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SIMULATION AND OPTIMIZATION OF INTEROPERABILITY PLANNING

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ABSTRACT

Optimizing Resource allocation and effort dispatching of interoperability enhancement is a key requirement to effectively setup, develop and evolve intra and inter organizational collaboration. To ensure this objective of effectiveness, this paper proposes initially an approach for representation of interoperability evolution and planning. Interoperability degree is assessed using a ratio metric taking into account all the significant aspects such as potentiality, compatibility and operational performance. In a second stage, a Modified Particle Swarm optimization (MPSO) algorithm is used as a heuristic optimization method to find the best distribution of effort needed in collaborative networks.

Keywords: *Interoperability planning, Effort dispatching, Simulation, Particle Swarm optimization*

1. INTRODUCTION

The present work focuses on applying heuristic mechanisms to optimize efforts required to improve the interoperability level of a business collaborative network. Interoperability involves the interconnection of several information systems located within a single organization or across a group of partners in collaboration.

Interoperability implementation involves usually different teams from independent entities. Effort dispatching, in such integration projects, requires advanced negotiations that could lead to divergences.

Therefore, as a measurement method, this work proposes to use *RatIop* [1] which is an interoperability composite metric that takes into account the three main following aspects:

– Interoperability maturity level of the environment where the studied information systems are located.

– Compatibility degree of the external interfaces of the information systems.

– Operational performance of the IT infrastructure that supports these systems.

This paper proposes as a first step to represent interconnected information system interoperability evolution over time with linear modelling. This is an innovative representation which opens the possibilities of several forms of usage that aims to manipulate interoperability on a large scale area.

As a heuristic method, it is proposed to use Modified Particle Swarm Optimization (MPSO) [2] which is known as an efficient approach with a high performance of solving optimization problems in many research fields. PSO based algorithms use population intelligence mechanisms inspired by social behavior simulations of bird flocking.

In this article, the second section is devoted to interoperability characterization. The third section reminds the five steps of *RatIop* measurement method. The fourth section describes how *RatIop* method is coupled with linear modelling in order to monitor interoperability evolution. The fifth section describes the used MPSO algorithm. The last section presents results analysis of the proposed contribution.

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2. INTEROPERABILITY CHARACTERIZATION

Interoperability is a research topic that attracted a lot of interest during the past three decades. In fact, Ford et al. list more than thirty definitions of this quality [3]. It concerns a system to system cooperation and characterizes «the ability, for any number of processing information systems, to interact and exchange information and services between them» [1].

Such a definition points to the «external nature» of the ability to interoperate. Indeed, the interoperation success depends not only on the system itself but also on the ecosystem in which it operates and on the underlying components with which it may collaborate. In addition, interoperability means both the ability to cooperate and the performance of interoperation.

2.1. Interoperability classification

To implement interoperability, enterprises in collaboration face technical and semantic difficulties but also organizational challenges. Moreover, monitoring interoperability is not easy on such a macroscopic level.

In fact, interoperability is a quality that can be viewed from various perspectives. Authors of [1] propose an illustrative classification for interoperability in integrated e-service delivery context structured over six axis as depicted in Figure 1:

– Several taxonomies have been proposed in this direction. In this sense, there are:

– Many levels of interoperability concern: business, process, service and data level.

– Various approaches to implement interoperability: integrated, federated, and unified approach.

– Multiple barriers could handicap interoperation: conceptual, organizational and technical barriers.

– Different scopes of application: within the same organization, cross independent organizations,

– Different transactional aspects of cooperation: synchronous or asynchronous collaboration.

– Diverse measurement perspectives: potentiality, compatibility, performance efficiency.

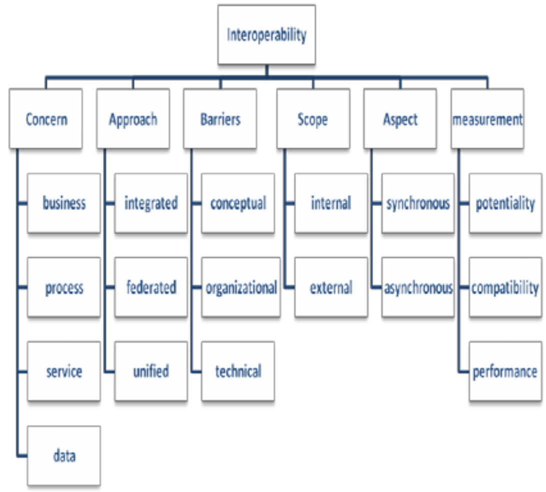

Figure 1 : Interoperability classification [1]

The present paper is more interested in the last axe present in Figure 1 which is interoperability measurement. In this sense, we can enumerate the three following aspects [4]:

– Interoperation potentiality: it is an «internal quality» of the system that reflects its preparation to interoperate. This involves identifying a set of characteristics that have an impact on communication with partner's systems without necessarily having concrete information on them. The objective is to foster interoperability readiness by eliminating barriers that may obstruct the interaction.

– Interoperation compatibility: it is an «external quality». Indeed, the ability of two support systems to interact is ensured through an engineering process aiming to establish interoperation between them.

– Interoperation performance: the third aspect characterizes the «quality in use» and focuses on monitoring operational performance. It consists of an assessment of the availability of the communication infrastructure, and the supporting system in general.

In this sense, Authors of *RatIop* model [1] propose in 2010, a new composite metric used to measure this quality by taking into account the three main operational aspects: potentiality, compatibility and performance monitoring. This work defines a practical process for interoperability characterization with a scalar ratio. This process uses existing data within an organization (quality maturity indicators, information technology dashboards, etc.).

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3. RATIOP

This section reminds the main stages of *RatIop* model explained in [1]. This method uses five steps to assess interoperability (See Figure 2):

1. Delineating the interoperation scope.
2. Quantifying the interoperation potentiality.
3. Calculating the compatibility degree.
4. Evaluating the operating performance.
5. Aggregating the degree of interoperability.

3.1 Delineating the scope of the study

Interoperability characterization of an information system requires the knowledge of its ecosystem. In fact, the quality of interaction between two systems S1 and S2 can be excellent, while the interoperation between systems S1 and S3 may be deficient and so require to be improved. In this case, the first phase is to identify the system to study and then list the underlying information systems of which we try to study the quality of interaction.

In general, the focus can be put on a macro business process consisting of a set of sub automated processes. These processes are linked together by several interactions identified in advance. The analysis will be held in this context: we identify the ecosystem surrounding each information system and the interactions that govern its relationship with the outside.

3.2 Quantifying the interoperation potentiality

Many interoperability maturity models (IMM) are proposed to describe the interoperation potentiality. Authors of [5] list:

- ITIM (IT Investment Management),
- LISI (Level of Information System Interoperability),
- OIMM (Organizational Interoperability Maturity Model),
- EIMM (Enterprise Interoperability Maturity Model),
- GIMM (Government Interoperability Maturity Matrix),
- SPICE (Software Process Improvement and Capability determination).

These models are usually structured into five levels.

The calculation of the potential for interoperability «PI» within an organization requires the adoption of a maturity model. The organization is classified then in one of these five levels noted IMML (interoperation maturity model level). To identify the potential degree of interoperability, we propose then the following mapping (See Table 1):

Maturity Level (IMML)	Potentiality quantification
1	0.2
2	0.4
3	0.6
4	0.8
5	1

Table 1: Quantification of the maturity of the interoperability

The potential is calculated using the following formula (See (1)):

$$PI = 0.2 * IMML \quad (1)$$

3.3 Calculating the compatibility degree

In order to open an information system to its ecosystem, there is a necessity to study the external interfaces of its support systems. In this phase, the degree of compatibility «DC» is calculated on the basis of a mapping between the underlying components and the adjacent IT systems.

Several studies have focused on the interoperation compatibility characterization. For instance, author of [6] identifies several indicators to describe this compatibility.

To assess the compatibility degree, we can consider using a modified version of the matrix of [7]. (See Table 2). It consists of a combination of the “levels perspective” and “the barriers perspective” seen in section 2.1. In practical terms, we enumerate conceptual, technical and organizational barriers in the different levels of interoperability concern: business, process, service and data. Therefore, if the criteria in an area marked satisfaction the value 1 is assigned; otherwise, the 0 value is assigned if a lot of incompatibilities are met.

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	Conceptual		Organizational		Technology	
	Syntactic	Semantic	Authorities responsibilities	Organization	Platform	Communication
Business	dc_{11}	dc_{12}	dc_{13}	dc_{14}	dc_{15}	dc_{16}
Process	dc_{21}	dc_{22}	dc_{23}	dc_{24}	dc_{25}	dc_{26}
Service	dc_{31}	dc_{32}	dc_{33}	dc_{34}	dc_{35}	dc_{36}
Data	dc_{41}	dc_{42}	dc_{43}	dc_{44}	dc_{45}	dc_{46}

Table 2 : interoperability compatibility

By noting the elementary degree of interoperation compatibility «dc_{ij}» (i takes values from 1..4, and j takes values from 1..6). The degree of compatibility «DC» is given as follows (See formula (2)):

$$DC = \sum_i \sum_j \frac{dc_{ij}}{24} \qquad (2)$$

3.4 Evaluation of operating performance

The operational performance «PO» assessment is done on the basis of IT dashboards of the organization. It takes into account indicators as the availability score of the application servers, communication quality of service, and the end users degree of satisfaction about the interoperation in use. This information is collected based on surveying key end users.

By Denoting:

- «DS» the overall availability rate of application servers.
- «QoS» service quality of different networks used for interacting components communication. QoS is represented mainly by the overall availability of networks.
- «TS» end users' satisfaction level about interoperation.

Given the cumulative nature of these three rates, the evaluation of operational performance is given by the geometric mean [8] (See formula. (3)):

$$PO = \sqrt[3]{(DS * QoS * TS)} \qquad (3)$$

3.5 Aggregating the degree of interoperability

The final calculation of the ratio characterizing the interoperability process in question is obtained by aggregating the three previous indicators using a function f defined in (0,1)3 → (0,1) (See formula. (4)):

$$RatIop=f\,(PI, DC, PO) \qquad (4)$$

Given the independent nature of these three indicators, we opt for using the arithmetic mean [8] as aggregation function (See formula. (5)):

$$RatIop = \frac{(PI + DC + PO)}{3} \qquad (5)$$

In case the IT department has elements for pondering each one of these three indicators with different weights (n1, n2, n3); we choose the weighted arithmetic mean. (See formula (6))

$$RatIop = \frac{(n_1 * PI + n_2 * DC + n_3 * PO)}{(n_1 + n_2 + n_3)} \qquad (6)$$

4. MULTI PROJECTS RESOURCE ALLOCATION

Business Interoperability implementation project within a collaboration network and across independent organizations can be seen as a multi-projects environment that targets a unified objective of collaboration but involves different teams in order to interconnect independent information systems [10].

In such environment, the challenge considered in such environment is resource allocation and effort dispatching in order to effectively establish interoperability on a projected level. The optimal allocation of effort refers to an optimization problem whose objective is to optimize the overall effort and better distribute it in a multi project implementation of interoperability.

In this section, we try to obtain the optimum distribution of effort in order to establish a specific organizational collaboration situation

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RatIop is a centric assessment approach that aims to quantify on a scalar form interoperability degree of an information system within its ecosystem.

RatIop stipulates that interoperability improvement of an information system is obtained by implementing changes in its supporting system and also bringing improvement on the external interfaces of the interlinked systems.

Coupling *RatIop* method with linear modeling tends to characterize the evolution of the overall interoperability degree of a set of interconnected information systems. It monitors the efforts needed to improve interoperability degree of the collaboration network.

To illustrate this, let's take a set of "n" systems (S1, S2,…, Sn). We suppose:

- Each system is ensured within one organization.
- Each information system is automated and supported by exactly one IT infrastructure.
- Each system may interact with any other systems.
- The IT systems have the ability to interoperate in a homogeneous way with the environment.

We associate to each system Si a ratio ai=RatIop(Si) representing interoperability degree within its ecosystem;

We aim to monitor the evolution of this indicator in a macroscopic way.

The vector I(a1,..,an) evolves in accordance with the effort made to adapt the internetworked system from the current As-is state to the target To-Be state in terms of the enterprise architecture vision.

By denoting:

$I=(a_i)$ represents the current interoperability vector.

$I'=(a'_i)$ represents the target interoperability vector.

We have for each a system Si

$$a'_i = \sum E_{ij} a_j. \quad (7)$$

Eij represents the effort to make on the Si system in order to improve the Sj system.

$E=(E_{ij})$ the matrix effort to make in order to reach the target interoperability.

$$I' = E\, I. \quad (8)$$

Or

$$\begin{pmatrix} E_{11} & E_{12} & \dots & E_{1n} \\ E_{21} & E_{22} & \dots & E_{2n} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ E_{n1} & E_{n2} & \dots & E_{nn} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ \dots \\ \dots \\ a_n \end{pmatrix} = \begin{pmatrix} a'_1 \\ a'_2 \\ \dots \\ \dots \\ a'_n \end{pmatrix}$$

If each system S_i is compatible with all other systems and there is no explicit barrier that impedes interaction, E_{ij} is equivalent to the ratio of workload N_{ij} (workload allocated to the improvement of the external interfaces of S_i to facilitate the S_j RatIop) over the overall workload allocated to interoperability enhancement [10].

$$E_{ij}=N_{ij}/N_{overall} \quad (9)$$

In this case, our goal is to find the optimal effort to reach the targeted interoperability vector.

So, the objective function to minimize is

$$a'_i - \sum_i \sum_j E_{ij} \cdot a_i \le 0 \quad (10)$$

The constraints are for each j:

$$\sum_i E_{ij} \le 100\% \quad (11)$$

Eij is to be multiplied with $N_i/N_{overall}$ with $N_i=\sum N_{ij}$

To optimize the objective function (10) with respecting the constraints in (11) it is possible to use deterministic techniques such the gradient function. But with problems with large dimensions these techniques remains inefficient in terms of performance. Heuristic algorithms such Particle Swarm Optimization [9] is a promising discipline to explore in this area.

5. MODIFIED PARTICLE SWARM OPTIMIZATION

The Particle Swarm Optimization (PSO), developed by Kennedy and Eberharts in 1995, is an approximation algorithm method proposed for the optimization problem of finding the global minimum [9]. Since then, it has been improved by many searchers. The principal of this algorithm is based on the movement of birds searching for a food in a flock; this animal behaviour is simulated to the optimization research. This method generates

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a group of particles, each one search for the minimum of the fitness by their own knowledge and movement, and is influenced by the search of his neighbour. If a particle finds a good site, all the others can become aware of it more or less directly, in order to take advantage of it.

5.1 Modified PSO Algorithm.

In Particle Swarm Optimization algorithm (PSO), each particle i is treated as a point in a space with dimension D, a position X_i, a velocity V_i and a personal best position X_{besti}. The personal best position associated with a particle i is the best position that the particle has visited. The best positions of all particles in the swarm are represented by the vector X_{gbest}.[11]

$X_i = (x_{i1}, x_{i2},\ldots,x_{id})$ is the position of the particle.

$V_i = (v_{i1}, v_{i2},\ldots,v_{id})$ is the velocity of the particle.

$X_{besti} = (p_{i1}, p_{i2},\ldots\ldots,p_{id})$ is the best personal position.

$X_{gbest} = (p_{g1}, p_{g2},\ldots\ldots,p_{gd})$ is the best global position of the swarm.

$1 \leq i \leq n$: n is the dimension of the problem representing the position X_i

$1 \leq d \leq D$: D is the space dimension of the swarm (Number of particles)

$$V_{id}(t + 1) = \chi (V_{id}(t) + \rho_1(X_{besti}(t) - X_i(t)) + \rho_2 (X_{gbest}(t) - X_i(t))) \quad (12)$$

$$X_{id}(t + 1) = X_{id}(t) + V_{id}(t + 1) \quad (13)$$

Where $\rho_1 = c_1 r_1$ and $\rho_2 = c_2 r_2$

c_1 and c_2 : positive acceleration components called social parameter.

r_1 and r_2 : Independent random number in the rang (0; 1).

χ: constriction coefficient.

We modified the velocity function by using a new term X_{Nbest} in the Eq.12 defined as:

$X_{Nbest} = (p_{n1}, p_{n2}\ldots\ldots\ldots p_{nd})$ the best position of the neighborhood.

The Eq.12 becomes:

$$V_{id}(t + 1) = \chi (V_{id}(t) + \rho 1 (X_{besti}(t) - X_i(t)) + \rho 2 (X_{gbest}(t) - X_i(t)) + \rho 3 (X_{Nbest}(t) - X_i(t))) \quad (14)$$

Where $\rho_3 = c_3 r_3$

c_3: positive acceleration components called social parameter.

r_3: Independent random number in the rang (0; 1).

The initialization of the swarm and velocities are usually performed randomly in the search space, following a uniform distribution. The best positions are initially set equal to the initial swarm. After the first time increment, the particles moved by the velocity V_i in Eq. 14. Then the algorithm searches for optima by updating generations.

The acceleration constants c_1, c_2 and c_3 in Eq. 14 represent the weighting of the stochastic acceleration terms that pull each particle towards X_{besti}, X_{gbest} and X_{Nbest} positions. c_1 represents the confidence that the particle has in itself, c_2 represents the confidence that the particle has in the swarm and c_3 represents the confidence that the particle has in his neighbor.

In most cases, the acceleration parameters c_1, c_2 and c_3 are affected to 1, however, if we want to eliminate the particle's own experience we take $c_1 = 0$; $c_2 = 1$ and $c_3 = 1$ or eliminate the influence of the best of the swarm we take $c_1 = 1$; $c_2 = 0$ and $c_3 = 1$ or we eliminate the influence of the best of the neighbor we take $c_1 = 1$; $c_2 = 1$ and $c_3 = 0$. Depending on the problems to resolve we can make the appropriate choices for these parameters to modify the velocity and to promote convergence.

The search procedure of a population-based algorithm such as PSO consists on the concept of neighborhood; the information regarding the best position of each neighborhood is gradually communicated to the rest of the particles through their neighbors in the ring topology. We have neighborhoods that consist of particles belong to different partitions. In this case, particles with different behaviors can interact by sharing information through their neighborhoods.

All particles in a neighbor share the same value of X_{Nbest} and each neighbor has a different value of X_{Nbest}. It is important to respect the number of particles that comprise the neighborhoods, therefore, in our experiments the swarm was divided into 7 partitions. In general there is no formal procedure to determine the optimal number or the size of the neighbor but case by case depending on the problems to resolve [11].

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5.2 Pseudo-code of Particle Swarm Optimization

Initialization
X_i ← Generate the initial particles of the swarm randomly.
V_i ← Generate the initial velocity of the particles randomly.
X_{besti} ← X_i Set the best positions to a randomized particle position.
X_{qbest} ← X_i Set the best positions of the swarm to a randomized particle position.
X_{Nbest} ← X_i Set the best positions of the neighbour to a randomized particle position.
Repeat
  ***For** i = 1 : N (All particles in the Swarm)*
    Fitnessi(t) ← Evaluate Fitness(Xi)
    ***if** Fitnessi(t) < Fitness(X_{besti})(t)*
      Xbesti ← Xi particle attractor
  end
  ***For** j = 1 : M (M number of neighbours in the Swarm)*
  $X_{Nbest(i)}$ ← defining the best position in every neighbour.
    End For
    ***if** Fitnessi(t) < Fitness(X_{qbest})(t)*
      X_{qesti} ← Xi swarm attractor
    end
    Update velocity $V_{id}(t + 1)$ in Eq 6
    Update position $X_{id}(t + 1)$ in Eq 5
    ***if** $X_{id}(t + 1)$ < Xmin OR $X_{id}(t + 1)$ > Xmax*
      $X_{id}(t + 1)$ ← Xrandom Xrandom €[XminXmax]
    end
  End For
***Until** Stop criterion*

Figure 2 : Pseudo code of PSO Algorithm

6. CASE STUDY AND RESULTS

To well illustrate the application of optimization method that couples *RatIop* and PSO, we take the case of 10 information systems that interact within an organization (See Figure 3).

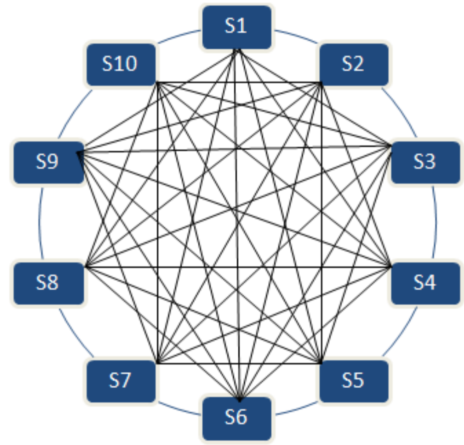

Figure 3: Interaction model of involved IS

After an initial assessment of interoperability degree of each cited system, we notice that they have respectively reached the values of: (0.62, 0.48, 0.8, 0.66, 0.75, 0.45, 0.58, 0.72, 0.63, 0.4) (see figure 4).

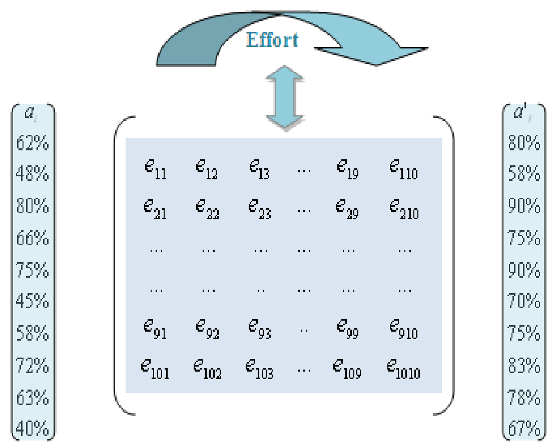

Figure 4: Interaction model of involved IS

Information System actors in accordance with business teams, target for the coming six months to improve interoperability degree of this collaboration situation and define the objective to reach respectively the values of: (0.8, 0.58, 0.9, 0.75, 0.9, 0.7, 0.75, 0.83, 0.78, 0.67).

In this case, we apply PSO algorithm to find the optimum matrix of effort that minimize the objective function and comply with the constraints in equation (11). So, in our case, the optimal effort Eij is represented in the following matrix in figure 5:

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17,33%	7,03%	29,28%	15,32%	11,73%	1,37%	2,46%	2,54%	9,98%	2,95%
5,41%	5,06%	26,64%	8,08%	9,75%	3,57%	12,54%	12,95%	15,34%	0,66%
1,90%	3,26%	9,65%	10,88%	17,82%	6,25%	12,74%	27,85%	7,44%	2,21%
6,35%	7,77%	22,22%	7,01%	13,48%	8,10%	9,93%	8,72%	16,25%	0,17%
4,45%	2,75%	21,93%	6,44%	39,96%	6,41%	0,33%	3,69%	9,07%	4,96%
2,97%	12,25%	23,12%	4,79%	20,09%	8,17%	3,06%	9,27%	15,74%	0,56%
5,03%	2,55%	20,93%	21,39%	7,38%	15,47%	6,98%	4,98%	13,00%	2,29%
7,59%	2,88%	18,61%	12,42%	18,73%	4,00%	7,70%	14,27%	10,57%	3,23%
8,33%	4,80%	20,22%	9,59%	17,37%	2,75%	11,49%	7,47%	14,81%	3,18%
4,75%	4,29%	32,51%	8,38%	12,95%	11,72%	3,12%	15,74%	3,55%	2,99%

Figure 5: Interoperability evolution owing to implementation Effort

6.1 Results analysis

In this paper we have presented an efficient approach for effort distribution optimization method for interoperability enhancement. First of all, we assess interoperability degree of an information systems network using the *RatIop* metric. Secondly, we define a desired interoperability degree to achieve. The proposed Enhanced *RatIop* method is able to optimize the system and propose a theoretical optimum effort required to reach the objective. This distribution is to be compared with the integration architects proposals regarding the estimation of effort needed to interface the involved information systems.

Indeed, if architects propose an estimate close to our theoretical result so this proposal can be accepted. Otherwise, the project manager invites architects to rethink their estimates.

6.2 Interoperability optimal control

The proposed result provides a visibility on the optimum configuration in the field of possible solutions.

It Helps teams to converge towards the proposed optimal theoretical solution

The result may not be realistic in practice although it respects the constraints. This can still be used by integration architects to approach the solution.

The performance improvement is always possible: All we need is to adjust the target interoperability vector and the system generates a new effort matrix. The optimization system is fully configurable, it can run as many times as necessary.

The size of the interoperability vectors in the practical case is 10 (number of information system to interact effectively). When the dimension exceeds 20, 30, etc., the prediction of the optimal effort matrix in a manual way becomes almost impossible. Our system is very well suited to large problems and offer optimal solutions within the constraints, and can be continually improved.

7. CONCLUSION

This paper studies interoperability as a quality characteristic of information systems interaction intra and inter organizations. It proposes a novel linear model to describe workload needed to enhance interoperability implementation. This linear model is coupled with Particle Swarm Optimization algorithm in order to propose optimum distribution of effort in a collaboration situation. Throughout this proposal, we use a ratio metric to measure this quality by taking into account the three main operational aspects: potentiality, compatibility and performance monitoring.

Many Analyses are listed in order to achieve an optimal control of interoperability implementation.

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