COMPUTATIONAL MODELS OF MULTI-NATIONAL ORGANIZATIONS*

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Abstract: An algorithm for designing multi-national organizations that takes into account cultural dimensions is presented and an example from the command and control field is used to illustrate the approach. *Copyright © 2002 IFAC*

Keywords: Organization Design, Petri Nets, Cultural Dimensions, Decision Maker, Command and Control

1. INTRODUCTION

A key objective in organization design is to relate structure to behavior, An executable model, i.e., a formal mathematical model with characteristics that are traceable to the static architecture designs, is used to determine the properties of the model and its performance characteristics. A wealth of theoretical results on discrete event dynamical systems, in general, and Colored Petri nets, in particular, can be applied to the executable model.

The problem of modeling multi-national organizations such as those found in military coalition operations has received renewed attention. Coalition partners may have differences in equipment or materiel, differences in command structures, differences in constraints under which they can operate, and, last but not least, differences in culture. The differences in equipment and in operational constraints can be handled easily in the existing modeling framework. Differences in command structures require some additional work to express them in structural and quantitative ways. The real challenge is how to express cultural differences in these, primarily mechanistic, models of organizations.

This work focuses on the ability to introduce attributes that characterize cultural differences into the organization design and use simulation to see whether these parameters result in significant changes in structure. The objective, therefore, is to relate performance to structural features but add attributes that characterize cultural differences. Specifically, the attributes or dimensions defined by Hofstede (2001) are introduced in the design process in the form of constraints on the allowable interactions within the organization.

In Section 2, the modeling approach is described briefly since it has been documented extensively in the literature. In Section 3, the Hofstede dimensions are introduced and then applied to the organization design algorithm. In Section 4, an illustrative example is presented, followed by conclusions.

2. ORGANIZATIONAL DESIGN APPROACH

2.1 *The Decision Maker Model And Organizational Design*

The five-stage interacting decision maker model (Levis, 1993) had its roots in the investigation of tactical decision making in a distributed environment with efforts to understand cognitive workload, task allocation, and decision-making. This model has been used for fixed as well as variable structure organizations (Perdu and Levis, 1998). The five-stage decision maker (DM) model is shown in Figure 1. The DM receives signals from the external environment or from another decision maker. The Situation Assessment (SA) stage represents the processing of the incoming signal to obtain the assessed situation that may be shared with other DMs. The decision maker can also receive situation assessment signals from other decision makers within the organization; these signals are then fused together in the Information Fusion (IF) stage. The fused information is then processed at the Task Processing (TP) stage to produce a signal that contains the task information necessary to select a response. Command input from superiors is also received. The Command Interpretation (CI) stage then combines internal and external guidance to produce the input to the Response Selection (RS) stage. The RS stage then produces the output to the environment or to other organization members. The key feature of the model is the explicit depiction of the interactions with other organization members and the environment.

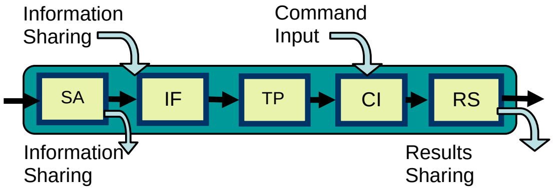

Fig. 1. Model of the Five-Stage Decision Maker

These interactions follow a set of rules designed to avoid deadlock in the information flow. The representation of the interactions between DMs can be aggregated into two vectors **e** and **s**, representing interactions with the external environment and four

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matrices **F**, **G**, **H** and **C** specifying intra-organizational interactions (Fig. 2).

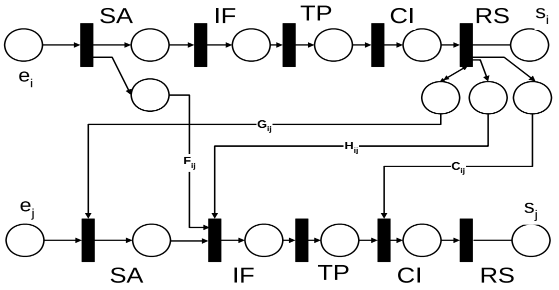

Fig. 2. One-sided Interactions Between DMi and DMj

2.2 *The Lattice Algorithm*

The analytical description of the possible interactions between organization members forms the basis for an algorithm that generates all the architectures that meet some structural constraints as well as application-specific constraints that may be present. The most important constraint addresses the connectivity of the organization - it eliminates information structures that do not represent a single integrated organization.

Remy and Levis (1988) developed an algorithm, named the Lattice algorithm, that determines the maximal and minimal elements of the set of designs that satisfy all the constraints; the entire set can then be generated from its boundaries. The algorithm is based on the notion of a simple path - a directed path without loops from the source to the sink. Feasible architectures are obtained as unions of simple paths. Consequently, they constitute a partially ordered set. The algorithm receives as input the matrix tuple of dimension n {**e, s, F, G, H, C**}, where n is the number of organization members.

A set of four different structural constraints is formulated that applies to all organizational structures being considered.

R1 A directed path should exist from the source to every node of the structure and from every node to the sink.

R2 The organizational structures should be acyclical.

R3 There can be at most one link from the RS stage of a DM to each one of the other DMs; i.e., for each i and j, only one element of the triplet $\{G_{ij}, H_{ij}, C_{ij}\}$ can be nonzero.

R4 Information fusion can take place only at the IF and CI stages. Consequently, the SA and RS stages of each DM can have only one input.

To introduce user-defined constraints that will reflect the specific application the organization designer is considering, appropriate 0s and ls can be placed in the arrays {**e, s, F, G, H, C**}. The other elements will remain unspecified and will constitute the degrees of freedom of the design.

A feasible structure is one that satisfies both the structural and user-defined constraints. A maximal element of the set of all feasible structures is called a maximally connected organization (MAXO). Similarly, a minimal element is called a minimally connected organization (MINO). The design problem is to determine the set of all feasible structures corresponding to a specific set of constraints. The Lattice algorithm generates, once the set of constraints is specified, the MINOs and the MAXOs that characterize the set of all organizational structures that satisfy the requirements. This methodology provides the designer of organizational structures with a rational way to handle a problem whose combinatorial complexity is very large. Having developed a set of organizational structures that meets the set of logical constraints and is, by construction, free of structural problems, we can now address the problem of incorporating attributes that characterize cultures.

3. MODELING CULTURAL ATTRIBUTES

Hofstede (2001) distinguishes dimensions of culture that can be used as an instrument to make comparisons between cultures and to cluster cultures according to behavioural characteristics. Culture is not a characteristic of individuals; it encompasses a number of people who have been conditioned by the same education and life experience. Culture, whether it is based on nationality or group membership such as the military, is what the individual members of a group have in common (Mooij, 1998). To compare cultures, Hofstede originally differentiated them according to four dimensions: *uncertainty avoidance (UAI)*, *power distance (PDI), masculinity-femininity (MAS),* and *individualism-collectivism (IND).* The dimensions were measured on an index scale from 0 to 100, although some countries may have a score below 0 or above 100 because they were measured after the original scale was defined in the 70's. The hypothesis here is that these dimensions may affect the interconnections between decision makers working together in an organization. Organizations with low power distance values are likely to have decentralized decision making characterized by a flatter organizational structure; personnel at all levels can make decisions when unexpected events occur with no time for additional input from above. In organizations with low scores on uncertainty avoidance, procedures will be less formal and plans will be continually reassessed for needed modifications.

The trade off between time and accuracy can be used to study the affect of both power distance and uncertainty avoidance (Handley and Levis, 2001). Messages exchanged between decision makers can be classified according to three different message types: information, control, and command ones. Information messages include inputs, outputs, and data; control messages are the enabling signals for the initiation of a subtask; and command messages affect the choice of subtask or of response. The messages exchanged between decision makers can be classified according to these different types and each message type can be associated with a subjective parameter. For example, uncertainty avoidance can be associated with control signals that are used to initiate subtasks according to a standard operating procedure. A decision maker with high uncertainty avoidance is likely to follow the procedure regardless of circumstances, while a decision maker with low uncertainty avoidance may be more innovative. Power distance can be associated with command signals. A command center with a high power distance value will respond promptly to a command signal, while in a command center with a low power distance value this signal may not always be acted on or be present.

3.1 *Using Cultural Constraints.*

Cultural constraints help a designer determine classes of similar feasible organizations by setting specific conditions that limit the number of various types of interactions between decision makers. Cultural constraints are represented as interactional constraint statements. An approach for determining the values of these constraints has been developed by Olmez (2006). The constraints are obtained using a linear regression on the four dimensions to determine the change in the range of the number of each type of interaction that is allowed.

$$dY = c + \alpha(PDI) + \beta(UAI) + \gamma(MAS) + \delta(IND)$$

where Y is #F or #G or #H or #C

Example: $\#F \leq 2,\ \#G = 0,\ 1 \leq \#H \leq 3,\ \#C = 3$

C-Lattice Algorithm. This is an extension of the Lattice algorithm that allows cultural constraints to be imposed as additional structural constraints, R5-R8, on the solution space. For the cultural constraint example given above, they become:

- R5: The number of F type interactions must be between 0 and 2
- R6: The number of G type interactions must equal 0
- R7: The number of H type interactions must lie between 1 and 3
- R8: The number of C type interactions must equal 3

The flowchart in Fig. 3 explains the generation of the culturally constrained solution. MAXOs and MINOs are generated using the same algorithm described in Remy and Levis (1988). The "Build Lattices" step checks if a MINO is contained within a MAXO. If it is, then the MINO is connected to that MAXO and forms part of a lattice. For each lattice, we check the MINO to see if it violates the cultural constraints. For example, if the number of F type interactions in the MINO is two and cultural constraint allows only one, then the MINO does not satisfy the cultural attributes and since the MINO is the minimally connected structure in that lattice, no other structure will satisfy the constraints. Hence the lattice can be discarded. If the MINO does pass the boundary test, then simple paths are added to it to satisfy the cultural constraints R5 to R8. The corresponding minimally connected organization(s) is now called the C-MINO(s) (culturally bound MINO). Similarly, by subtracting simple paths from the MAXO, C-MAXO(s) can be reached. The step "Build C-Lattices" connects the C-MINOs to the C-MAXOs. The advantage of using this approach is that the designer does not have to know the cultural attributes at the start of the analysis. He can add them at a later stage. This also enables him to study the same organization structure under different cultures, which will be useful in our coalition scenario.

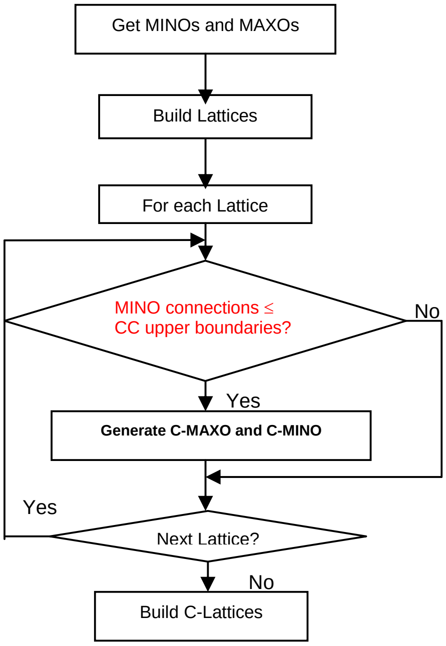

Fig. 3 Flowchart for culturally constrained solution

4. COALITION MODELING USING CAESAR III

The proposed computational approach for the design of coalition operations is illustrated using a hypothetical example in which an emergency situation in an island nation requires rapid humanitarian assistance and disaster relief as well as securing military assets. The alternative architecture designs and the associated simulations to evaluate performance were carried out using a new application called CAESAR III developed in System Architectures Lab at GMU.

The scenario depicts a situation in which anarchy has risen on an island due to a recent earthquake that caused substantial damage. The infrastructure and many of the government buildings are destroyed in the island's capital. The US maintains a ground station that receives data from space assets. It is concerned about the rising tensions, as there has been opposition to its presence on the island. As a result, US decides to send an Expeditionary Strike Group (ESG) to the island to: (1) provide timely Humanitarian Aid/ Disaster Relief (HA/DR) to three sectors of the island; and (2) counteract the effects of any hostile attacks which impede the normal operation of the HA/DR mission and the security of the ground station. As the ESG is away for the first critical day of the operation, countries A and B offer help to support the mission and agree to take part in a Coalition Force that would be commanded remotely by the US ESG commander. It is assumed that, close to the island, both countries hold different elements for an ESG compatible Coalition Force, which can be deployed in a matter of hours, while the ESG rushes to the island.

A team of five decision-making units carries out the HA/DR mission. The team is organized in the divisional structure and each unit under the team has its sub-organizations and staff to perform the tasks allocated to it. The five units are: (1) ESGC: Commander; (2) MEUC-Commander of the Marine Expeditionary Unit; (3) ACE-Air Combat Element with its Commander and sub-organizations; (4) GCE-Ground Combat Element with its Commander and sub-organizations; and (5) CSSE-Combat Service Support Element with its Commander and sub-organizations.

It is assumed that country A can provide support as ACE, GCE and CSSE while country B can only provide support as GCE and CSSE. The roles of ESGC and MEUC remain with the US. The countries are able to provide rapid assistance in coordination with each other and the design question becomes the allocation of different tasks to partners in this ad-hoc coalition.

This is a multi-level design problem in which interactions between different decision making units need to be determined both at the higher level (Level-1) as well as at the lower level (Level-2). The top level interactions correspond to interactions between culturally homogenous subunits, while the bottom level design problem consists of designing the internal structure of these homogenous subunits based on a defined set of interactional constraints and culture. Based on the structure of the ESG, one can impose user constraints to design the level-1 organization. Figure 4 shows the block diagram of this organization as designed in CAESAR III; the matrices describing the interactions are shown below.

$$e = \begin{bmatrix} x & 1 & 1 & 1 & 0 \end{bmatrix} s = \begin{bmatrix} 0 & 0 & 1 & 1 & 1 \end{bmatrix}$$

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

$$H = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} C = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Figure 5 shows the result of running the lattice algorithm on level-1 organization. The solution space contains one MINO, Fig. 6, and one MAXO, Fig. 7. The designer can pick a structure from this space and use it to design the sub-organizations at level-2.

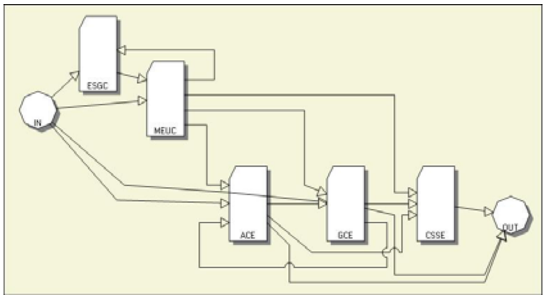

Fig. 4. Level-1 organizational block diagram.

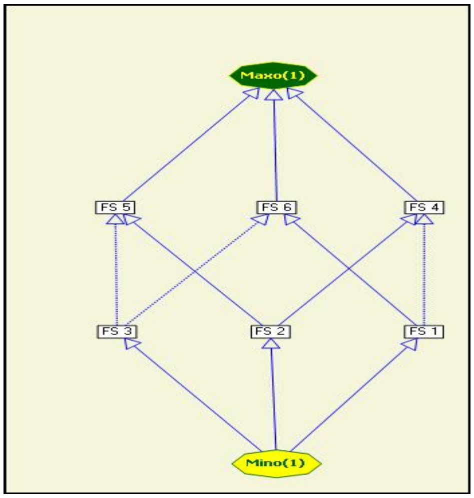

Fig. 5. Solution space for Level-1 organization design as seen in CAESAR III

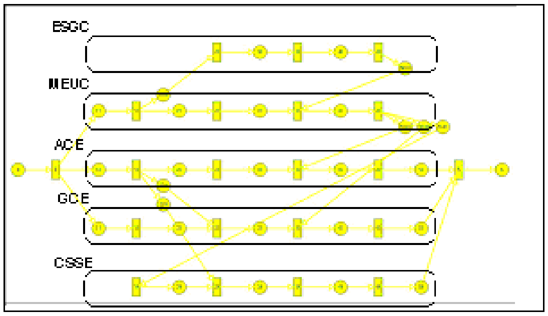

Fig. 6. MINO of Level-1 design

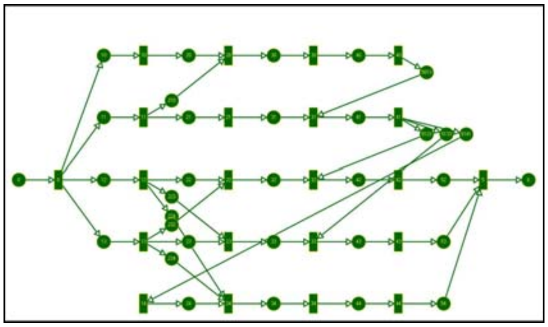

Fig. 7. MAXO of Level-1 design

Level-1 design is free of cultural constraints. However Level-2 design uses the C-Lattice algorithm to include cultural attributes to form the various coalition options. The sub-organizations of ACE, GCE and CSSE are designed using CAESAR III. Figures 8, 9 and 10 show the respective block diagrams along with the matrices specifying the user constraints. Since the US always performs the roles of ESGC and MEUC, these sub-organizations are not decomposed further.

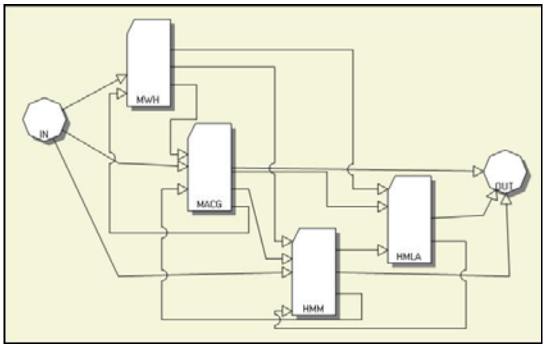

Fig. 8. Block diagram for ACE

$$e=\begin{bmatrix} x & 1 & 1 & 0 \end{bmatrix} s=\begin{bmatrix} 0 & x & 1 & 1 \end{bmatrix}$$

$$F=\begin{bmatrix} 0 & 0 & 0 & 0 \\ x & 0 & 0 & x \\ 0 & x & 0 & x \\ 0 & 0 & 0 & 0 \end{bmatrix} G=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$H=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & x & 0 & x \\ 0 & 0 & x & 0 \end{bmatrix} C=\begin{bmatrix} 0 & 1 & x & x \\ 0 & 0 & 1 & x \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

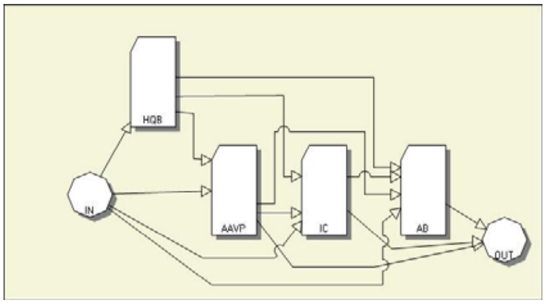

Fig. 9. Block diagram for GCE

$$e=\begin{bmatrix} 1 & x & x & x \end{bmatrix} s=\begin{bmatrix} 0 & 1 & 1 & 1 \end{bmatrix}$$

$$F=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} G=\begin{bmatrix} 0 & x & x & x \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

$$H=\begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & x & x \\ 0 & 0 & 0 & x \\ 0 & 0 & 0 & 0 \end{bmatrix} C=\begin{bmatrix} 0 & x & x & x \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Table 1 gives the Hofstede's scores for US, Country A and Country B. Using a multiple linear regression model, these scores are converted into limits to be placed on allowable interactions based on culture. These are imposed as additional structural constraints on the solution space of the sub-organizations. The cultural constraints for the three sub-organizations are shown in tables 2, 3 and 4. Maximum indicates the limit placed on the number of interactions by user constraints.

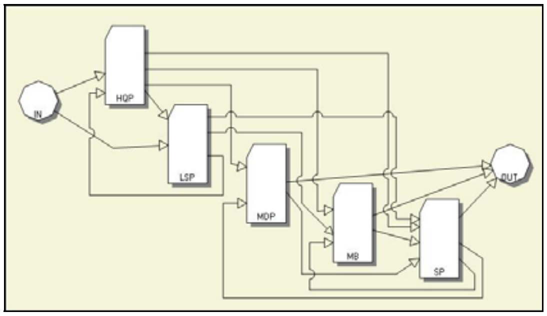

Fig. 10. Block diagram for CSSE

$$e=\begin{bmatrix} 1 & 1 & 0 & 0 & 0 \end{bmatrix} s=\begin{bmatrix} 0 & 0 & 1 & 1 & x \end{bmatrix}$$

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

$$H=\begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & x \\ 0 & 0 & 0 & 0 & x \\ 0 & 0 & x & x & 0 \end{bmatrix} C=\begin{bmatrix} 0 & 1 & 0 & x & x \\ 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Table 1 Hofstede's scores for the three countries

Country	PDI	IND	MAS	UAI
US	40	91	62	46
A	38	80	14	53
B	66	37	45	85

Table 2 Cultural Constraints corresponding to ACE

Country	#F	#G	#H	#C
Maximum	0≤F≤4	0	0≤H≤3	2≤C≤5
US	3≤F≤4	0	2≤H≤3	3
A	2	0	2≤H≤3	3
B	2	0	1	4≤C≤5

Table 3 Cultural Constraints corresponding to GCE

Country	#F	#G	#H	#C
Maximum	0	0≤G≤3	0≤H≤3	0≤C≤3
US	0	2	2≤H≤3	2
A	0	2	2≤H≤3	1
B	0	2≤G≤3	2	2≤C≤3

Table 4 Cultural Constraints corresponding to CSSE

Country	#F	#G	#H	#C
Maximum	1≤F≤3	0	0≤H≤4	3≤C≤5
US	2≤F≤4	0	3≤H≤4	3
A	2	0	3≤H≤4	3
B	2	0	2	4≤C≤5

Using the C-Lattice algorithm, the solution space for each sub-organization is computed for each culture and a suitable structure is selected by the user. These structures are then used to form the different coalition options and analyse the performance. In view of the limited space, the complete solution spaces are not shown here. Figures 11-13 show the structures selected by the user for each country for CSSE. A similar approach can be use to select different structures to be used for ACE and GCE.

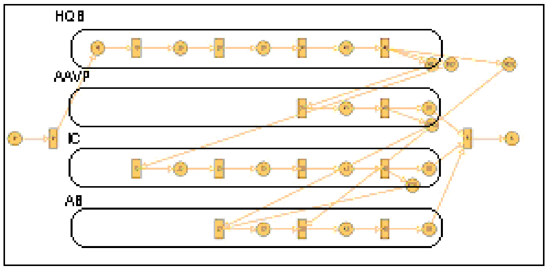

Fig. 11. GCE structure selected for US

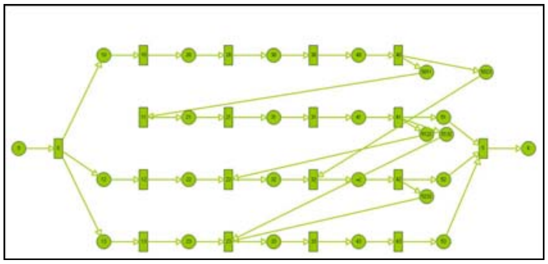

Fig. 12. GCE structure selected for Country A

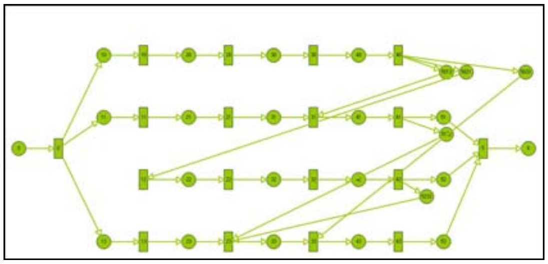

Fig 13. GCE structure selected for Country B

Once the structure is selected, CAESAR III has the functionality of exporting it as a Colored Petri net to *CPN Tools* where it can be simulated to analyse performance. For the given scenario, based on the availability of support from the two countries, eight coalition options are possible, excluding the homogeneous option of all US. The five sub-organizations are combined together using Level-1 MINO and the eight options were simulated to study performance in terms of tasks served. The following assumptions are made. Each process (transition) needs 50 units of processing time. Each additional incoming link increases this time by 50 units. The reasoning is that the additional input(s) will require more processing. Hence, structures that have more interactions will take more time to process the tasks, which will affect the overall performance. Figure 14 shows the results of this analysis for all combinations. The x-axis shows the percentage of tasks **un-served**.

Based on these results, US-US-US-B-A performs best. Most options with country B in the CSSE role perform badly. This is because country B needs a high number of command relationships and the structure of CSSE allows for this to occur, thereby increasing the processing delay. User constraints on GCE allow for very similar cultural constraints for all countries and hence changing the ordering in this role does not change the performance very much. Similar results were obtained when the coalition options were simulated using a Level-1 MAXO organization.

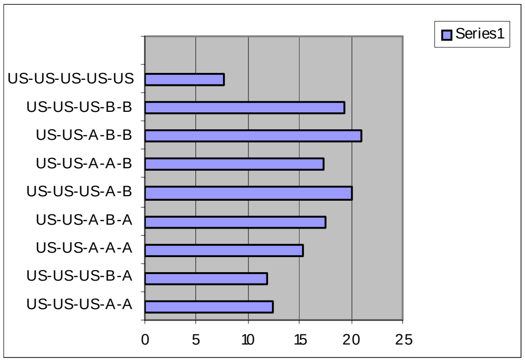

Fig. 14. Percent of tasks un-served for coalition options.

5. CONCLUSION

A previously developed methodology for the computational design of information processing and decision making organizations has been enhanced to include cultural constraints that affect the choice of organizational structures. While the Hofstede cultural dimensions have been used, other cultural metrics can be used to derive the cultural constrains. A simple example illustrates the approach for designing coalition organizations and analysing their performance. The results indicate that culture does affect the structure and working of organizations thereby affecting the overall performance. This could aid in the allocation of different tasks to partners in an ad-hoc coalition.

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