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THE INTEROPERABILITY INDEX MODEL: IMPROVING THE I-SCORE MODEL FOR INTEROPERABILITY MEASUREMENT

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Abstract: *The vast attempts to build a quantitative model for interoperability measurement has been drawn down to a model called the i-score model, built at the Air Force Institute of Technology. This model has a great capacity to be used as a domain-free model for heterogeneous collaborative systems. The model introduced in this paper improves the i-score model in a way that makes it much simpler and more applicable. The model presented in this paper, the interoperability index model, accounts for direct interfaces among different systems and assigns a weight to each of them. By implementing these new changes, the interoperability index model will be a more accurate measure for interoperability in a system of systems framework and provides a quantitative basis for systems integration and a standard for composability.*

Keywords: *Interoperability measurement; Standardization; Systems integration; Composability; Collaborative systems.*

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INTRODUCTION

Interoperability has always been one of the most important aspects of systems engineering andit challenges us anytime different agents try to interact with each other in a process. The concept of interoperability is deeply imbedded in all sorts of systems, e.g. social systems, political systems, languages, communication, etc. Althoughinteroperability has been amatter of concern since the industrial revolution its official accepted definition was not established until 1977 (Ford et al., 2007a). During the industrial revolution inventors tried to find better ways to ease the operation between different parts of a machine.That led to more interoperable mechanical parts and better designs to increase a system's effectiveness. The attempt to theorize and measure interoperability in the scholarly world is fairly recent. A survey done at the Air Force Institute of Technology (Ford et al., 2007a) shows that from 1995 to 2006 there has been a great interest in producing different interoperability measurement models. This should not be a surprise for us.Because the problem of interoperability rises whenever there is a matter of exchange. Thus the great boom of globalization in the '90s made us share our resources and exchange more information.

The most accepted and robust definition of Interoperability is the Department of Defense's (DoD) definition: "*The ability of systems, units, or forces to provide services to and accept services from other systems, units, or forces and to use the services so exchanged to enable them to operate effectively together*"(DoD Directive #4630.05, 2007). There are three important points in this definition: 1. interoperability is a *condition* between systems; 2. interoperability happens when there is an *exchange* of services or goods; 3. interoperability seeks *effective* operation among units.Since interoperability is the basis of effective integration it is extremely important for us to quantify it. Or in DoD's words*"interoperabilityis the foundation of effective joint,multinational, and interagencyoperations"*(Ford et al., 2009). Large models and systems are usually designed to be modular,*"That is, they have parts that can be independently developed and tested, parts that are seen by the rest of the model as black-box building blocks that can be interacted with only through the inputs and outputs of a well-defined interface such as ports"* (Davis and Anderson, 2004). Davis and Anderson look at interoperability as a mean to effective composability whenever there is a case of system integration: *"Composability then, is the capability to select and assemble components in various combinations to satisfy specific user* *requirements meaningfully"*(Davis and Anderson, 2004).The ability to measure harmonious operation of different components enables us to improve our systems. This happens not only in the defense domain, but also in the commercial word. For example we always come across different types of smart phones that are incapable of exchanging data effectively. A smart phone which is able to cooperate with other cell phones will have much more competitiveness in the market.

LITERATURE REVIEW

The survey mentioned before (Ford et al., 2007a)shows that there arecurrentlyfourteen different interoperability measurement models but only one of them is completely quantitative. This model is called the i-score model, presented by Ford et al(Ford et al., 2007b). This model along with the model presented in this paper, seekto build a quantitative measure for interoperability in a heterogeneous set of systems. The i-score model is of special interest for the author of this paper since it introduces a general and domain-free quantitative way to calculate interoperability in systems. This model has a great capacity to be applied to different processes and systems that have multiple complex interfaces in a collaborativeinteraction. There has been a distinction between collaborative and confrontational interoperability (Ford et al., 2009) which is important to notice. Collaborative interoperability is the conventional assumption for interoperability and has a different dynamic from confrontationalinteractions. "*Collaborative interoperability is the idea ofservice, joint, and allied systems, units,and forces workingtogether to mutual advantage. On the other hand,confrontational interoperability occurs when sets of opposingsystems attempt to control each other"*(Ford et al., 2009). Ford et al have built a general method of measuring interoperability among confrontational systems which is not related to the model ofthis paper(Ford et al., 2009). This paper presents a model to measure collaborative interoperability, because most systems tend to have units who seek a mutual goal. As Ford et al point out: "*Collaborativeinteroperability is the most commonlyunderstood type ofinteroperability today. In the DoD, when the term interoperabilityis used, collaborative interoperability, or the idea ofservice, joint, and allied systems, units, and forces workingtogether to mutual advantage, is implied*"(Ford et al., 2009).

The other interoperabilitymeasurement models are: SoIM(LaVean G, 1980), QoIM(Mensh et al., 1989), MCISI(Amanowicz and Gajewski, 1996), IAM(Leite, 1998), Stoplight(Hamilton et al., 2002), LISI(DoD C4ISR Architecture Working Group Final Report, 1998), OIM(Clark and Jones, 1999), LCI(Tolk, 2003), LCIM(Tolk and Muguira, 2003), NMI(NATO Allied Data Publication, 2003), NCW(Albert and Hayes, 2003), NTI(Stewart et al., 2004), OIAM(Kingston et al., 2005)and NID(Schade, 2005). These models have been categorized as "leveling" or "non-leveling" by Ford et al (Ford et al., 2009).The first five models are non-leveling and the rest are leveling models, including the i-score model. "*Leveling interoperability assessment methods are largelybased upon the maturity model concept developed by theUnited States Air Force in 1987 and represent maturity bythresholds of increasing interoperability capability*"(Ford et al., 2009). Ford et al also point out that these types of models are very weak in quantitative measurement due to "*(1) limited precision of measurement, (2) fixed number of unchangeable interoperability attributes which can become outdated, (3) applicability to only one type of system, and (4) an interoperability measurement tied to a single system vice a pair of systems"* (Ford et al., 2009).

It is worth mentioning that *standardization*has been another approach to understand interoperability in integration and composability problems. Chari and Seshadripoint out that *"adopting standards-based integration solutions is the most promising way to reduce the long-term costs of integration and facilitate a flexible infrastructure"* (Folmer and Verhoosel, 2011). Interoperability is the main factor that can assess a standard for integrabilityandcomposability. In State of the Art on Semantic IS Standardization, Interoperability & Quality(Folmer and Verhoosel, 2011)Folmer et al have discussed the relation between integrability standards and interoperability and the way they can reduce costs in any kind of process. For instance in the US automotive case the imperfect interoperability standards have cost the industry about $1 billion per year (Brunnermeier& Martin, 2002). Also in the health care industry *"98,000 people die in hospitals due to errors (1999), and these errors costs hospitals $29 billion every year, while three out of four errors can be eliminated by better use of information technology. The lack of standardization and integration among the systems has made it difficult to reduce the medical errors. Lack of integration and data standardization is making health care services inefficient and costly"* (Venkatraman et al., 2008) (Folmer and Verhoosel, 2011). Although Folmer et al correctly point to the problem it happens that none of the standards that they presentarequantitative. This gives more credit to the i-score model along with the model presented in this paper.

Because "*if these factors* [of composability] *could be roughly quantified, they could be used to characterize the probability of success of a particular proposed composition effort"* (Davis and Anderson, 2004). Although the authors of the i-score model presented an improved version of their model two years later after its first publication(Ford et al., 2008), there is still room to improve some conceptual and quantitative aspects of it. In the next section we briefly introduce the elements of the i-score model and then try to introduce our new model, the interoperability index model.We believe that our interoperability index model is a simple, applicable and accurate measure to be the basis of a quantitative standard for interoperability.

BRIEF DESCRIPTION OF THE I-SCORE MODEL:

The i-score model is based on two elements: 1. the frequency of system pairs, 2. the quality of system pairs' interfaces. For each of these we build an n×n matrix. The name of these matrixes arethe *multiplicity*(or the frequency) and the *spin* matrix respectively.To develop the frequencymatrix we should have an operational thread. The thread should show the sequence of operations carried out in the process by all systems. Let "T" be the ordered set of all systems in the thread andF_{ij}be the frequency of a system pair that is repeated when the elements of "T" are taken two at a time in a forward direction. In our example (Figure 1) which is exactly the same as the example inFord et al's paper(Ford et al., 2007b), T={1,2,2,3,4,2} and there are 15 system pairs taken in a forward direction, {(1,2), (1,2), (1,3), (1,4), (1,2), (2,2), (2,3), (2,4), (2,2), (2,3), (2,4), (2,2), (3,4), (3,2), (4,2)}. For example the number of times that pairs of system number 1 and 2 are repeated is equal to 3. Thus, $F_{12}= 3$, we can find this value at the junction of the first row and the second column of the frequency matrix.The complete frequency matrix is shown below (Ford et al use C_{ij} instead of F_{ij}). The other element of this model, interoperability spin, can take three values, $S_{ij}= +1$, *0* or *-1*. A value of $S_{ij}=+1$ shows perfect interoperability withinthe system pair"i" and "j", 0 shows that there is a need of a non-human intervention to translate between a system pair, and -1 means there is a need of a human translation for the system pair. There can be many ways to assign a value to the spin of a system pair. The most obvious ways are expert judgment techniques or technical performance measurements, which are not the subjects of this paper.

By multiplying F_{ij} into S_{ij} we will have the interoperability matrix: $M=[F_{ij} \cdot S_{ij}]_{n\times n}$. Finally, by summing the elements of M_{ij} we can calculate a measure of interoperability, i.e.,*i-score*= $\sum\sum m_{ij}$. As for our example, the value of i-score will be -6. By giving the spin matrix its highest and lowest values, we can have an upper and lower bound for the i-scoreand an optimum value for it. The whole process of calculating the i-score is shown in figure-1.

$$F\ (frequency) = \begin{bmatrix} 0 & 3 & 1 & 1 \\ 0 & 3 & 2 & 2 \\ 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix}, \quad S\ (spin) = \begin{bmatrix} 1 & -1 & -1 & -1 \\ -1 & 1 & 0 & -1 \\ -1 & -1 & 1 & 0 \\ -1 & -1 & 0 & 1 \end{bmatrix} \Rightarrow M = \begin{bmatrix} 0 & -3 & -1 & -1 \\ 0 & 3 & 0 & -2 \\ 0 & -1 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{bmatrix}$$

$$\text{i-score} = \sum_{i=1}^{4}\sum_{j=1}^{4} mij = -6$$

Improving the i-score Model:

The i-score model can be improved in three areas. This paper will show that implementing these improvements will provide a better model for interoperability measurement.

1. Thefrequency (multiplicity) matrix:

In the i-score model all system pairs are credited in the frequency matrix, no matterwhetherthey have a direct or indirect interface. This means for calculating the overall interoperability the authors gave equal weight to direct and indirect system pairs. It seems the logic behind this consideration is that any output from a unit has an impact on the income of a latter unit. For example in figure1 the input of system #4 has passed through systems #1 and #2 and #3 and has been influenced by all of them. Although the frequency matrix should account for all interfaces, Ford et al do not show how we should weight direct and indirect interfaces. We can assume that a direct interface would have the most influence on the input of a system. Eliminating the frequency of indirect interfacesmakes the value of interoperability closer to reality and simpler to calculate. By crediting only direct interfaces the overall interoperability measure will be more effective in showing how systems in a System-of-System frameworkoperate harmoniously.

Besides the quantitative advantage of this consideration, the systems theory supports this distinction"*a system is a bounded set of inter-connectedelements forming a whole that functions for a specific finalityin an environment, from which it is dissociable and withwhich it exchanges through interfaces*(Naudet et al., 2009)". This definition emphasizes interacting elements. The authors of this definition continue to say that there is a difference between relation and interaction"*relations can be local orglobal…The original definitionof system* *speaks about interacting elements... Interactionis defined commonly as the mutual influencebetween two things. A difference we can make betweenboth concepts is that interaction bears a dynamicaspect and implies behavior, contrary to the term relationthat can be only structural. Things can be inrelation while not being interacting"*(Naudet et al., 2009). It is our choice whether to choose "interacting" or "relating" systems in an interoperability model. We can also consider both direct and indirect interfaces and assign different weights to them. But it seems that since interoperability is a problem of exchanging goods among systems in direct contact, the term 'direct interaction' works better for building an interoperability measurement model.There is another benefit to crediting only direct interfaces: if there is a parallel or simultaneous activity in the thread, there will be twice as much indirect interfaces in the calculations. That makes the measure less accurate and more complicated.

2. Considering weights for interfaces:

Although the operational thread shows the process of how data travels between systemsit doesnot show the importance of each interface. The i-score model weights all operations equally. But having interoperability in a complicated interface is much more important and desirable than having interoperability in a simple one. Let us assume that in our illustrative example the relation between systems #2 and #3 involves a highly complicated process and millions of dollars in operation cost. And let's assume the other processes are simple and routine anddon't involve high costs. Thus,having interoperability between systems #2 and#3 increases the whole SOS's interoperability. The i-score model neglects this important issue andweights all of the processes equally. Therefore, if we have two processes in a thread, one withahigh level of interoperability for a complicated and critical processand the other one with a poor interoperability for a simple and not important process, the i-score model simply averages them and shows a moderate level of interoperability in the whole system.Thus, it is better to add an extra matrix, the 'weight matrix'and multiply it to the formula: $M=[F_{ij}S_{ij}W_{ij}]$, where $\Sigma\Sigma\ W_{ij}=1$. The weight matrix shows the importance of having interoperability between two systems or how complex and costly it is to provide interoperability between two systems.

3. Interoperability Index:

In the 2007 version of Ford etal paper there is no scale for the i-score and it can take any value from $-\infty$ to $+\infty$. But, in the 2008 revision (Ford et al., 2008) of the i-score model they introduce the normalized i-score which is "*a positive real number ranging from 0 to 1 which is moremeaningful because a score of zero indicatesno interoperability and a score of one indicates perfect interoperability*"(Ford et al., 2008). A normalized i-score in the Ford etal paper is equal to $(1/|T|)\times\sum\sum m_{ij}$, where |T| is the number of system pairs. Although the i-score needs to be a real number from 0 to 1, the way Ford et al calculate the normalized i-score does not reflect an exact scale for total system's interoperability.Because it should not be the matter of how many systems are supporting the thread but how difficult it is to achieve a level of interoperability among them. Thus, the better way to calculate the normalized i-score is to divide $\sum\sum m_{ij}$ to the range of possible i-score values. We call the result 'the interoperability index'. By using the interoperability index we can easily compare how difficult it is for threads to reach their maximum interoperability level regardless of how many systems are supporting it. It does not matter how big or small a thread is but how far the i-score is standing from its maximum and minimum values. It is more meaningful to understand the interoperability measure within a range of allowable values.

The concept of interoperability index has been previously presented by Howard Eisner in an attempt to build an interoperability measurement model using system's functional decomposition(Eisner, 2008). He seeks interoperability among different functions in a system. Although his approach is different,his concept of an interoperability index is applicable for our model. Eisner describes interoperability as "*the degree to which system solutions will operate harmoniously with one another*(Eisner, 2008)" and in order to measure this degree of harmonious operation he proposes an indexbetween zero and one.He developsthis index by dividing the current state of interoperability to the "Maximum interoperability Score", which is the same concept that this paper is implementing in the interoperability measurement model.

Table 1 summarizes the differences and assumptions of these two models.

Building the Interoperability Index Model:

1- The frequency matrix:

$F= [f_{ij}]_{n\times n}$, where $f_{ij}$is the frequency of direct interfaces between system iand j. For our illustrative example the frequency matrix is:

$$F=\begin{bmatrix}0 & 1 & 0 & 0\\ 0 & 1 & 1 & 0\\ 0 & 0 & 0 & 1\\ 0 & 1 & 0 & 0\end{bmatrix}$$

2- The spin matrix;

$S=[s_{ij}]_{n\times n}$, where s_{ij}belongs to {-1, 0, 1}; $s_{ij}=1$ means perfect interoperability, 0 means there is a need of non-human translation, and -1 means a need of human translation between the system pairs. It is important to mention that Ford etal have presented a better spin matrix in their revision of the i-score model (Ford et al., 2008). There they substitute a continuous value for the spins rather than discrete values. Since in this paper we are concernedabout the building blocks of the model, we will still use the discrete form of the spin matrix.

$$S=\begin{bmatrix}1 & -1 & -1 & -1\\ -1 & 1 & 0 & -1\\ -1 & -1 & 1 & 0\\ -1 & -1 & 0 & 1\end{bmatrix}$$

3- The weight matrix:

$W=[w_{ij}]_{n\times n}$, where $\Sigma\Sigma\ w_{ij}=1$andw$_{ij}$takes a value only if $F_{ij}=1$, because we should notassign a weight to an interface that does not exist.

$$W=\begin{bmatrix}- & 0.1 & - & -\\ - & 0.4 & 0.2 & -\\ - & - & - & 0.2\\ - & 0.1 & - & -\end{bmatrix}$$

By multiplying the three matrices we will have the interoperability matrix:

$M=[F_{ij}.\ S_{ij}.\ W_{ij}]_{n\times n}$

$$M=\begin{bmatrix}- & -0.1 & - & -\\ - & 0.4 & 0 & -\\ - & - & - & 0\\ - & -0.1 & - & -\end{bmatrix}$$

Finally we divide the sum of m_{ij} by the range that the interoperability score takes. We can produce the maximum value for interoperability score by giving the value of +1 to all arrays of the spin matrix, and the minimum by changing them all to -1. Obviously this is a symmetric range with the zero as its center.

$$Interoperability\ index = \frac{\sum mij - Min\ (i)}{Max\ (i) - Min\ (i)}$$

In our example $\Sigma\Sigma\ m_{ij}= 0.2$, Max(i) is the maximum interoperability= +1 and Min(i) is the minimum interoperability= -1.

Thus, the interoperability index= $\frac{0.2-(-1)}{1-(-1)}$ = *0.6*

CONCLUSION

The interoperability index model is purposely designed to be simple and applicable in any domain. The output of this model is a measure to evaluate interoperability in a system. It helps improving systems from their current interoperability level to the possible maximum level of interoperability. The interoperability index model also prepares a framework to build standards for integrability and composability. Lack of robust and quantitative standards leads to high cost and less effective operations. By using this model we can see if different systems are suitable to be integrated and co-operate,e.g. if the interoperability index model shows a high level of interoperability for a set of components, there is a high probability that the integration of those components will be successful and will avoid high costs. The most critical area which can be improved in this model or any other interoperability measurement model is the *interfacequality*or the spin matrix. Here we used the concept of needing *human* or *non-human translation* among systems, following the i-score model. But all sorts of technical performance measurements can be good quantitative representations for an interface quality.

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Table1: The differences between the i-score model and the interoperability index model

	System Pair Frequencies	**Weights**	**Final Score**
The i-score model	Accounting all interfaces	Assigning no weight to interfaces/equal weight to all interfaces	A real number between -∞& +∞
The interoperability index model	Accounting only direct interfaces	Assigning more weight to critical interfaces	An index from 0 to 1

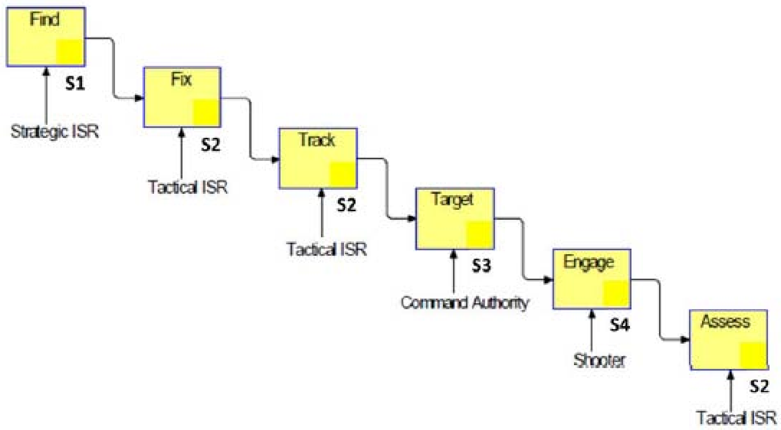

Figure 1. Sample of an operational thread. The kill chain, based on IDEF0 activity model (DODAF 2004)

Source: (reused from reference Ford et al. 2009 with changes)