROCESS EXECUTION BASED ON GRAPH THEORY

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Abstract

Improving collaboration between enterprises depends on the effective interoperability of their information systems. This interoperability has a rate that depends on the overall cost of resource consumption associated with the multiple exchanges between the Web services that implement the associated business process tasks. This cost can be calculated and analyzed in order to optimize the inter-organizational business process execution. Several previous studies have made significant contributions to calculate of this cost. However, the formal definition of the resource consumption optimization problem within business process execution, which help us to interpret this cost is still under discussion in the information system scientific community. In this paper, we propose a resource consumption optimization model based on graph theory. We define the properties, and we test the model to optimize the creation of a brand image for a customer in an enterprise network.

Introduction:-

Enterprises need to collaborate in order to form a resilient networked enterprise. The implementation and operation of these inter-enterprise collaborations requires the interoperability of their information systems because for making this collaboration possible, it is important for companies to have an information and communication technology support tools (Yahia, 2011) which can be used to share data. To achieve a common goal in this collaboration, networked enterprise information systems develop different interactions based on communication protocols. Information exchanges between two protocols involve sub-elements such as format compatibility, data quality, or semantic data preservation (Y. Chen et al., 2023) which improve the interoperability of information system.The interoperability of information systems is defined as the ability of two or more information systems to interact based on multiple understandable requests initiated by useful web services, performing tasks of an inter-organizational business processes to achieve common goals defined by the enterprises strategies. In an interoperability context, each of the information systems is constituted by a set of business processes, so that the instances are executed in the

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form of an orchestrated web services. The role of web services in orchestrating business processes in information systems can be categorized into three categories: the interoperation effect, the architecture effect, and the infrastructure effect (Zhao & Cheng, 2005). In interoperation effect, web services in orchestrating business processes take advantage of universal standards, namely BPEL4WS language, HTTPS protocol, SOAP protocol, and XML language, by enabling the remote invocation of any programs running in any computing environment. This allows the communication of two web services on the internet, regardless of the programming language and the operating systems on which the programs are built. In the architecture effect, web services in orchestrating business processes allow the simplification of application architecture with standard APIs. This reduces the strong coupling between application interfaces and promotes the coordination of shared resources. This makes it possible to design an open architecture that enhances business process execution. In the infrastructure effect, web services in orchestrating business processes, enabling us to manipulate the concepts and techniques of process management, which are served in service-oriented computing. This is achieved by considering information flow relationships and assigning specific business process tasks to web services.

As organizations interact and develop relationships, these relationships become heavy with physical resources and technological resources over the time (Kompella, 2020) . Business processes are then the units in which, the creation of deliverables and the consumption of resources within the enterprise are identified. These resources are exchanged between inter-organizational business processes in the form of requests. When interoperability is partially or fully achieved, instances of inter-organizational business processes exchange and consume a large number of resources. The consumption of these resources belonging to the interoperable information systems of networked organizations has a cost, which is referred to as the overall cost of resource consumption. In this paper, we consider that the overall cost represents the total consumption of resources when the interoperation mechanism is carried out at the level of web services, which perform the tasks of inter-organizational business processes of a network of enterprises despite the environmental risks associated with their information systems. This cost, which reflects the rate of exchanges and operations between instances of inter-organizational business processes, can be minimized.

To specify this cost, it is important to have an idea of the challenges encountered in establishing and maintaining inter-enterprises collaboration, and to master the phases of an interoperation cycle. Among these challenges we have conceptual, technological, and organizational issues (D. Chen, 2006). An interoperation cycle is made up of two phases: the exchange phase and the operation phase. For these authors (Daclin et al. 2014), "exchange" means that a given information system - called "sender" - sends (physically or not, e.g. by mail, telephone, etc.) or makes available data, templates for another information system. "Operation" means that a given information system, called "receiver", is able to use for a certain task the data, models provided by the sending information system. Therefore, in this article we address the problem of resource consumption optimization within business process execution and we propose an appropriate resolution method. To better conduct our work, we rely on the Enterprise Interoperability Framework (Chen, 2006), we use the graph theory, the Design Science research methodology to construct the artifacts; we study an interoperable information system during its execution phase, and we argue that the information systems studied are at least interoperable. This means that there is either a technical, organizational, or semantic interoperability relationship between the information systems. The rest of this paper is organized as follows: section 2 presents the related work on the analysis of inter-process collaboration cost in networked enterprises. The research methodology is presented in section 3. Section 4 presents our contribution. Finally, section 5 concludes the paper.

Related Work On Inter-Process Collaboration Cost And Resource Optimization In Business Process:-

To better address the issue of resource consumption within inter-organizational business process execution in networked enterprises, it is important to give an overview of the work that had been done by our peers. The authors Castano and De Antonellis (1998) defined the framework for expressing semantic relationships for cooperation between multiple information systems. This framework allows semantic and quantitative analysis of information flows exchanged between heterogeneous distributed information systems. To better conduct this analysis, the authors defined the degree of coupling between business processes as follows : : $\mathrm{AC}(\mathrm{P_i},\mathrm{P_j}) = \mathrm{Card}\left\{\langle \mathrm{n}_{\mathrm{e_k}}, \mathrm{n}_{\mathrm{e_h}} \rangle \middle| \mathrm{P_i} \xrightarrow{\mathrm{e_k},\ \mathrm{e_h}} \mathrm{P_j}\right\}$; where $\left\{\langle \mathrm{n}_{\mathrm{e_k}}, \mathrm{n}_{\mathrm{e_h}} \rangle \middle| \mathrm{P_i} \xrightarrow{\mathrm{e_k},\ \mathrm{e_h}} \mathrm{P_j}\right\}$ denotes the set of names of the different entities that originate the flow of information between the processes $\mathrm{P_i}$ and $\mathrm{P_j}$ of two different information systems, and Card cardinality of this set. This degree of coupling makes it possible to optimize information exchange flows between information systems, measure the quantity of relationships between processes and discover similarities between process data structures. The greater the degree of coupling between processes, the greater the degree of interoperability (Yahia, 2011).

The work of Brunnermeier and Martin (1999) provides an analysis of the costs of partial interoperability at the supply chain level in the automotive industry by defining metrics such as avoidance costs, mitigation costs, and delay costs. Avoidance costs are a means of anticipating technical interoperability problems before they occur. Avoidance costs include the cost of purchasing, developing, and training on the new system, as well as the cost of outsourcing the exchange of services and data. Mitigation costs reflect the resources required to resolve interoperability issues after they have occurred. They include the cost of reengineering business process models. Delay costs are very often related to organizational interoperability problems that prevent the implementation of the interconnection and composition of services of different information systems.

Sampath (2013) presents a methodology for calculating the cost of successfully executing an inter-organizational business process. Inter-organizational business processes enable the implementation of interoperability between different information systems. The authors define the business cost, which is the cost induced by the execution of inter- and intra-organizational business processes leading to the successful interoperability of partner information systems, as follows: $Businesscost = C/R$, $C \geq 0$ et $0<R=1$ where C is the cost of business processes and R is the reliability of business process execution.

A methodology for implementing and improving interoperability to develop business collaboration was developed by Daclin et al. (2014) to calculate the cost of interoperability based on the interoperation cycle. The interoperation cycle consists of two phases: exchange and operation. Thus, the total cost of interoperation is defined as the sum of the exchange cost and the operation cost Cin = Cex + Cop . The idea behind this analysis is to specify the costs of removing interoperability barriers and modifying cooperating systems. Each of these costs is obtained by taking into account the current state of the information system (initial cost Cini) and the future state of the information system (expected cost Ceff).

The paper by Mork et al. (2014) focuses on estimating the cost of interoperability based on canonical data modeling. Canonical data modeling (CDM) is a method to reduce the total cost of integrating information systems. These costs are given by: TCO = Total Cost of Data Modeling using Canonical Data Modeling + Total Cost of Integration + Cost of Data Modeling To define the degree of interoperability of information systems, the authors Koulou et al. (2020) have defined a method for distributing the effort required to interconnect information system interfaces. This method measures system interoperability using three metrics: degree of compatibility DC, interoperability potential PI, and operational performance PO. The degree is calculated as follows IMA = n1∗PI + n2∗DC + n3∗PO / (n1 + n2 + n3), where n1, n2, and n3 are the weights for each of the metrics.

The authors (Y. Chen et al., 2023) have proposed an interoperability assessment methodology for the industrial domain, to help decision-makers choose the most appropriate solution for solving interoperability problems. For that, they defined a scalability cost of interoperability from an economic analysis perspective. The scalability cost includes all direct and indirect costs associated with the scalability of the interoperability solutions deployed. This cost is defined with metrics categorized into reusability, ease-of-use and interoperability scores.Reading the previous works, we notice that several terminologies encapsulate the ideas linked to the quantification of data and information exchange between inter-organizational business process during the runtime. For example, we have "degree of interoperability", "business cost", "cost of inter-organizational business processes", "degree of process coupling", "total cost of ownership". All these terminologies show that the definition of the notion of the overall cost of resource consumption remains an open question, which we intend to address in this work. In another hand, we observe that the main problem with most of these works, as we can see in Table 1, is that they only calculate costs and do not formally define the problem of resource consumption optimization within business process execution. This issue is overcame in this paper. The following section presents the design science research methodology.

Authors	Metrics defined to estimate the overall cost of interoperability between information systems	Analysis point of view	Problem formalization
(Castano and De Antonellis, 1998)	Degree of coupling between processes	Computer science	No
(Brunnemeier and Martin, 1999)	Avoidance cost, mitigation cost, delay cost	Financial	No
(Sampath, 2013)	Business cost	Financial	No
(Daclin et al., 2014)	Cost of exchange, Cost of operation	Computer science	No

(Mork et al., 2014)	Total cost of data modeling using canonical data modeling, Total cost of integration, Cost of data modeling.	Computer science and Financial	No
(Koulou et. al., 2020)	Degree of compatibility, Interoperability potential, and Operational performance	Computer science	No
(Y. Chen et al., 2023)	Reusability, ease-of-use and interoperability scores	Economic	No
Our work	**Service interoperation cost vectors, QoS criteria**	Computer science	**Yes**

Table 1: Synthesis of related works

Methodology:-

Design science research (DSR) is a problem-solving paradigm that seeks to advance human knowledge through the creation of innovative artifacts (vom Brocke et al., 2020). In information systems research, design science creates and evaluates IT artifacts that are intended to solve identified organizational problems (Hevner et al., 2004). These artifacts can be defined as constructs, models, instantiations, methods, algorithms, and prototype systems. DSR in information systems addresses problems with one or both of the following characteristics: complex interactions between subcomponents of the problem and its solution; a critical dependence on human cognitive abilities (creativity) to produce effective solutions (Hevner et al., 2004). The problem addressed in this paper follows these characteristics because the issue of providing a formal definition of the interoperability cost analysis problem, highlights the complex interactions (the sending of messages) between the different services that constitute the inter-organizational business processes and requires human cognitive abilities to find a way to model these costs.

In the DSR methodology, we will focus on the DSR process, which describes how to build artifacts that are the scientific contribution to the problem being solved. The DSR process has six steps: identify the problem and its causes; define the goals of a solution; design and build the artifacts; evaluate these artifacts; and produce results that can be shared. To apply this process, the researcher uses the design science framework (Figure 1), starting with an environment composed of people, organizations, and technologies. The researcher identifies the problem to be solved in this environment and measures its relevance by defining the goals of the intended solution. Once the relevance of the problem has been established, the researcher proceeds with the construction of the artifacts (algorithms, models, concepts, etc.) that represent the solution to the problem posed, using a knowledge base consisting of theories, frameworks, etc.). Once the artifacts are built, they are evaluated through case studies, simulations, or experiments.

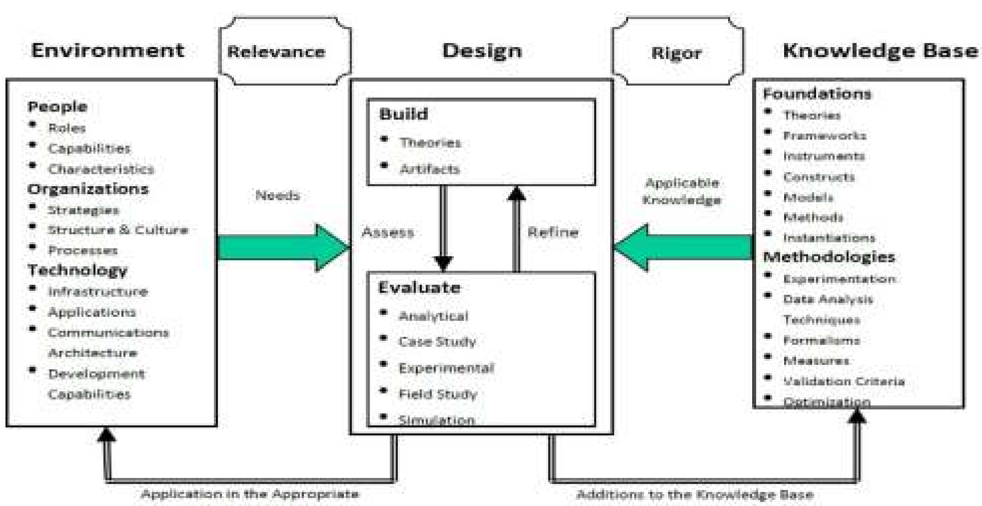

Figure 1: Design Science Research Framework (vom Brocke et al., 2020)

Based on our work, we can complete each step of the DSR process as follows:

- Problem Identification: resource consumption optimization within inter-organizational business process execution.
- Objective: Formally define this problem and provide an analysis of the overall cost of resource consumption in networked enterprises.
- Design and development: To define the artifacts for transforming an inter-organizational business process like a dependency graph between web services executing the business process tasks
- Evaluation and demonstration of the validity of the constructed artifacts: we demonstrated the validation of the constructed model by applying it to a case study which exist in the literature.
- Communication: publication in progress.

Each of these steps is developed in the following section.

Results and Discussion:-

To develop our contribution, we will follow the DSR process step by step.

Problem identification:-

Based on the state of the art, we have found that the problem of resource consumption optimization within inter-organizational business process execution remain not fully resolved by the scientific community in the field of information systems.

Objectives of the proposed solution:-

Goals can be quantitative or qualitative. We are interested in the qualitative goals of our solution. Qualitative goals describe how a new artifact is expected to support solutions to problems that have not been addressed so far (Vom Brocke et al., 2020). Thus, the main objective to formalize this problem is to find a vector of decision variables such that each component describes the utility percentage of the service during the execution of instances of business processes.

Design and development:-

This step deals with the construction of artifacts. A DSR artifact can be any designed object in which a research contribution is embedded in the design (vom Brocke et al., 2020). To better design the artifacts, we have defined an approach to elaborate the model for optimizing the resource consumption.

The approach consists of the following four steps:

- Verify the nature of the interoperability between information systems
- Define and select the business domains of the information systems involved in the interoperability.
- Build a dependency graph between all identified services that make up the inter-organizational business processes.
- Translate the dynamic of the previously constructed graph into an optimization problem, which is a mathematical model and specify the model parameters.

Verify the type of interoperability between information systems:-

In this step, we verify whether the collaborative information systems have an interoperability relationship (technical, semantic, or organizational). This can help us to know in advance who are the interoperability partners and to identify all the barriers to interoperability (Yahia, 2011). In this work, we analyze the interoperable information systems at runtime. For this, we will build two artifacts in this step: the formal definition of an interoperable information system and the interoperability relationships.

Let‘s consider two interoperable information systems IS_i and IS_j noted: $IS_i \cap IS_j$. $IS_i \cap IS_j$ means there is at least one interoperability relationship I_R between the two information systems. $\widetilde{IS} = \{IS_1, IS_2, \ldots, IS_m\}$ a set of m information systems and TI= {Organizational,Technical,Semantic} a set of the types of interoperability; numerically, TI= {1,0,-1}.

Formally, I_R is defined as follows $I_R : \widetilde{IS} \times \widetilde{IS} \to TI, \ \forall IS_i, IS_j \in \widetilde{IS}, \ (IS_i, IS_j) \mapsto I_R(IS_i, IS_j)$:

$$I_R(IS_i, IS_j) = \begin{cases} 1, \text{if organizational interoperability} \\ 0, \quad \text{if technical interoperability} \\ -1, \quad \text{if semantic interoperability} \end{cases}$$

Finally, IS_i∩IS_j= {I_R (IS_i ,IS_j)= -1 ∨ I_R (IS_i ,IS_j)= 0 ∨ I_R (IS_i ,IS_j)= 1}. This symbol ∨ represents the logical OR. In practice, checking interoperability relationships means looking at how two or more information systems work together. In other words, it is about analyzing the system requirements, the standard message format used by different applications, the architectural layers, the user and system interfaces, the data models, the protocols for exchanging data, and the understandability of the exchanged information. This can be done with the help of questionnaire.

Define and select the business domains:-

A business domain (DM) is a structuring element that allows business processes to be grouped into a separate module (Abdmouleh, 2004). These business processes can be implemented as a service composition. A DM comprises a set of orchestrated services that perform specific business process tasks. To better delineate the different DMs of an interoperable information system, we will use the business process analysis method. Business process analysis is a method for finding and understanding the sequence of tasks in an organization and their execution by software or humans. Thus, the artifacts produced in this step will be the formal definition of a business domain, an algorithm for delineating and selecting a business domain, the formal definition of a service, and the formal definition of a business process.

Formally, a business domain DM is a quintuplet, $DM = \langle N, S, CS, FS, RS \rangle$ where:

- N is the name of a business domain;
- S is the set of services in the domain that can be orchestrated like business processes;
- CS is a set of service consumers;
- FS is a set of service providers;
- RSis a service registry containing the discovered services that participate in the execution of business processes instances.

In networked enterprises, business domains can be composed of services from any of these information systems. Algorithm 1 is used to select the business domain in networked enterprises participating in the interoperability mechanism.

Algorithm 1: Selection of business domains
Input: $\widetilde{IS}$set of interoperable information systems
Output: Ω: set of business domains
Var: $n, p, m \in \mathbb{N}^*$.
Begin

- $\Omega = \emptyset$
- Provide the business process mapping of the networked enterprises.
- Group the business processes into master processes $\Delta = \{BP_1, \dots, BP_n\}$.
- Group master processes into functional areas $Z = \{DM_1, \dots, DM_p, p \leq n\}$, taking into account the common activities of the organizations.
- Name each functional area as a business domain.
- Select the business domains $\Omega = \{DM_1, \dots, DM_m, m \leq p\}$participating in the interoperability mechanism.
- Return Ω.

End:-

A business domain contains a set of services $S, s \in S$**. Formally, we define a service** s**as a tuple:** $s = \langle \textbf{Idtype}, \textbf{Name}, \textbf{Description}, \{\textbf{Port}\}, \textbf{QoS} \rangle$

- Idtype : unique identifier of the service that can be represented by a natural number.
- Name : represents the service's name.

- Description : service descriptions include data on services (execution dependencies, locations, memory size, functionalities). Services are hosted on local or remote registries and are described by description files.
- $\{\text{Port}\} = \{< \text{input} >, < \text{output} >\}$: represents the set of input and output ports of the service; it designates the address on which the service receives or sends messages.
- QoS : some of the most used QoS attributes for web services are described by (Cremene et al., 2016) as follow : response time (Re), availability (Av), reliability (Rel), price (Pr), user rating (Ur) and security (Sec).

An instance of a business process is an orchestrated set of services executable by following a control logic defined by flow relationships, which can be: sequence (seq), parallelism (par), iterations (ite), conditions (con), and synchronization (syn). Therefore, we formally define a business process as follows BP={bpn,$< s_1, s_{2,} \dots, s_n >$,FR} where :

bpn : business process name.

- $< s_1, s_{2,} \dots, s_n >$: a set of orchestrated services,
- $s_i, 1 \leq i \leq n$, $n \in \mathbb{N}^*$: the number of web services constituting the business process BP .
- $\text{FR} = \{\text{seq}, \text{par}, \text{ite}, \text{con}, \text{syn}\}$: flow relationship.

Build a dependency graph between services:-

We will use graph theory to abstractly represent the interoperable information systems of networked enterprises by the set of services contained in the service registries that belong only to the business processes that are part of the interoperability mechanism. The services are represented as nodes in a weighted directed graph. A service is connected to other services through its ports. A service receives messages through its input ports and sends messages through its output ports. The orientation of the arc indicates the direction of the exchanged message flow, and the weight of the arc reflects whether or not the exchanged information is useful to the target service. To build the dependency graph between the different services, we will label the arc with 1 if the information exchanged is useful, otherwise the arc is weighted with -1, and 0 means that no interaction occurred. Algorithm 2, which is another artifact that we build, allows us to build the dependency graph between the services that participate in interoperation mechanisms in networked enterprises.

Algorithm 2 : Service dependency graph
1. Gω = (V,Eω,W);Eω = ∅ ;
2. V = ∅ ;
3 S = {s1, s2, ..., sn} ;
4. p ∈ ParIn(oj); q ∈ ParOut(oi) ;
5. α ∈ [0, 1] ;
6. Selectionner le service point d'entree Select the service entry point sj ;
7. For si ∈ S \ sj do
8.If sim(p, q) ≥ α then
W(si, sj) = 1 ;
Eω = Eω ∪ (si, sj) ;
9. If sim(p, q) < α then
W(si, sj) = −1 ;
Eω = Eω ∪ (si, sj) ;
10. If (si, sj) = ∅then
W(si, sj) = 0
11. Return (Gω) ;

Definition 1. (Service dependency graph): Let S = {s1, ..., sn}be the service space containing all web services executing inter-organisational business process tasks. The service dependency graph is definedas the weighted directed graph Gω = (V,Eω,W) ,ω ∈ τ such that:

1. E ω = {(s_i, s_j) ∈ V × V , ∃ Output_i, Input_i∈ s_i , ∃ Output_j , Input_j∈ s_j :s_i.Output_is−e−n→ds_j .$\text{Input}_j$and s_j.Input_jr←e−c−ei−v−es_i.Output_i}.
2. W : E ω → {−1, 0, 1}, (s_i, s_j) → W(s_i, s_j) , W(s_i, s_j) = p , p ∈{−1, 0, 1}

Definition 2. (Dependency of operations): Let O = {o1, o2, ..., on}be the set of operations performed by all web services executing the tasks of business process. o_1 designates the set of operationsof the web service identified as 1, denoted s_1. ParOut(o_i) and ParIn(o_i) represent the output and input parameters of operation o_i, respectively. $\alpha \in [0, 1]$ is a given threshold and sim is the similarity function.Operation o_j depends on operation The operation o_j depends on the operationo_i if and only if:$\forall p \in$ ParIn(o_j), $\exists q \in$ ParOut(o_i) such that sim(p, q) $\geq \alpha$ wheresim(p, q) = 1 − NGD(p, q) .Where NGD(p, q) denotes the similarity factor between the two terms. TheNormalised Google Distance (NGD) is a measureof semantic similarity derived from the number of results returned by the Google search enginefor a given set of keywords.

Formalize the problem and define the solution:-

The problem of resource consumption optimization within inter-organizational business process execution aims to determine the set of useful web services, by optimizing the overall cost of resources, the time of interoperation and the numbers of interactions between web services executing the inter-organizational business process tasks in networked enterprises. Remember that the overall cost of resource consumption represents all the resources consumed when the information systems interoperation mechanism occurs at the service level that performs business process tasks in an enterprise network, despite the disruptions associated with their environments. The interoperation mechanism relies on interactions between services. Interaction means the exchange of data, models or information plus the value of the exchange (the information sent by the sender is useful to the receiver).

The information transfer, the significance of nodes and arcs, and the specific graph substructures serve as three guiding principles that highlight the value of using a weighted directed graph to represent services within interoperable information systems. With regard to information transfer, several areas of computer science use graph structures to model communications between components of computer systems and to characterize the connections between these components. Among these components, we have chosen web services, and connections between web services represent exchanges of messages, data, and information.

We consider an interoperable information system as a set of business processes defined in the form of web service orchestration. The orientation of the arc indicates the direction of information flow between the source web service and the target web service, and the weighting of the arc characterizes the interaction between two web services. If the interaction is successful, in our work we annotate the arc with 1, if the interaction has failed, we annotate the arc with -1, and the absence of interaction between two services is annotated with 0.

Graph theory defines a set of properties for nodes and arcs (diameter, connectedness, density, and centrality indicators) that enable us to measure the usefulness of a node or arc in communications in a graph. Thus, the search for appropriate abstractions of heterogeneous elements of information systems, such as web services, helps us take advantage of the properties of graphs to design the functional properties of interoperable information systems. What's more, within a graph, we can obtain sub-graphs with particular structures (related or strongly related graphs); these sub-graphs also enable us to highlight particular compositions of web services.

In our work, we don't consider the order of interactions. That is, if at one time T=t, service i sends information to service j, and at another time T=t+1, service j sends data to service i, the order in which the information is sent is not taken into account. However, this does not affect the dynamics of the environment, because when the unit of time is the second, the dependency graph between services, which can be represented by an interaction matrix, can vary.

Let MI be the interaction matrix derived from the dependency graph between services of interoperable information systems in networked enterprises. MIij represents the type of interaction between service i and service j. For each interaction between two services, an unanticipated event may occur in the information system that disrupts data transmission on either the source or target service side. These may include organizational contingencies (power cuts, low bandwidth) and security contingencies (network attacks disrupting service operation) as well as organizational culture and governance structures which can the total cost of interoperability.To clarify this assertion, we consider the IT governance framework defined by Van Grembergen and De Haes (2008), where the structure of the framework consist of the set of roles and responsibilities, IT organization structure, Chief Information Officer (CIO), IT strategy committee, and IT steering committee. So, at the level of governance structure, organizational changes and poor human competences are risks that can disrupt the interoperable information system environment. On the other hand, organizational culture encompasses the characteristics of people within the organization, their histories, practices, and values shared by employees, organizational ethics, beliefs, behaviors, and organizational structures.

For diagnosing organizational culture, the author (Parisa Aasi, 2018) presents an Organizational Culture Assessment Instrument (OCAI) developed by Cameron and Quinn (2011), based on six key dimensions to be evaluated, namely: the dominant characteristics of the organization, the leadership style and approach that permeate the organization, the management of employees or the style that characterizes how employees are treated, the organizational glue or bonding mechanisms that hold the organization together, the strategic emphases that define what areas of emphasis drive the organization's strategy, and the criteria of success that determine how victory is defined and what gets rewarded and celebrated. Assessing each of these dimensions within a networked enterprise can lead to failures that can constitute risks or disruptions in the information systems environment. We can therefore conclude that governance structures and organizational culture influence the management of the overall cost of resource consumption.

In our work, we have materialized these perturbations by a column vector R of size θ. An element Ri of R denotes the probability of the risk associated with service i; Ri ∈ [0; 1]. Formally, the problem of resource consumption optimization within inter-organizational business process execution can be defined as follows: let's consider θ interacting services of inter-organizational business processes of an interoperable information system of networked enterprises. Each service j ∈ {1;2;3;...; θ} is subject to a perturbation Rj associated with the information system environment and has an interoperability cost Cj defined by its time of interoperation and throughput. The problem of resource consumption optimization consists in finding the services with the best percentage of utility U that minimize the overall cost of resource consumption fval, while considering the constraints and the dynamic of information system environment. These constraints are expressed as mathematical inequalities (Coello et al., 2007). Finally, the resource consumption optimization model within inter-organizational business process execution is defined as follows:

$$\begin{cases} \min f(U)_{U\in\mathbb{R}^{\theta}} = \sum_{j=1}^{\theta} C_j U_j \\ \text{s.c } \sum_{j=1}^{\theta} MI_{ij} U_j \geq R_i \text{ , } i \in \{1\ ;2\ ;3\ ;\ldots\ ;\ \theta\}. \\ 0 \leq U \leq 1 \end{cases} \quad (1)$$

Problem formalization:-

- Objects to be analyzed: Interaction matrices between services MI of size θ* θ
- Question: How to determine the web services of inter-organizational business process instances with the best utility percentages U that minimize the overall cost of resource consumption fval?
- Solution: define an optimization model of resource consumption within business process execution as follows:

Resource consumption optimization model properties:-

- $\min f(U)_{U\in\mathbb{R}^{\theta}} = \sum_{j=1}^{\theta} C_j U_j$:means thatwe want to find the service utility vector U that minimizes the overall cost of resource consumption.
- $\sum_{j=1}^{\theta} MI_{ij} U_j > R_i$, $i \in \{1\ ;2\ ;3\ ;\ldots\ ;\ \theta\}$: this constraint means that the disruptions induced by the information systems environment must be less than the interactions between the services of inter-organizational business processes instances.
- $0 \leq U \leq 1$ **:** The utility percentage of the service can be 0% or 100%, so the vector's components are bounded between 0 and 1.
- U :column vector, representing the service utility vector, dimension θ.
- $f : \mathbb{R}^{\theta} \rightarrow \mathbb{R}$,the objective function or the fitness function. A fitness function that takes an input X, where X is a vector with as many elements as the number of variables in the problem, calculates the function's value and returns this scalar value in its return argument Y.
- Ci components of service interoperability cost vector. This value can be calculated using the other QoS attributes; in this paper, we only use response time and throughput.

- If $U_j \in [0;50[$, the service j is not useful for inter-organizational business process execution.
- If $U_j \in [50; 80[$, the service j is partially useful for inter-organizational business process execution.
- If $U_j \in [80;100]$, the service j is completely useful for inter-organizational business process execution.
- The fval value of the objective function, represents the overall cost of resource consumption in inter-organizational business process execution.

Calculation of service interoperability cost vector components:-

We calculate the components of service interoperability cost vector C using QoS attributes that emphasize exchanges between services throughput (Th) and the time of interoperation. As defined by (Koulou et al., 2020), the time of interoperation encompasses the request time (t_{req}), treatment time (t_{treat}), return time (t_{ret}), and time to use (t_{use}). TIj and Thj represent respectively the time of interoperation and the throughput of the service j.

We have: $TI_j \in [\,TI_0;\ TI_{max}\,]$; $Th_j \in [\,Th_0;\ Th_{max}\,]$ and $TI_j = \sqrt[4]{t_{req} \times t_{treat} \times t_{ret} \times t_{use}}$

- TI_0 : represents the theoretical minimum time of interoperation that we aim to achieve, which improves the business process interoperability performance.
- TI_{max} : represents the theoretical maximum response time that degrades the business process interoperability performance.
- Th_0 : represents the theoretical minimum flow rate or throughput that degrades the business process interoperability performance.
- Th_{max} : represents the theoretical maximum throughput that we aim to achieve, which improves the business process interoperability performance.

To compensate for the different units of measurement between the different QoS attribute values, the values need to be normalized to lie within the interval [0; 1]. (Agushaka J. O. et al., 2010) For example, time of interoperation should be normalized by minimization, while throughput should be normalized by maximization.(Agushaka J. O. et al., 2010) The interoperability cost Cj of the service j is given by the formula:

$$C_j = \left(\frac{Vmax_{TI} - TI_j}{Vmax_{TI} - Vmin_{TI}} + \frac{Th_j - Vmin_{Th}}{Vmax_{Th} - Vmin_{Th}}\right) \quad (2)$$

- $Vmax_{TI}$: represents the maximum time of interoperation of all services participating in the interoperability mechanism.
- $Vmin_{TI}$: represents the minimum time of interoperation of all services participating in the interoperability mechanism.
- $Vmax_{Th}$: represents the maximum throughput value of all services participating in the interoperability mechanism.
- $Vmin_{Th}$: represents the minimum throughput value for all services participating in the interoperability mechanism.
- θ : is the number of services.
- TI_j : represents the effective time of interoperation of service j.
- Th_j : represents the effective throughput of service j.

We can state the strategy adopted by the enterprises to minimize the overall cost of resource consumption while maximizing the benefits of collaboration and information exchange as follows: “Choose web services for orchestrating business processes with a low time of interoperation and a high throughput. These web services will be assigned to each activity of the business processes”. To this strategy, we add the fact that enterprises should adopt standardized IT processes and technologies, streamline these processes for reducing resource utilization.

To summarize, the steps taken to determine the overall cost of the interoperability are :

- Transform the dependency graph between services into a matrix, which we have named the service interaction matrix MI .
- Define the risks associated to the interoperable information system environment that could disrupt exchanges between the web services implementing the business process tasks R.
- Calculate the interoperability cost associated with each service C_j, equation (2), taking into account response time and throughput, which are service quality attributes.
- Take into consideration the components of the service utility vector U, which are the problem variables.

- Determine the solution of equation (1), which is the extreme vector U^*, such that $f(U^*) \leq f(U)$, $\forall U \in \mathbb{R}^\theta$. Thus, it is the optimal solution of the problem $f(U^*)$that gives the optimal value fval, $f(U^*) =$ fval , which in our work represents the overall cost of interoperability.

The factors that contribute to the determination of this cost are the service interaction matrix MI, the risk vector associated with the interoperable information system R, service interoperability cost vector C and Ucolumn vector, representing the utility vector of services. After defining how to calculate the interoperability cost of a particular service, the next section is devoted to the demonstration stage of the Design Science Methodology.

Demonstration:-

This activity demonstrates the use of the artifact to solve one or more instances of the problem and could include its use in experiments, simulations, case studies, proofs, or any other appropriate activity (vom Brocke et al., 2020). In this work, we will use the Factory Group case study (da Silva Serapião Leal, 2019) as an example. In order to make better use of this case study, we will divide this section into two subsections: context and application. In the context subsection, we will briefly present the case study. In the application subsection, we will test the constrained nonlinear optimization model for interoperability cost analysis in networked enterprises.

Context of the case study:-

The following example is based on a case study carried out within the Factory Group (da Silva Serapião Leal, 2019). We reuse this example to evaluate the constrained nonlinear optimization model for interoperability cost analysis in networked enterprises, using the different services orchestrated by the business process under study. In this example, the author considers a scenario of collaboration and interoperation among the companies that are members of The Factory Group (TFG). TFG consists of four independent and autonomous companies: Exxus, Concept Factory, Sustain, and Interact. The business scenario described in this study involves the creation of a brand image for client X. Only Exxus and Concept Factory are involved in this process. For the purposes of this case study, each company has a single information system that can be considered its business domain. To contextualize this case study in our work, we have decided to name each business domain DMex, DMcf, and DMx, respectively, the business domains of Exxus, Concept Factory, and the client X business. Based on the related business process of this case study (Figure 2), each activity lane represents a DM and contains a set of tasks that can be implemented and executed by a specific web service.To construct the dependency graph of services in this scenario, we assume that in the workflow, messages exchanged with sequence links marked "no" mean that the target service is unable to use the data models provided by a sender for a particular task. Therefore, the arc of the graph is marked with -1, otherwise with 1. The next subsection presents Table 2, which describes the services of each DM with dummy QoS attributes, then the dependency graph between services is given, and finally the interaction matrix is presented.

Application of the case study:-

We will follow the predefined approach to present the case study:-

Verification of the type of interoperability:-

The author (da Silva Serapião Leal, 2019) uses a questionnaire to verify the type of interoperability and states that the members of TFG Enterprises have a low interoperability maturity, although this does not systematically imply dysfunction at all levels and for all functions of the company. After this assessment, the author proposes a list of best practices to eliminate or reduce the negative impact of the identified interoperability barriers. In this work, we consider that the proposed best practices have been implemented by the companies members of TFG and their information systems are at least partially interoperable, although some disruptions related to organizational interoperability (lack of an organizational chart), technical interoperability (access to the storage of administrative data) and semantic interoperability remain unresolved.

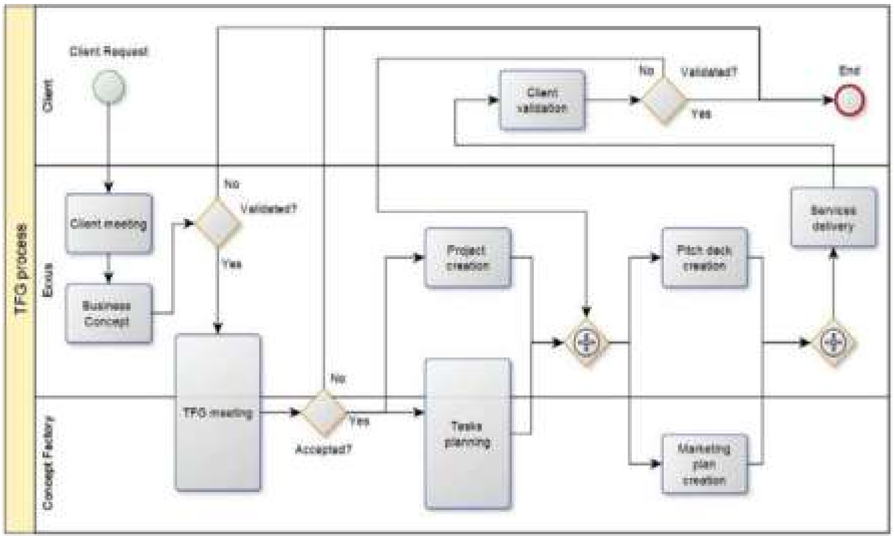

Figure 2: The TFG overall collaborative process(da Silva Serapião Leal, 2019).

Definition of the business domains and services:-

The TFG business process (figure 2) is a composition of services; each task in the process is implemented by a specific service, and each lane is considered like a business domain (DM). In table 2 below, we define the services contained in the service registry of the DMx, DMex, and DMcf, respectively.

Creation of the dependency graph between services:-

Based on the discovery of services in the previous step, we apply Algorithm 2 and obtain the graph G=(V,E), where the weight of the arcs is numbered as a power. V = {1,2,3,4,5,6,7,8,9,10,11} ; E = $\{(1,4)^1; (2,3)^1; (3,3)^1; (2,7)^{-1}; (2,11)^{-1}; (4,5)^1; (5,3)^{-1}; (5,9)^1; (6;7)^1; (6,11)^1; (7,8)^1; (8,2)^1, (9,10)^1; (9,6)^1; (9,3)^{-1}; (10,7)^1; (10,11)^1; (11, 8)^1\}$.

Application of the resource consumption optimization model:-

We apply the model to evaluate the cost of interoperability of information systems, or the total cost of interoperability, in the networked enterprises constituted by the TFG group and the collaborative enterprise of client X. For this purpose, we instantiate the model based on the previous analysis of the problem.

Business Domain (DM)	Service Registry (RS)	Service Name	Services Representations
DMx	RSx	client request (cr)	<1; cr; TI:12; Th:5;{ <->, <out1> }>
		client validation(cv)	<2; cv; TI:11; Th:6; {<out8>,<out2, out2', out2''>}>
		end task (en)	<3; en; TI:2; Th:18; {<out2,in3,out5,out9>,<out3>}>
DMex	RSex	client meeting(cm)	<4; cm; Re:4; Th:17; {< out1>,<out4>}>
		business concept(bc)	<5; bc; TI:4; Th:16; {<out4>,<out5, out5'>}>
		project creation(pc)	<6; pc; TI:20; Th:200; {<out9'>,<out6, out6'>}>
		pitch deck creation(pd)	<7; pd; TI:40; Th:300; {<out2',out6, out10>,<out7>}>
		service delivery(sd)	<8; sd; TI:400; Th:700; {<out11, out7>,<out8>}>
DMcf	RScf	tfg meeting (tm)	<9; tm; TI:2; Th:750;{<out5'>,<out9, out9', out9''>}>
		task planning(tp)	<10; tp; TI:1; Th:800; {<out9''>;<out10, out10'>}>

		marketing plan (mp)	<11; mp; TI:100; Th:400; {<out2'',out10',out6'>,<out11>}>

Table 2: Description of the business domains and their services

Calculate the component C_i of the vector C with VmaxTI = 400; VminTI=1; VmaxTh = 800; VminTh=6. We have to solve this equation $\min f(X) = \sum_{j=1}^{11} C_j U_j$ while respecting the constraints.

$$\text{Subject to}\begin{cases}\begin{pmatrix} 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & -1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{pmatrix}\begin{pmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \\ U_5 \\ U_6 \\ U_7 \\ U_8 \\ U_9 \\ U_{10} \\ U_{11} \end{pmatrix} \geq \begin{pmatrix} 0{,}5 \\ 0{,}5 \\ 0{,}5 \\ 0{,}5 \\ 0{,}5 \\ 0{,}5 \\ 0{,}5 \\ 0{,}5 \\ 0{,}5 \\ 0{,}5 \\ 0{,}5 \end{pmatrix} \\ 0 \leq U \leq 1 \end{cases}$$

Service (j)	TI(j)	Th(j)	Cj
1	12	5	0,971171632
2	11	6	0,974937343
3	2	18	1,012607084
4	4	17	1,006335107
5	4	16	1,005075661
6	20	200	1,196713446
7	40	300	1,272532717
8	400	700	0,874055416
9	2	750	1,934521442
10	1	800	2
11	100	400	1,248101362

Table 3: Service interoperation costs To solve this system, we use Matlab R2016a and we obtain the following results.

fval	U_1	U_2	U_3	U_4	U_5	U_6	U_7	U_8	U_9	U_{10}	U_{11}
9.7935	0%	100%	87,36%	100%	0%	80,30%	31,45%	49,97%	100%	100%	31,00%

Table 3: Results

The next section is devoted to the evaluation step of the Design Science Research Methodology, which provide the discussion phase of our study.

Evaluation:-

The evaluation measures how well the artifact supports the solution of the problem (vom Brocke et al., 2020). This step helps us to have a discussion about the results obtained. Specifically, to show how the model provides a better understanding of the problem of resource consumption optimization among the members of the TFG group of companies. The U vector contains the decision variables, provide the utility percentage of a service. Based on the properties of the model, if Uj ∈ [0;50[, the service j is not useful for the execution of the business process; if Uj ∈ [50; 80[, the service j is partially useful for the execution of the business process; if Uj ∈ [80;100], the service is fully useful for the execution of the business process. In our case study, services 1, 5, 7, 8, and 11 are not useful for business process execution, so they contribute to increasing the overall cost of resource consumption. Decision makers may decide to remove these services from the business process and replace them with similar services that provide the same type of functionality. Services 2, 3, 4, 6, 9, and 10 are fully useful for business process execution, and the total cost is 9.7935, which is greater than 1, so the resource are overused in the studied process and remove unnecessary web service can optimize the consumption of the resource in the business process.

Conclusion:-

In this paper, we have presented a new model, based on graph theory, to improve collaboration between companies through their information systems. This model is the resource consumption optimization model within inter-organizational business process execution. It was developed following the research methodology of design science. The model was validated by testing the resource consumption within an inter-organizational business process to create a brand image for a customer. The results show that certain web services in the process increase the consumption of resources during the execution of the inter-organizational business process. To overcome these shortcomings, decision makers need to remove the unnecessary web services, the barriers to interoperability and the disruptions associated with the IS environment, thereby reducing the likelihood of risks associated with the interaction of one service with another. The future work will involve testing the model on a larger number of services.

References:-

1. Agushaka J. O. et al. (2010). Effect of Weighting Scheme to QoS Properties in Web Service Discovery ((IJCSIS) International Journal of Computer Science and Information Security, Vol. 7, No. 3, March 2010). (IJCSIS)
2. Chen, D. (2006). Enterprise Interoperability Framework. Https://Www.Researchgate.Net/Publication/220921500, 6.
3. Chen, Y., Annebicque, D., Philippot, A., Carre-Menetrier, V., & Daneau, T. (2023). Evaluation Methodology of Interoperability for the Industrial Domain : Standardization vs. Mediation. Processes, 11(4), 1274. https://doi.org/10.3390/pr11041274
4. Cremene, M., Suciu, M., Pallez, D., & Dumitrescu, D. (2016). Comparative analysis of multi-objective evolutionary algorithms for QoS-aware web service composition. Applied Soft Computing, 39, 124-139. https://doi.org/10.1016/j.asoc.2015.11.012
5. da Silva Serapião Leal. (2019). Decision Support for Interoperability Readiness in Networked Enterprises. Thèse. Universite de Lorraine, 216.
6. Kompella, L. (2020). Role of organisational aspects in requirements engineering processes of a socio-technical system : Insights from e-governance case studies. International Journal of Electronic Governance, 12(2), 113. https://doi.org/10.1504/IJEG.2020.109551
7. Koulou, A., Zemzami, M., El Hami, N., Elmir, A., & Hmina, N. (2020). Optimization in collaborative information systems for an enhanced interoperability network. International Journal for Simulation and Multidisciplinary Design Optimization, 11, 2. https://doi.org/10.1051/smdo/2019021
8. Mork, P., Melo, W., Dutcher, S., Curtis, C., & Scroggs, M. (2014). Cost Estimation for Model-Driven Interoperability : A Canonical Data Modeling Approach. 2014 14th International Conference on Quality Software, 145-153. https://doi.org/10.1109/QSIC.2014.51
9. Parisa Aasi. (2018). Information Technology Governance : The role of organizational culture and structure [PhD Thesis]. Stockholm University.
10. vom Brocke, J., Hevner, A., & Maedche, A. (2020). Introduction to Design Science Research. In J. vom Brocke, A. Hevner, & A. Maedche (Eds.), Design Science Research. Cases (p. 1-13). Springer International Publishing. https://doi.org/10.1007/978-3-030-46781-4_1
11. Yahia, E. (2011). Contribution à l'evaluation de l'interoperabilite semantique entre systèmes d'information d'entreprise : Application aux systèmes d'information de pilotage de la production. Sciences de l'ingenieur [physics]. Universite Henri Poincare - Nancy 1. Français. NNT : 2011NAN10049.tel-01746201v2, 162.
12. Zhao, J. L., & Cheng, H. K. (2005). Web services and process management : A union of convenience or a new area of research? Decision Support Systems, 40(1), 1-8. https://doi.org/10.1016/j.dss.2004.04.002