# Proposal for Modeling a Coalition Interoperability

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## Abstract

Nations are taking part in coalitions to face an unusual situation such as a crisis or a latent conflict. These coalitions are formed for the purpose of increasing efficiency, by the coordinated action of military means and their related technical systems, for instance : networks, C4IRS. In merging these systems, we have to cope with a major problem, which is to have heterogeneous systems to (**inter)cooperate.** We intentionally use this neologism to highlight the fact that we have to reflect about new exchange mechanisms, differing completely from the simple exchange messages (or data). This heterogeneity remains an intricate problem for a coalition in the process of being formed, often because of enormous interoperability deficiencies. Since the solution of making gateway is not easily and reasonably generalized, we are obliged to get a new vision of what can be an **interoperability mechanism** for a system entering into a coalition**.** In this paper, we propose a formal approach to model a coalition interoperability. This one is relying on three main concepts : openness structure for a coalition, interoperability space with the definition of an interoperability matrix, intercooperability domain which enables us to define parameters allowing to assess interoperability-systems from different points of view.

**Keywords** : interoperability, cooperative systems, distributed systems, knowledge shareability.

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## 1 Motivation

A great deal of important transformations generated by the evolution of geopolitical and geostrategical context implies the responsibility of the international community as soon as a crisis or a conflict is emerging. All nations in a position to share this ''responsibility'', whatever may be their dimension on the international scene, are therefore more and more often involved in international coalitions. These coalitions are formed with the aim of an increased efficiency, by the coordinated action of military means and the gathering of their relating technical systems : networks, C4IRS. The different systems put in the coalition must **(inter)cooperate** for executing a common mission fixed by the coalition authority (under particular conditions and temporal constraints). The term (inter)cooperate is intentionally used, at that point, to highlight the communication type required in a coalition framework. This one completely exceeds the simple exchange messages as we are going to show it later on. At that point, we can illustrate that by the example of a person who realizes, either by a lack of knowledge or insufficient know-how, that he alone cannot achieve an objective, he is going to request the other people's assistance. In explaining his case, the person specifies a "context of openness" in a potential cooperative framework in order for the others to bring the right assistance. So, when people are bringing a mutual assistance, they must place themselves in a cooperative framework. This coalition cannot be successful if its members are not willing :

- To exchange the most part of knowledge they have about the problem that makes their intervention necessary. This must be enriched as long as the process is going on (validity of a knowledge may be depending on time).
- To exchange know-how in operating processes and methods application.
- To share, timely and in appropriate conditions, useful knowledge for the evolution and the action of other agents of the cooperation.

What we can say at that point is that each participant of the cooperation framework may be of a great help to others if and only if they are willing to add "intelligence"[1] at the different levels of the interoperability mechanisms.

In the coalition's perspective, the first step one has to consider is to make these systems (inter)cooperate to achieve a mission. But one has a real and major problem to cope with, because most of the time, they are **heterogeneous** (most of the time an heterogeneity, inherent to national design and employment concepts), as a result, they present enormous deficiencies at the interoperability level. One could object that it is always possible, to solve this question by making gateways, but one should be aware of what that represents a temporary solution. Moreover, this solution cannot be easily and reasonably generalized. Such a generalization is getting more difficult as the number of systems is increasing (dependence on combinations (n,2)). Therefore, what seems more reasonable is to design new concepts of **interoperability mechanisms** which can be implemented in each of them.

### *1.1 Space of interoperability*

In our approach, we propose to define a space in which we will make a distinction as in [Bares-1996], between three domains relevant to interoperability. These domains are obviously structured and, they in addition have semantic links[2].

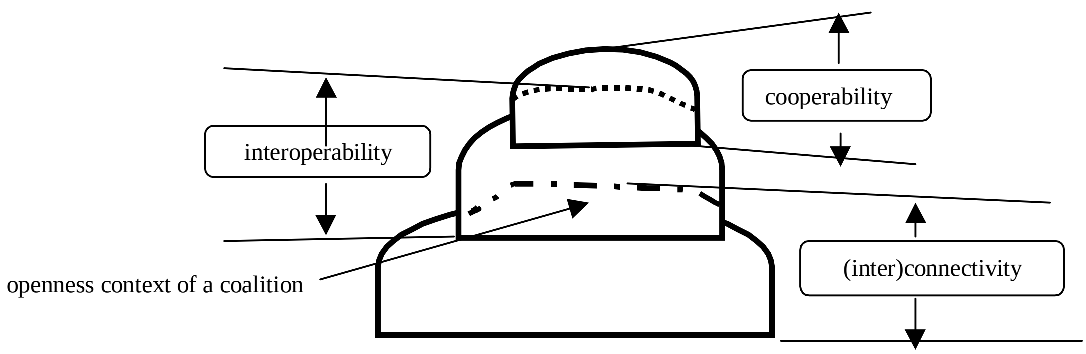


Fig 1 Domains concerned by a coalition

#### *1.1.a (Inter)connectivity domain:*

This concerns essentially all necessary means to allow systems to communicate with each other, through a liaison and its relevant software mechanisms. We will consider interconnectivity in our approach as a prerequisite of interoperability.

#### *1.1.b Interoperability domain :*

If we consider now that C4IRS systems must exchange more than simple messages, i.e., knowledge, we must go beyond interconnectivity framework, because the exchange of knowledge supposes that we have symbolic representations to carry this knowledge. Moreover, C3I systems in the future will be called upon, to bring each other a mutual assistance (a requisite in the NATO definition of C3IS) in their cooperative action to reach a common objective. In such a perspective, C4IRS systems must

[1] In the sense of artificial intelligence
[2] in particular necessary because of knowledge shareability

be in a position to have a mutual comprehension of what they are doing, of what processes they are performing, and so on. That makes necessary to introduce semantic notions in the interoperability domain and also to determine modalities that enable to add''intelligence'' and how to interpret it, in the exchange mechanisms. At that point, the interoperability domain can be characterized by the following points :

- A C4IRS becomes interoperable when it can organize itself and enrich its exchanges within an **openness context** characterizing the coalition.
- The precedent point represents a necessary but not a sufficient condition in an interoperable exchange; in addition, we need to have a common vision of the universe in which systems are going to cooperate with others.
- It must start by taking into account semantics in the mechanism of exchange.

***1.1.c Intercooperability domain :***

This represents the final objective to reach, through the definition of a world, in which all (cooperative) systems are able to share all elements constituting their common activity in the coalition; but also, to take systematically advantage of everything that is appealing to intelligent behavior.

### *1.2 Introduction to the openness concept*

The role of what is called in this paragraph **openness context**, is to specify, beyond interconnectivity, ways and limits of opening (systems) which are necessary to have a basic interoperability within the coalition framework. So in our view, openness will constitute the first and necessary step of interoperability.

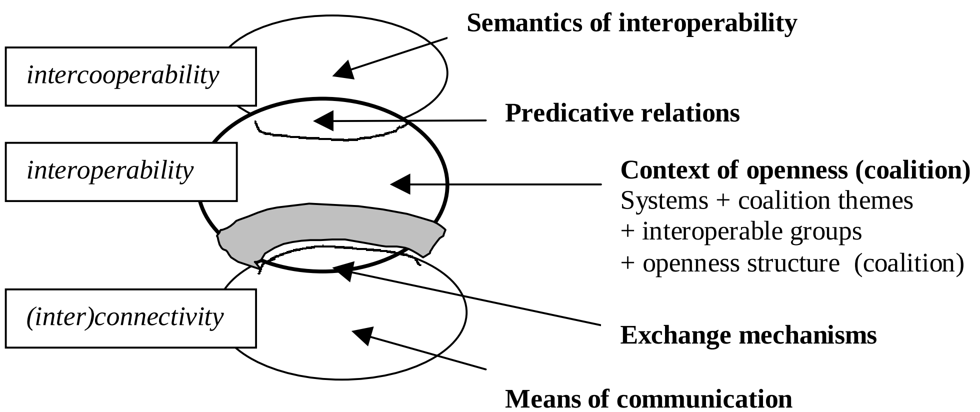


Fig. 2 Openness context role in interoperability

First of all, we will consider that a coalition can be identified by :

- Coalition-themes pertaining to the global mission assigned to the coalition, for instance : medical assistance or civil rescue (depending on politics of the involved allied nations); they are also regarded as a set of knowledge required for it and describing a speciality, a feature, an ability.
- Specific missions devoted to systems, a mission that can be regarded as a set of elementary (interoperable) actions that may be devoted to the different systems participating to the coalition.

We will have to mention what systems are involved and how they are related (relationships existing between systems and themes of the coalition).

- *Designation of a system* :

A **system i** will be referenced by : $\mathbf{S}^{\mathbf{i}}$ where $i \in [1, n]$, (n = number of systems placed in the coalition). They are supposed to be able to share a minimum common knowledge and to have common comprehension of fundamental orders.

- *Designation of coalition-theme* :

A **coalition-theme t** will be referenced by $\mathbf{T}_t$ with $t \in [1, q]$ (q is the maximal number of themes of the coalition). These coalition-themes can be stated by syntactic formulas obeying the syntactic rules of a formal language.

- *Designation of an action*

$\mathbf{T}_t$ encompasses a variable number of elementary actions (depending on the mission). An **action j** will be referenced by $\mathbf{A_j}$.

## 2 Coalition openness concept

After having designated basic elements taking part to the coalition, we have to determine the network of existing relationships between systems and the coalition-themes in a formal way. In doing so we will define the concept of a context of openness (the formalization of which is based on some mathematical notions : relations, Galois connections).

### *2.1 Definition of a context of openness*

In introducing the concept of **openness context** we indicate, in a semantic point of view, what necessary links may be attached to coalition-themes and systems operating in the coalition. It will be formally defined by a triplet :

(S, T, R),

where : $S :: \{S^1, \ldots, S^n\}$ the set of the systems, in the coalition,

$T :: \{T_1, \ldots T_q\}$ the set of the themes specified in the coalition,

R is a binary relation : : $R \subset S \times T$.

The context may be given a priori when the coalition, put in place, is defining the mission of every system. It can be also defined a posteriori when the coalition is running and evolving.

For example :

Three different nations are asked to interoperate within the framework coalition for rescuing civil people in an African state. The coalition is defined as follows :

- 3 nation-systems $S^1$, $S^2$, $S^3$ are concerned,

-3 coalition-themes are fixed : ground evacuation operations ($T_1$), airborne transportation ($T_2$), and logistical medical aid ($T_3$).

This supposes first that systems can (inter)operate on different actions relevant to the coalition-themes and secondly they exchange knowledge required to achieve their respective missions. Let us suppose, in defining the openness context, we then obtain following couples :

$R(S^1, T_1), R(S^1, T_2), R(S^1, T_3), R(S^2, T_1), R(S^2, T_2), R(S^2, T_3), R(S^3, T_1), R(S^3, T_2)., R(S^3, T_3) \subset S \times T$

This openness context is summarized by the table :

| Relation R | $T_1$ | $T_2$ | $T_3$ |
|---|---|---|---|
| $S^1$ | * | * | * |
| $S^2$ | * | * | * |
| $S^3$ | * | * | * |

Tab. 1 Openness context example

This is a particular case where relation **R** on $\{S^1, S^2, S^3\} \times \{T_1, T_2, T_3\}$ is **total.**

Considering strictly the semantic point of view, systems are totally open to the themes involved in this coalition. This example describes a situation which is ideal and will rarely take place in reality. The subset $\{S^1, S^2, S^3\}$, must be considered as **totally open** on the subset $\{T_1, T_2, T_3\}$.

Consequently, we get a unique totally open couple in the sense of a Galois connection:

$$(\{S^1, S^2, S^3\} \times \{T_1, T_2, T_3\})$$

### *2.2 Interoperable Group (IG) notion*

Table 1 describes an ideal case, because all systems of the set S are totally open to all themes of the set T.

We will define a condition of openness :

$$\exists\, i, t \mid S^i \in S \text{ and } T_t \in T, \text{ and } \nexists\, (S^i, T_t) \subset R \subset S \times T.$$
$$i \in [1,2,..,n],\ t \in [1,2,..,q]$$

We will define an (totally) **interoperable group** as :

interoperable-group :: < IG-#( < s >ρ< t >) > [3]

where : s ∈ P (S) and p∈ P (T)

Remark:

ρ : to indicate that R is a total relation on **s** x **t**, the subset **s** is totally open on the subset **t.**

\# : all IG must be numbered to construct the lattice of the openness coalition later on.

In other words, there exists only one dependency between the subset s and the subset t.

### *2.3 Openness structure of a coalition*

The IG represents an interesting notion because it enables us to represent formally a structure of the coalition openness. We are actually going to obtain a formal structure with interesting properties, in particular these ones of a lattice. Let us illustrate that with an example, for that purpose, we consider a coalition C whose openness context is given by the following table :

| | $T_1$ | $T_2$ | $T_3$ | $T_4$ | $T_5$ | $T_6$ |
|---|---|---|---|---|---|---|
| $S^1$ | * | * | | | * | * |
| $S^2$ | | * | * | * | * | |
| $S^3$ | * | | * | | * | |

Tab. 2 openness structure of the cooperation C

First of all, we notice that the openness context of C is composed of 8 subsets of systems. In view of what precedes we can “translate” this context through IG and we will obtain one after the other :

IG-1 ( $\{S^1, S^2, S^3\}$ ρ $\{T_5\}$ ),

IG-2 ( $\{S^1, S^2\}$ ρ $\{T_2, T_5\}$ ) ,

IG-3 ( $\{S^1, S^3\}$ ρ $\{T_1, T_5\}$ ) ,

IG-4 ( $\{S^2, S^3\}$ ρ $\{T_3, T_5\}$ ) ,

IG-5 ( $\{S^1\}$ ρ $\{T_1, T_2, T_5, T_6\}$ ) ,

IG-6 ( $\{S^2\}$ ρ $\{T_2, T_3, T_4, T_5\}$ ) ,

IG- 7 ( $\{S^3\}$ ρ $\{T_1, T_3, T_5\}$ ) ,

IG-8 ( $\{\emptyset\}$ ρ $\{T_1, T_2, T_3, T_4, T_5, T_6\}$ ).

We are able to construct a diagram with the different IG we previously determined. As shown below, the nodes of the graph correspond to numbers IG.

[3] the symbol : : indicates a definition

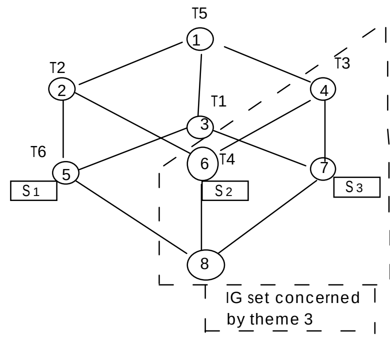


Fig. 3 Openness structure of a coalition C

Fig. 3, which represents the only possible openness structure of the coalition C. This one is obviously depending on the way of fixing the context. This openness structure presents a great deal of interest because from this diagram, we can interpret easily the openness structure when considering the following points :

- Every IG indexed by a number inherits all coalition-themes linked up to it in the diagram.
- Every node number is constituted of all the systems which are linked down to it.
- From this diagram we can envisage different consequences of C decision-makers'acts upon basic interoperability: elimination of a link, assignment of a system to a coalition-theme, suppression of themes or restriction of a node for security reason, et cetera.

## 3 Specificity of the interoperability space

As told previously, the openness context is representing the first component of the interoperability space, in the sense that we have determined first criteria concerning the coalition conditions, which must be taken into account later on, particularly in predicative relations of interoperability cf. § 3.2 . Space interoperability relies upon different notions whose certain of them are appearing on the figure below.

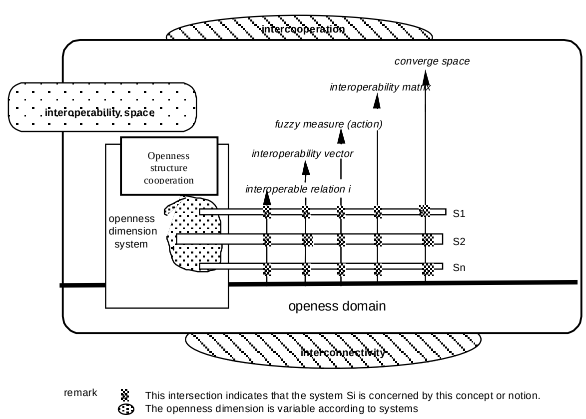


Fig. 4 Interoperability space

### *3.1 Interoperable action characteristics*

We will consider that an action is not interoperable with itself, but only with system(s) that is (are) able to handle it. For that reason, we will always designate an interoperable action by a couple :

$(S^i, A_j)$ where $S^i \in S$, $A_j \in A$ (the set of all allowed actions of the coalition)

Remark : This couple : $(S^i, A_j)$ must encompass time variable (reification), because systems, and more actions, are likely to be modified in run time. We will consider that its validity will depend on a **temporal window** or « opportunity window », which will be denoted as follows :

$(S^i, A_j, \theta_M)$ : the system i acts (or (inter)operates) on the action j, in a temporal interval θ, assigned to the mission M.

The time parameters will be fixed by those who are in charge of the coalition.

### *3.2 Predicative relation of interoperability*

We will now define a **relation** $\Re$, in a propositional calculus view, the arity of which is 3, and by which any system evaluates its aptitude to operate with an action of the coalition. This relation must be applied by every system and to every action of the coalition.

we form the proposition : $\Re(S^i, \{A_j\}, \theta_M)$,

$\forall$ i $\in$ [1, n], (n : number of systems in the coalition), $\forall$ j $\in$ [1, p],

$S^i$ considers that it is competent to interoperate on different(s) action(s) belonging to $\{A_j\}$,

We suppose that all $A_j$ can be described in a formal way (formal language words).

Each system is bound to determine a first condition, **necessary** but not **sufficient** of its interoperability. According to its own knowledge (and truths it can get) of its neighboring world, a system is able to say if it has required competence to interoperate on such an action. In fact, the relation $\Re$ which allows to define an **effective interoperability** : a system $S^i$ can evaluate its competence to operate on any action, in window time θ attached to the mission framework M, under normal and usual conditions.

As $\Re( S^i, A_j, \theta_M)$ is considered like a proposition, so we can assign a truth value to it :

Val [ $\Re( S^i, A_j, \theta_M)$ ] :: True (T/1),

means : $S^i$ can interoperate on $A_j$, in time window θ, fixed by mission M. $\forall$ i $\in$ [1, n], $\forall$ j $\in$ [1, p]

Val [ $\Re( S^i, A_j, \theta_M )$ ] :: False (F/0) $\Rightarrow$ **interoperability incapicity** of $S^i$ on $A_j$

Remark : In practice, those who are responsible for $S^i$ are entitled to apply this relation, and thus, to decide about the (in)capacity of their interoperability in light of the current context in which they are going to act (in a formal way, $S^i$ is interpreting in its own possible world).

### *3.3 Fuzzy representation of an interoperable action*

A fuzzy measure refers to a means of expressing uncertainty when, not disposing of complete information, it is impossible to use probability. We are going to determine numerical coefficients (in a subjective way), or **certainty degrees**, to indicate how it is **necessary** for a system to interoperate on (or with) such an action beforehand declared **possible**. In doing the (reasonable) hypothesis that a system only executes one interoperable action at a time, we can for instance, form a **universe W** from the following singletons :

$W = \{ (S^i, A_1), (S^i, A_2), (S^p, A_3), ...,(S^q, A_n)...\}$, with : $d (S^i, A_n)$ :: degree of possibility

$d (S^i, A_n) \in [0, 1]$, this value assesses the possibility which $S^i$ executes the action $A_n$.

A fuzzy measure is completely defined as soon as a coefficient of possibility has been attached to every subset of a **universal set U**. If the cardinal number is n, to be rigorous, we must state $2^n$ coefficients, in order to specify the measure of possibility. Here, we will proceed more simply in observing that each subset of U may be regarded as an union of singletons it encompasses. So, the determination of the possibilistic measure can be done from only n elements. To define an interoperable action we here introduce :

(a) A **feasibility** measure comparable to a possibility,
(b) A **imperativity** measurecomparable to a necessity which will be dual of (a),
(c) A **credibility** measure to assess trust put by systems in the fulfillment of an action by anyone of them.

(a), (b), will be defined by distributions of possibility. Therefore we will represent an interoperable measure in a "fuzzy cube".

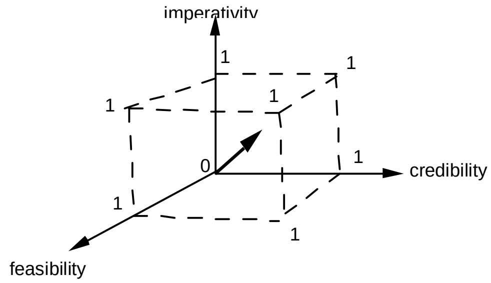


Fig. 5 Fuzzy representation of an interoperable action

### *3.4 Fuzzy matrices of interoperability*

For a given system $S^i$, if we successively apply the relation $\Re$ to couples $(S^i, A_j)$, j varying from 1 to p, we obtain for example:

$$\mathrm{Val}\,[\Re\,(S^i, A_1)\,] :: T$$
$$\mathrm{Val}\,[\Re\,(S^i, A_3)\,] ::: F$$
..........................
$$\mathrm{Val}\,[\Re\,(S^i, A_p)\,] :: T$$

Tab. 3 Application of the predicative relation of interoperability

We bring together these elements in order to get a binary vector. There are as many vectors as systems in the coalition.

Let a component of vector $V(S^i)_j$ ( row j), if we have :

$\mathrm{Val}\,[\,V\,(S^i)\,]_j :: F \Rightarrow \neg\exists\,\Re\,(S^i, A_j)$ (in the present openness context) ,

therefore, $S^i$ has no semantics to evaluate, $[\,V\,(S^i)\,]_j$ is not supposed to exist.

From the binary vector, or from the (logic) world resulting of the application of $\Re$, it becomes possible to affect fuzzy measures to each vector components whenever the value is not false. These fuzzy vectors are established in taking :

either couples of the world $\Re$ , such as : $((V\,(S^i)_{j\,=\,1,2,..p}) :: 1$,

or vector's elements $V\,(S^i)$, such as : $[[\,V\,(S^i)_{j\,=\,1,2,..,p}\,]]\,(\Re\,) :: 1$.

We assign a fuzzy measure to them, corresponding to 3 dimensions, as described in Fig. 5 :

$$\Phi\,(S^i, A_j) \rightarrow \text{measure of feasibility,}$$
$$N\,(S^i, A_j) \rightarrow \text{ measure of imperativity}$$
$$\lambda\,(S^i, A_j) \rightarrow \text{measure of credibility.}$$
$$i \in [1, n],\ \ j \in [1, p]$$

Every system is able to establish its own interoperability vectors.

whenever for $j \in [1, p]$, $\mathrm{Val}\,(V\,(S^i)_j) = T \rightarrow$ semantics evaluation to do.

This evaluation of the semantics has been made necessary because : either unpredictable facts arrived in the own system's world or an unexpected mission could have modified the world of $S^i$; which means that $A_j$ has no longer the same meaning for the system $S^i$ and possibly also for the coalition. In gathering all vectors of interoperability $V(S^i)$, we get what we call an **interoperability matrix**.

$$[\,I\,(S^i)_{i\,=\,1,2,..,n}\,] = [\,V(S^1)\,V(S^2)\,......V(S^n)]$$

This matrix represents only an **apparent interoperability**. It can be used in different ways :

- to indicate what is theoretically the most interoperable system, relatively to a determined action,

- to give the most adequate system to operate under special conditions : a mission which imposes a temporal constraint to operate an action. We will construct three kinds of fuzzy interoperability matrices.

***a) Matrix of feasible interoperability***

This matrix gives a dimension of feasibility of the interoperability of $\{S^i\}$ will be denoted by :

$$[\ I\text{-}\Phi\ (S^i)_{i = 1,2,\ldots,n}\ ]$$

***b) Matrix of imperative interoperability***

The matrix of necessary interoperability is also constructed with fuzzy vectors of necessity as described above. It presents a great interest in informing us about necessary conditions which are imposed on some systems in their way of interoperating. This matrix will be denoted by :

$$[\ I\text{-}N\ (S^i)_{i = 1,2,\ldots,n}\ ]$$

Example with 3 systems and 4 actions :

$$\left[I - N(S^i)_{i=1,2,3}\right] = \begin{bmatrix} 0.8 & 0.8 & 0.0 \\ 0.0 & 0.6 & 0.8 \\ 0.8 & 0.0 & 0.6 \\ 0.8 & 0.6 & 0.8 \end{bmatrix}$$

Tab. 4 Matrix of imperative interoperability

We observe that in the previous matrix, system 1 must have the strongest interoperability in spite of its component $I(S^i)_{2,1} = 0$, which can incidentally indicate an interdiction to interoperate on action $A_2$.

***c) Matrix of credible interoperability***

This matrix gives us a visibility on systems which are in the best position to interoperate successfully. It will be denoted by :

$$[\ I\text{-}\lambda\ (S^i)_{i = 1,2,\ldots,n}\ ]$$

Example with 3 systems and 4 actions :

$$\left[I - \lambda(S^i)_{i=1,2,3}\right] = \begin{bmatrix} 0.3 & 0.0 & 0.3 \\ 0.0 & 0.0 & 0.3 \\ 0.8 & 0.3 & 0.3 \\ 0.3 & 0.6 & 0.3 \end{bmatrix}$$

Tab. 5 Matrix of credible interoperability

We observe that in this example, system 2 presents little degrees of credibility; this means that all systems consider that it is liable to be the least to interoperate successfully in the coalition.

## 4 Cooperability space concept

In this paragraph, we will try to go beyond the system interpretation regarding actions, and to see how any systems can interpret the other systems ability for interoperating on actions. What one can summarize simplistically :

(1) interoperability $(S^i) \rightarrow$ system $S^i$ interprets $[\ S^i$ (interoperability) / {action(s)}], $\forall\ i \in [1, n]$

(2) intercooperability $(S^i) \rightarrow$ systems $\{S^k\}$ interprets $[(S^i)$ interoperability /{action(s)}], $\forall$ i, k $\in$ [1, n]

We can still illustrate (1) and (2) in an explicit manner :

*(1) for the domain of interoperability cf. fig. 2:*

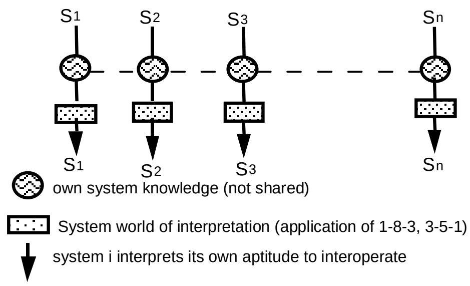


Fig. 6 Interpretation in the interoperability domain

*(2) for the domain of intercooperability cf. fig. 2:*

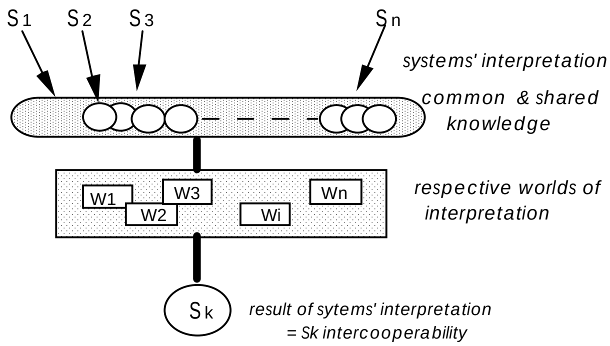


Fig. 7 Interpretation in the intercooperability domain

### 4.1 *Predicative relation of intercooperability*

When defining the relation of the predicative relation of interoperability in § 3.2, we have considered that systems, obviously placed in a symbolic context, are able to interpret their own ability to interoperate on actions as requested by different missions in the coalition. In this paragraph, we are now envisaging to go beyond, by seeking to extend the system interpretation ability in defining a predicative **relation of intercooperability.**

We will consider that a system $S^i$ has a competence in intercooperability when, it will be able to "judge" the ability of adjoining (cooperative) systems to interoperate on a set of actions $\{A_j\}$, in a time window $\theta_M$. This competence will be denoted by a quadruplet :

$S^i / S^k$, $\{ A_j \}$, $\theta_M$ (the symbol / indicates the way of interpretation)

$\forall i,\ k \in [1,n],\ j \in [1, p]$

We will define a predicative relation of intercooperability in the same way we do for the predicative relation of interoperability. This one will be designated by $\Re'$, in the following conditions :

$\Re'$ :: « is able to (inter)cooperate »

$\Re'$ :: « interpret the other systems' aptitude to interoperate on $\{A_j\}$ », we form the predicate relation

$\Re'$ [ $S^i / (S^k, \{A_j\}, \theta_M)$ ] $\forall$ i, k $\in [1, n]$, $\forall$ j $\in [1, p]$.

This means that : $S^i$ judges that (its confidence in the success of) $S^k$ is able to interoperate on $\{A_j\}$ in the time-window $\theta_M$ (this evaluation is made with a fuzzy measure of credibility).

In a predicate calculus view, the relation $\Re'$ defined in these conditions, is equivalent to a **propositional function**: $S^i$, $S^k$, $A_j$, representing the variable. $\theta_M$ may be considered here as a constant [4]. So, for a given $S^i$, we can evaluate the truth value of the predicate : $S^k$ is interoperable on each $A_{j=1,2,..,p}$

[4] We make the hypothesis that the time-window limits are well defined in the coalition.

(1) if Val $[\Re'[S^i / (S^k, \{A_j\}\theta_M)]]$ :: True,
that means : $S^i$ interprets that $S^k$ is able to interoperate on the actions $\{Aj\}_{j=1,...,p}$,
(2) if Val $[\Re'[S^i / (S^k, \{A_j\})]]$:: False,
$S^i$ considers that $S^k$ is unable to interoperate on $\{Aj\}_{j=1,...,p}$,

Nota bene : $\theta_M$ has been considered as a constant in (1) and (2), for previously mentioned reasons.

***4.2 Fuzzy Intercooperability matrices***

In gathering the vectors of intercooperability, we will get what we are now call an **intercooperabilility matrix**. Although the interoperability matrix is unique, it is necessary to establish two categories of matrices in the domain of intercooperability.

1) The first category, called **intercooperability-system,** is going to indicate how the set of systems interpret their respective interoperability .

2) The second one, called **intercooperability-action**, is regarding actions, i.e. a matrix to comprehend the interoperability of the coalition from its elementary actions.

***4.3 Matrix of intercooperability-systems***

Now the question is to comprehend how the set of systems of the coalition, interprets the ability of interoperating one another. Let us keep in mind that all systems are more or less interoperable according to the other systems judgment (knowledge shareability). The intercooperability matrix of a system $S^i$ will be denoted : **[C($S^i$)]** and presents a great interest. In fact, we can make special computations with rows and columns of **[C($S^i$)**]. Therefore, we obtain some interesting elements to characterize what we are going to call **intercooperability capacity** of the coalition, i.e. the visibility about the more or less easiness of system interoperation.

***Properties of a column***

Let $[C(S^k)]$ be the matrix of intercooperability-system of the system $S^k$, and consider the $m^{th}$ column of this matrix. If we sum up all components of the **vector-column m** of the matrix $[C(S^k)]$, we are going to get a certain scalar, designated by : $\alpha_c(S^k)$.

$$\alpha_c(S^k) = \sum_{j=1}^{p} \left[C(S^k)\right]_{j,m}$$

this scalar indicates how $S^m$ assesses the interoperability « strength » of $S^k$ regarding the actions of the cooperation. By way of an example it can be interesting to examine the following cases and consequences for the coalition :

$\alpha_c(S^k) = 0$,

according to its evaluation, $S^m$ considers that the system $S^k$, is not interoperable : $S^k$, must play no role in the coalition because it is unable to execute any actions. This does not mean that $S^k$, has no interoperable capacity, as long as we do not know the other systems' assessment. In the cooperation framework, several issues are possible :

- Is there a misjudgment between $S^m$ and $S^k$, ?
- Is there anything in common between $S^m$ and $S^k$, , like knowledge, processes, etc.?

$S^m$ and $S^k$, cannot work together for reasons (the coalition would be better off if it tries to explain).

$\alpha_c(S^k) \neq$ **0,**

That means $S^m$ trusts more or less in the aptitude of $S^k$ to interoperate with however a distinction :

if $\alpha_c(S^k)$ is in close proximity to 0, its trust is weak and $S^m$ thinks that $S^k$, is likely to fail in its interoperating processes,

if $\alpha_c(S^k)$ is in close proximity to 1, its trust is very strong, $S^k$, must be strongly successful in its interoperations.

### *4.4 Matrix of intercooperability-action*

We now define an other kind of fuzzy matrix which enables us to get a visibility of the intercooperability of all systems of the coalition. This special matrix is going to indicate the systems which are in the best conditions to interoperate on actions. These matrices will be called **matrices of intercooperability-action** for that reason**.** Let us go back to the matrices of intecooperability-system; if we take the $j^{th}$ row in each of the previous matrices, we can form a new matrix that reports about the systems intercooperability capacity relatively to the action $A_j$. This matrix will be denoted by $[C(A_j)]$.

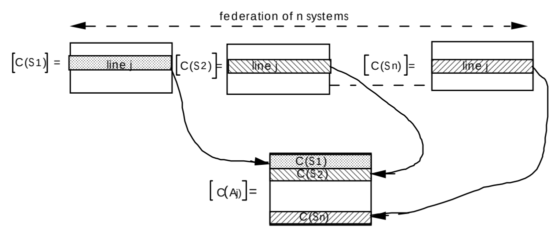


Fig. 6 Matrix of intercooperability-action

The matrix of intercooperability-action presents interesting features :
- its shape is square,
- it allows to understand what are the systems of the coalition which are in the best position to interoperate on such an action $A_j$,
- it gives an idea about the lesser or greater systems easiness to interoperate on particular actions,
- its columns and rows have interesting characteristics.

If we compute the p matrices corresponding to all actions of the coalition, we have a good visibility of the intercooperability in the coalition framework. That means we are able to say :
- what are the actions which are difficult to carry out, and
- what are the ones which are likely either to get the coalition into trouble or to force the coalition to face difficult issues.

## 5 Conclusion

In this paper, we have began to introduce a notion of openness for a coalition : openness context and interoperable group. We have afterwards demonstrated that it was possible to formalize the structure openness of a coalition and to get interesting properties. Then we have defined an interoperable action in using three kinds of fuzzy measures **: feasibility, imperativity, credibility (**determined through distribution of possibility). By introducing a predicative interoperability relation, we have shown that it was possible to construct a vector of **effective interoperability**, resulting of the system interpretation in its own logic world. This way, we got a quantitative evaluation of interoperability pertaining to a system of the coalition. The gathering of fuzzy vectors of interoperability enables us to define fuzzy **matrices of interoperability** which gives a right visibility on the global interoperability pertaining all systems of the coalition. We afterwards went beyond this ability of a system to interpret its own ability to interoperate and to see how it could interpret the other systems' ability for interoperating on actions. For that purpose, we have extended the relation of interoperability through a predicative relation of intercooperability. This relation enlarges our comprehension of interoperability. We established two kinds of matrices; the first one regarding the global systems interoperability, the other one concerning the easiness to be interoperable on actions. These matrices also present interesting properties, which have allowed us to establish a whole family of parameters which represents a first significant step in our way of seeing the interoperability issue.

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