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N2C2M2 Validation using abELICIT: Design and Analysis of ELICIT runs using software agents

Topics: 5 - Experimentation, Metrics, and Analysis, 2 - Approaches and Organizations, 1 - Concepts, Theory, and Policy

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Abstract

Recently developed by the NATO SAS-065 Group, the NATO NEC C2 Maturity Model (N2C2M2) has been subjected to multiple validation efforts, including those applying the ELICIT experimentation platform and involving human subjects. In order to enlarge the dataset for analysis and validation, as well as to provide a fully controlled – albeit simpler – environment, the ELICIT platform was adapted and a new software agent-based version (abELICIT) was created.

This paper describes the application of abELICIT to the N2C2M2 tests, presenting the experiments' formulation (hypotheses, reference model and setup), the platform's limitations and the data collection plan. A thorough analysis of the N2C2M2 experiments and associated conclusions is then provided, highlighting that obtained results corroborate and reinforce the hypothesis that more network-enabled approaches develop more shared information, shared awareness and self-synchronization.

These experiments also generated surprising findings, leading to the conclusion that the most effort-efficient approach is the Coordinated C2. These key findings suggest new directions for future research and the ELICIT platform's enhancement.

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1 Introduction

Past research on the validation of the N2C2M2 (NATO NEC C2 Maturity Model) using ELICIT, the Experimental Laboratory for Investigation Collaboration, Information-sharing and Trust and human subjects (Manso and B. Manso, 2010) yield overall results compliant with the model's expectations. Nonetheless, human subjects also generated unpredictable behaviors, thus hampering the ability to fully control those experiments (e.g., set precisely the C2 approach space region in which an organization should operate) resulting in a noisy environment to test the model.

The newly developed software agents (SW Agents) capability in ELICIT (Ruddy, 2009) presents itself as a valuable tool to conduct further experiments on the N2C2M2 since (i) it allows experimenters to fully control subjects' behavior in runs and (ii) substantially increases the number of ELICIT runs available for analysis since using SW-agents saves time and money.

Therefore, abELICIT experiments add to the existing N2C2M2 validation efforts[1] important evidences to support the hypotheses underlined in the model. The analysis and conclusions made also consider the limitations of the abELICIT platform, such as the simple nature of the ELICIT problem as well as of the agents themselves. These aspects limit the extent to which the model may be validated, as will be explained later on in this paper.

This paper starts by presenting the background theory and past research relevant for this work and then describes the formulation of the N2C2M2 experiments using abELICIT. In the last part, the analysis of the experiments and conclusions are presented. Annexes provide more detailed information about the abELICIT runs and configuration used, and include a comparison of results between human runs and agent runs.

2 Background

This work is a continuation of the "N2C2M2 Experimentation and Validation" effort using ELICIT (Manso and B. Manso 2010). Thus, it is based on the same fundamentals of Network-Centric Warfare (NCW) and the N2C2M2 with added perspectives from abELICIT. For purposes of completeness and reader convenience, we start by presenting the relevant background used in (Manso and B. Manso 2010) and then we present abELICIT.

2.1 Fundamentals of NCW and the N2C2M2[2]

This work's foundations lie in the Network-Centric Warfare (NCW) theory including the NCW tenets[3], NCW Value Chain (SAS-065 2010, 27), C2 Domains (Alberts and Hayes 2006), C2 CRM (SAS-050 2006) (Alberts and Hayes 2006) and C2 Approach Space (SAS-050 2006) (Alberts and Hayes 2006). These theories were used to define the experimentation model, its key variables and their interrelations and the experimentation design.

A core aspect of this work consists of observing several C2 CRM variables and their implications as conjectured in the **NCW Value Chain** and depicted in Figure 1. More specifically, we change the way a force is networked, and measure the effects on (the quality of) shared information, shared situational awareness and mission effectiveness. These variables cover different portions of the C2 domains, namely, the *Physical Domain* (e.g., network characteristics and performance), the *Information Domain* (e.g., capability to share, access, display, store, process and protect information), the *Cognitive Domain* (e.g., individual and collective capability to develop high quality awareness) and the *Social Domain* (e.g., C2 processes and the interactions between and among entities).

To understand in more detail the NCW Value Chain and C2 processes, and to provide *the conceptual foundation for C2 research and experimentation necessary to develop and explore the new C2 Approaches needed* for the Information Age transformation in the Armed Forces (Alberts and Hayes 2006), two efforts were conducted to develop a **C2 Conceptual Reference Model** (CRM). The first, a joint ASD-NII/OFT effort (Alberts and Hayes 2006), took a top-down approach based on the tenets of NCW, and the second, a

[1] Within NATO SAS-065, the N2C2M2 was tested through analysis of case studies and experiments (see SAS-065 2010).
[2] This subsection is reused from (Manso and B. Manso 2010)
[3] Network Centric Warfare Department of Defense Report to Congress. July 2001.

NATO RTO effort via the SAS-050 Group (SAS-050 2006), took a bottom-up approach. Both models are compatible and we will focus on the NATO model.

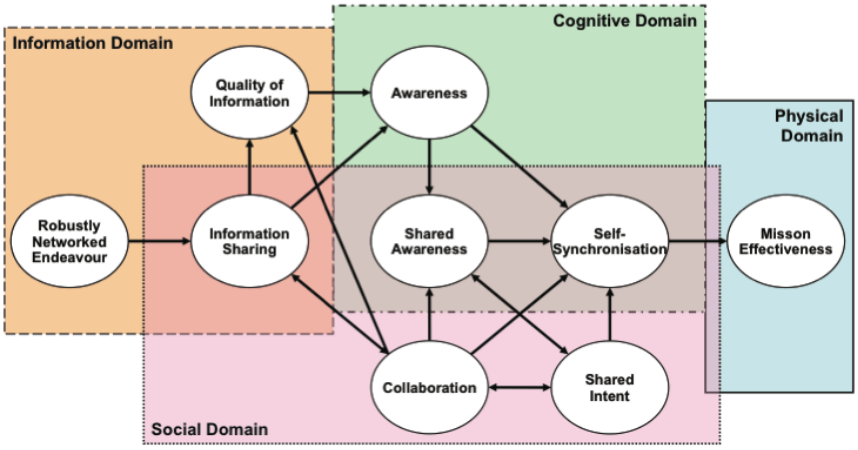


Figure 1 - The NCW Value Chain

The SAS-050 adopted a framework to define a **C2 Approach** based on the following three key-dimensions: **Allocation of Decision Rights** (ADR), **Patterns of Interaction** (PI) and **Distribution of Information** (DI). The three key-dimensions form the C2 approach space, in which a given C2 approach may be positioned. The C2 approach space is depicted in Figure 2.

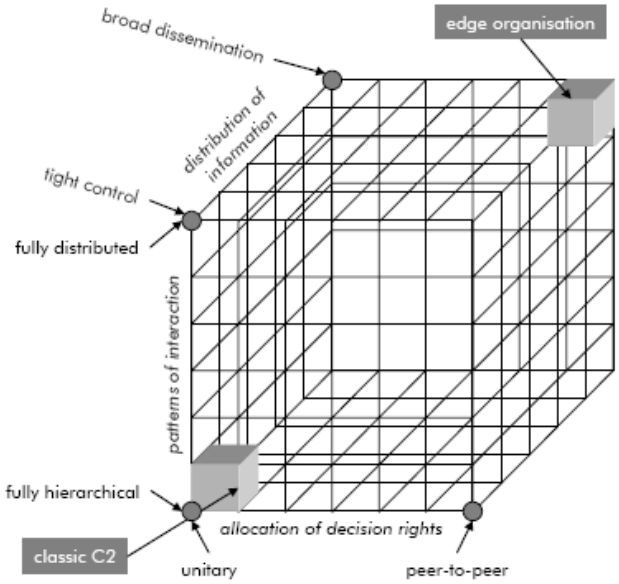


Figure 2 – The C2 Approach Space

Based on the C2 CRM and the C2 approach notion, the SAS-065 defined the N2C2M2, which is introduced next.

The NATO NEC C2 Maturity Model (SAS-065 2010)

The N2C2M2 defines several degrees of operational coherence (i.e. the ability to generate synergies across a set of participants) that can be achieved. These are framed into the five levels of NATO NEC operational capability (levels 1 to 5). Associated with each level is the ability of the collective to adopt one or more approaches to C2. Moreover, associated with increased maturity is the ability to adopt a wider range of approaches to C2 that, in turn, cover a large portion of the C2 Approach Space.

The five classes of **Collective C2 Approaches**, representing a major differentiating aspect in each maturity level, are: **Conflicted C2**; **De-conflicted C2**; **Coordinated C2**; **Collaborative C2**; and **Edge C2**. These approaches fit into specific regions of the Collective C2 approach space[4], as depicted in Figure 3.

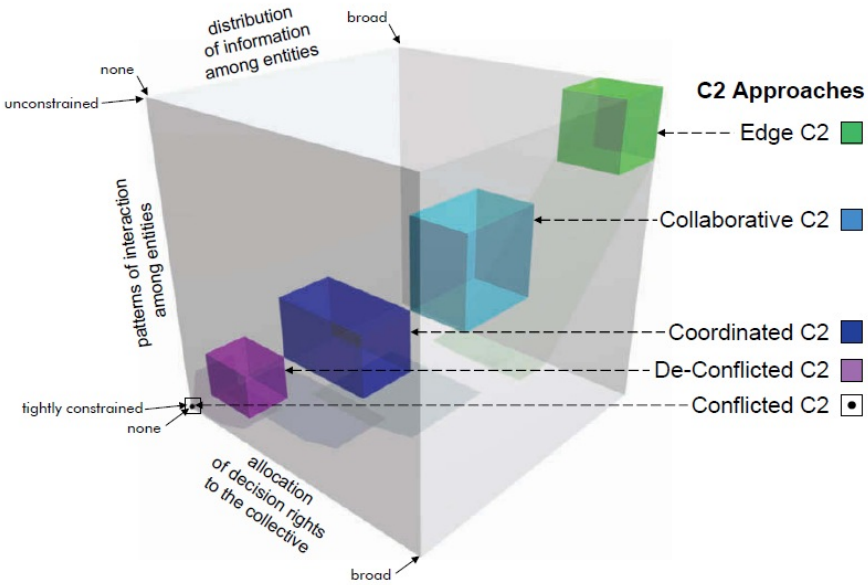


Figure 3 - Collective C2 Approach Space

Higher maturity levels include the ability to adopt C2 approaches located at the 'upper right' side of the C2 approach space (e.g., an organization operating at Level 4 is able to adopt De-conflicted C2, Coordinated C2 and Collaborative C2). For convenience, C2 approaches located close to the upper right corner will be referred as being more network-enabled (or having a higher C2 approach) than those located close to the lower-left corner (referred as less network-enabled, or having a lower C2 approach).

A key assumption in the N2C2M2 is that the **more network-enabled a C2 approach is** (i.e., more distribution of decision rights across the collective, less constrained patterns of interaction and broader dissemination of information), ***the more likely it is to develop shared awareness and shared understanding*** (SAS-065 2010, 69).

2.2 ELICIT and Related Research

ELICIT is a research and experimentation platform developed for the Command and Control Research Program (CCRP) to conduct research related to collaboration, information sharing and trust.

It includes a game-based simulation that provides a network-enabled collaborative environment for a small group or organization using different C2 approaches (e.g. Hierarchy and Edge). The group's baseline task is to find the *Who*, *What*, *Where* and *When* of a future terrorist attack. Throughout the duration of an experiment, information elements (i.e., pieces of the puzzle) are distributed to individuals. Individuals may (or may not) disseminate them to others by sharing information and collaborating using the platform. However, only by sharing information may they achieve sufficient levels of awareness to solve the problem.

The platform allows instantiating different C2 approaches and observation of behaviors and dynamics in the information, cognitive and social domains. It was originally developed to test hypothesis related to edge and hierarchical (traditional) command and control practices (Ruddy 2007), but its fields of application for research have been enlarged due to its increased configuration capabilities and flexibility, including, easy manipulation and setup of organization models and communications control. There is a clear mapping to the theory of NCW and a subset of the C2 CRM where several variables of interest are observable, including: *Quality of Individual and Shared Information Position, Information Distribution, Patterns of Interaction, Quality of Individual and Shared Understanding, Quality of Interactions, Self-Synchronization,*

4 Note that the N2C2M2 deals with the set of entities engaged in a complex endeavor (Alberts and Hayes 2009, 4). Hence, the C2 approach concept is interpreted in the perspective of a 'collective' (i.e., Collective C2). This implies re-interpretation of the dimensions of a Collective C2 approach space (SAS-065 2009, 2) as *allocation of decision rights to the collective* (ADR-C), *patterns of interaction among entities* (PI-C), and *distribution of information among entities* (DI-C).

Mission Effectiveness and *Mission Efficiency (given Effectiveness)* (Manso and Nunes 2007) (McEver, Hayes and Martin 2007) (Martin and McEver 2008).

More recently, ELICIT was extended to support configurable software agents (complementing or replacing humans) thus allowing full control of experiments and the efficient generation of a large number of runs and datasets for analysis. This version is named abELICIT (Ruddy, Wynn and McEver 2009). For detailed information about ELICIT and abELICIT see (Ruddy 2009), (Wynn, Ruddy and Nissen 2010) and (Ruddy 2011).

In this work, abELICIT version 2.5 build number 29 is used[5].

Past N2C2M2 Validation Results with ELICIT

ELICIT was used for a two step validation of the N2C2M2:

- A first and preliminary experimentation stage using two pre-existing models: Hierarchy and Edge (SAS-065 2010).
- A second experimentation stage that recreated the N2C2M2 five C2 approaches (Manso and B. Manso 2010).

Both stages used runs involving human subjects.

Step 1: Hierarchy vs. Edge

The first experimentation step, conducted within the aegis of the SAS-065, mapped the ELICIT Hierarchy organization model as an approximation of De-Conflicted C2 and the ELICIT Edge organization model to a region of the C2 approach space further along the central diagonal vector (towards Edge C2) allowing *testing the hypothesis that More Mature Levels of C2 would Perform More Efficiently and More Effectively*. The data used for analysis comprised experiments conducted at Boston University and the Naval Postgraduate School resulting in a total of 26 trials (13 Hierarchy and 13 Edge).

The conclusions were that *Edge structures indeed exhibited more mature behaviours than hierarchical ones, in terms of more extensive distribution of information, better quality of information (position), a greater extent of shared awareness, and higher levels of information seeking behaviours (in terms of web pulls)* (SAS-065 2010, 223-227). Additionally, Edge C2 achieved better results in terms of effectiveness (fraction of authorized correct IDs) and efficiency in time (productivity in person-minutes).

Results were *clear and unambiguous* (SAS-065 2010, 132): For the types of tasks studied, Edge organizations were more effective, faster, shared more information and were more efficient than Hierarchies.

Step 2: Recreation and Validation of the Five N2C2M2 Approaches

The second experimentation step recreated the five N2C2M2 C2 Approaches with an aim to increase the depth of observation and analysis of the N2C2M2 model in the ELICIT platform, including measuring key variables defined in the model so that a quantitative analysis could be conducted.

A total of 18 valid runs were performed involving human-subjects.

The overall assessment of the C2 approaches, according to the results obtained in the ELICIT experiments, is presented in Table 1. C2 approaches were evaluated in a 1-5 scale: 1 refers to best score and 5 refers to the worst score. Grey background in scores indicates non-compliance with the model hypotheses.

Overall, the results were consistent with the model expectations, although a few deviations were observed.

Edge reached the best scores in the **Information and Cognitive Domains**, but it was surpassed by Collaborative in the **Interactions Domain and Measures of Merit** (MoMs). As expected, Conflicted performed worst in all assessed variables.

[5] Accessible via http://azigo1.verdigrid.net:8080/ccrp2.5/

Domain / Variable Assessed \ C2 Approach		Conflicted C2	De-conflicted C2	Coordinated C2	Collaborative C2	Edge C2
Information Domain	Shared Information Reach	**5**	4	3	2	**1**
	Critical Information Accessible	**5**	4	3	2	**1**
Interactions	Quality of Interactions	**5**	4	3	**1**	2
Cognitive Domain	Extent of Correct Understanding	**5**	3	4	2	**1**
	Cognitive Self-Synchronization	**5**	4	3	2	**1**
MoM	Organization Effectiveness	**5**	3	4	**1**	2
	Time-Efficiency	**5**	4	3	**1**	2
	Effort-Efficiency	**5**	3	2	**1**	3

Table 1 – Overall Position of C2 Approaches across assessed variables

The most surprising results were the following:

- Collaborative MoM scores surpassed Edge.
- Edge's low effort-efficiency score, being equivalent to De-conflicted (Edge was the most effort spending from all approaches).
- Coordinated was surpassed by De-conflicted in terms of effectiveness (Coordinated was in overall low performing).
- Coordinated achieved a good effort-efficiency score (second best).

The work concluded by stating the *need to increase the amount of experimental data (i.e., valid ELICIT runs) for analysis to ensure robustness of results and findings obtained,* and that *the agent-based ELICIT (Ruddy 2009) presents a cost-effective way to replicate experiments described herein by resorting to software-agents instead of humans, and exploiting further manipulations in the context of the N2C2M2 and NCW* (Manso and B. Manso 2010, 26). This paper presents the results of the work conducted using abELICIT as the experimental platform to respond to gaps identified in the previous N2C2M2 experiments.

3 Formulation of abELICIT N2C2M2 Experiments

The abELICIT experiments recreate the N2C2M2 human experiments with respect to the hypotheses, model and design using software agents and not human subjects. This approach has the additional benefit of allowing the comparison of results between agent runs and human runs.

This section presents the formulation of abELICIT N2C2M2 experiments. It starts by presenting the hypotheses to verify and the associated abELICIT limitations, followed by the presentation of the experimentation model, the modeling of the C2 approaches and the definition of the agents' parameters. It concludes with the data collection and measurements plan.

3.1 Hypotheses

The hypotheses to verify in this work are derived from the N2C2M2 work involving human runs (in which the original numbering is kept), with necessary adaptations. These are presented next.

[1] ***For a complex endeavor, more network-enabled C2 approaches are more effective than less network-enabled C2 approaches.***

Testing this hypothesis using the abELICIT platform faces limitations in what respects to the nature of the problem. The factoid problem defined in ELICIT is not a complex and dynamic one. Based on (Alston

2010), in the view of the *problem setter* the ELICIT problem *must have a solution* and *contains a known number of Factoids* (i.e., pieces of information), but these characteristics are not usually present in real and complex problems. Nonetheless, the way the problem is presented and setup (e.g., existent factoid interdependencies, delivery of factoids across subjects and teams) over different organization models (e.g., Hierarchy vs Edge) results in a difficult one to solve, as it has been demonstrated empirically by experiments: past ELICIT experiments with human-subjects achieved effectiveness scores below 60% for teams and organizations (see section 2.2). Hence, we consider the ELICIT problem – i.e., a combination of the factoid problem, the organization model, the platform setup (e.g., factoids distribution), the instructions and humans (in this case, agents mimicking human behavior) – a valid one to study this hypothesis.

[2] ***For a given level of effectiveness, more network-enabled C2 approaches are more efficient than less network-enabled C2 approaches.***

The N2C2M2 hypothesizes that, for a given level of effectiveness, increasing the level of maturity shall also increase the organization's efficiency. Herein, this hypothesis is tested considering the N2C2M2 C2 Approaches using the same methods to measure effectiveness and efficiency as those in the N2C2M2 human runs (the detailed formulas are presented in 8.4).

For a more accurate and insightful assessment, intermediate variables associated with the network centric value chain are also measured. The following hypotheses are also tested:

More network-enabled C2 approaches exhibit increased/better levels of:

[4] ***Shared Information;***

[5] ***Shared Awareness;***

[6] ***Self-Synchronization (at cognitive level);***

Than: less network-enabled C2 approaches.

[7] ***A minimum level of maturity is required to be effective in ELICIT.***

It is expected that a minimum level of maturity is required for an organization to be effective in the ELICIT game. In accordance to the N2C2M2 terminology, this is called *requisite maturity* (SAS-065 2010, 85). For this work, it will be identified which C2 approaches succeed and fail.

Furthermore, the N2C2M2 experiments included the following additional hypotheses that are NOT covered in this work:

[3] ***More network-enabled C2 approaches have more agility than less network-enabled C2 approaches.***

Testing the agility of a C2 approach is outside the scope of this work.

[8] ***Increasing the degree of difficulty in ELICIT requires organizations to increase their network-enabled level to maintain effectiveness in ELICIT*.**

Changing the difficulty of the ELICIT problem is outside the scope of this work.

3.2 Limitations

It is important to mention the limitations of the ELICIT platform when studying C2-related aspects, complex endeavors and the N2C2M2.

First, the ELICIT is not a C2 system: it does not recreate a C2 organization nor does it includes physical resources (e.g., vehicles, bridges and weapons) and decision-produced effects on the environment. Instead, ELICIT is an experimentation platform that allows easy setup and implementation of a rich set of

experiments, involving humans or software agents, focusing on infostructure, information (including logical network links), social (e.g., interactions) and cognitive (e.g., awareness) aspects, their interrelations and relations with organization approaches and performance.

Additionally, the ELICIT problem is well defined and static, but its setup (e.g., delivery of factoids in multiple waves and necessity of sharing factoids) results in a problem with interdependencies between subjects and teams, a difficult one to solve (as demonstrated empirically in past experiments). Hence, the use of ELICIT to study complex situations under network-enabled environments seems adequate but limited.

Finally, the abELICIT replaces, totally or partially, human involvement with software agents. While humans are a source of complexity and unpredictability, software agents are not. Software agents bring a fully controlled environment to ELICIT at the expense of the human intrinsic complexity, still an important aspect to consider when studying C2-related aspects. Therefore, abELICIT is fit for testing preliminary sets of hypotheses (with large datasets), but it is advisable to reinforce and corroborate its findings, by conducting experiments involving human subjects as well.

3.3 Model

The experimentation model defined for this work, reused from the N2C2M2 experiments, is presented in Figure 4.

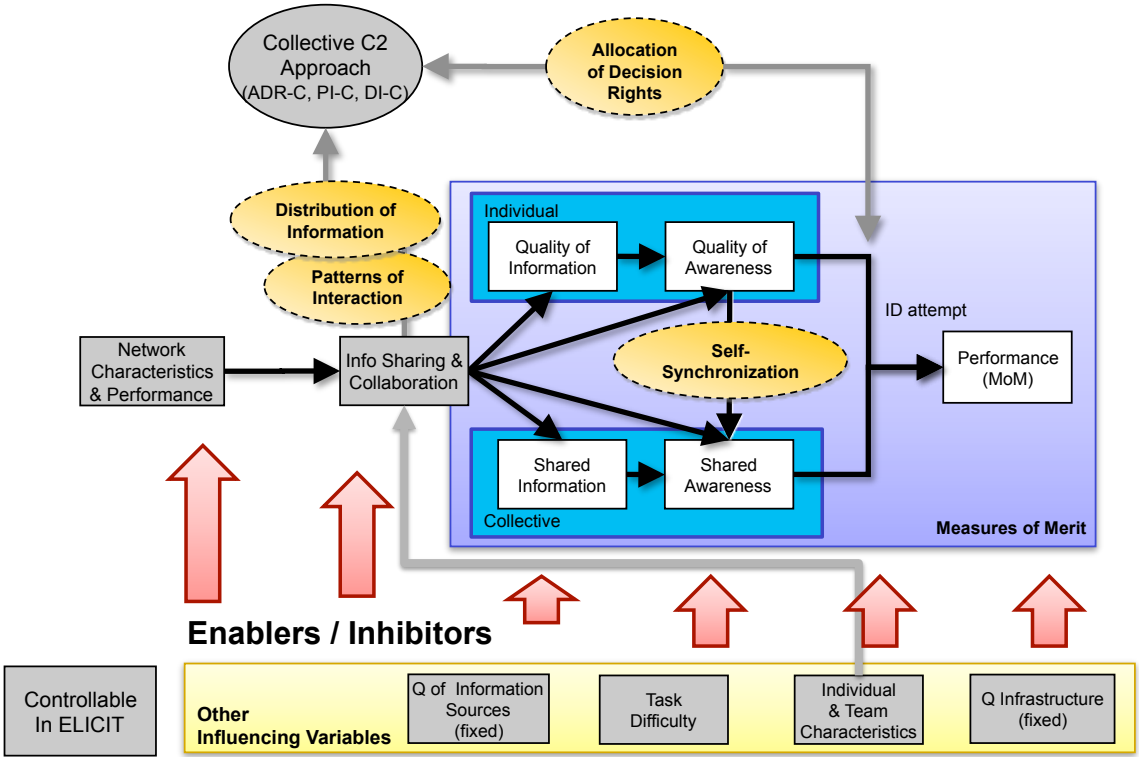


Figure 4 - abELICIT N2C2M2 Experimentation Model

The model includes the following modifications from the N2C2M2 human experiments:

- The system is fully controllable (no human unpredictability).
- Awareness encompasses understanding (ELICIT has no effects or consequences over the environment).
- The quality of decisions is removed (decisions in ELICIT are mapped to Identification actions accordingly to the organizational model adopted and it is already measured in awareness and MoM variables).
- Allocation of Decision Rights is determined based on who is responsible to determine the success of the organization (i.e., determine the mission effectiveness).
- A direct relation exists between Individual and Team Characteristics (ITC) and Information Sharing and Collaboration (ISC) (in abELICIT, ITC are fully controllable and directly affect ISC).

Testing the N2C2M2 model requires recreating each of the C2 approaches in ELICIT (i.e., position the system in the right region of the C2 approach space) and measuring the variables defined in the model. First, each C2 approach is modeled in ELICIT as described in the next section.

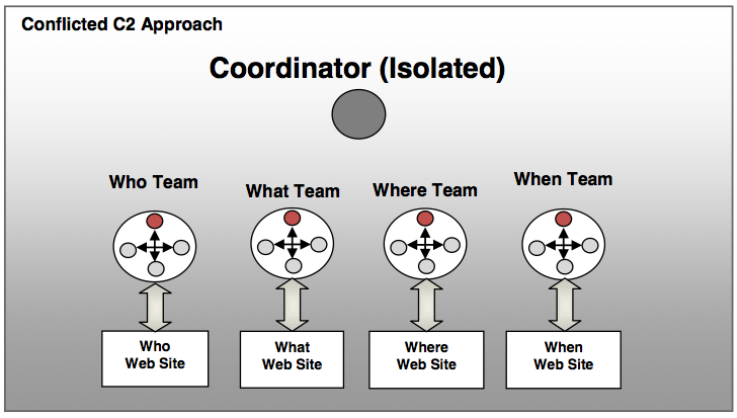
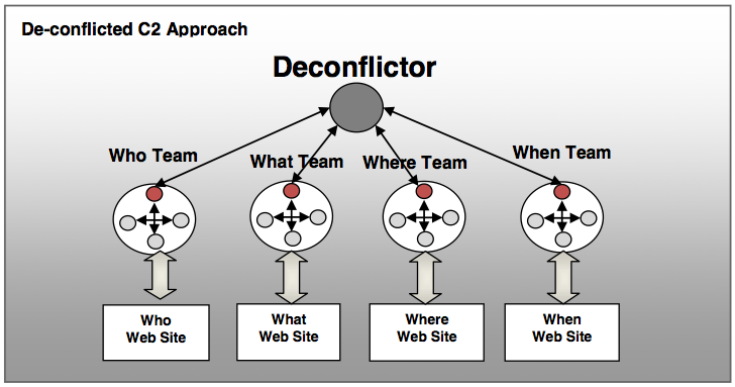
3.4 C2 Approach Modeling

The experiments recreate the five C2 approaches defined in the N2C2M2, similarly to the definitions in (Manso and B. Manso 2010), and derive from the setting of the adequate agent parameters. The implemented strategy is as follows:

- ADR-C are set by (i) determining who has the right to provide identifications that are accounted for mission effectiveness and (ii) setting the agents' parameters so that they do identification actions during a run[6].
- The two interdependent variables DI-C and PI-C are the results of sharing and posting actions (i.e. information sharing and collaboration) and are influenced by the following variables:
  - Individual and Team Characteristics (ITC) are set by via software agents' parameters (e.g., *propensity to share* and *propensity to seek information*).
  - Network characteristics and performance (NCP), set to physically allow or restrict interactions between subjects (i.e., availability of network links between subjects.

In this way, organizational policies define ADR-C and NCP, while the agent parameters define behaviors associated to individuals and teams that influence ISC (and consequently DI-C and PI-C) and also ADR-C (e.g., Identify actions performed during a run).

The modeling of the C2 approaches in ELICIT - including their success criteria and associated characteristics for ADR-C, NCP and ITC - are described in Table 2. The following acronyms are used: Cross-Team Coordinator or Coordinator (CTC), Deconflictor (Deconf), Coordinator-Facilitator (CF), Team Leader (TL) and Team Member (TM).

C2 Approach Model	Characteristics:
	ADR-C: None. Three roles defined: CTC, TL and TM. Decision rights are allocated to each TL (right to identify in her/his own solution space). NCP: Teams with exclusive access to their website. Non-interoperable (no cross-teams communications). ITC: No sharing of information outside own teams. CTC is isolated. Success Criterion: Each Team pursues independent goals. Success occurs if all TLs find the correct solution to her/his respective problem space. Legend: CTC (grey circle), TL (red circle), TM (light grey circle)
	ADR-C: Established constraints. Three roles defined: Deconf, TL and TM. Decision rights are allocated to each TL (right to identify in her/his own solution space). NCP: Minimum connectivity allowed. Stove-pipe: between TLs and Deconf. Teams have exclusive access to their websites. ITC: Interactions across teams allowed but strictly between each TL and Deconf. Success Criterion: Each Team pursues independent goals for an interdependent problem. Success occurs if all TLs find the correct solution to her/his respective problem space. Legend: Deconf (grey circle), TL (red circle), TM (light grey circle)

[6] Granting decision rights to a subject is not a sufficient condition for her/him to actually take decisions. For example, in a N2C2M2 human run with the Coordinated approach, the Coordinator didn't provide any Identify.

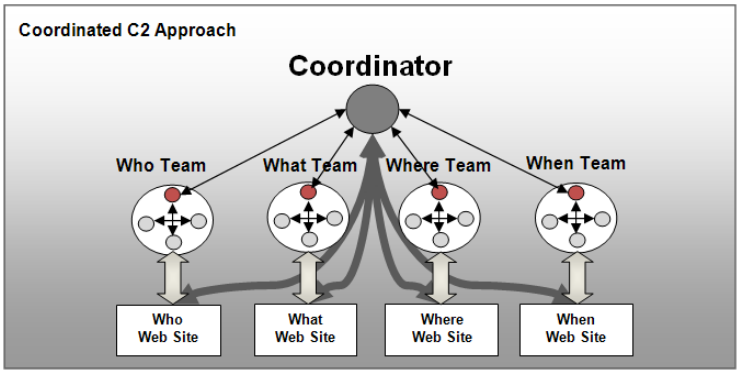
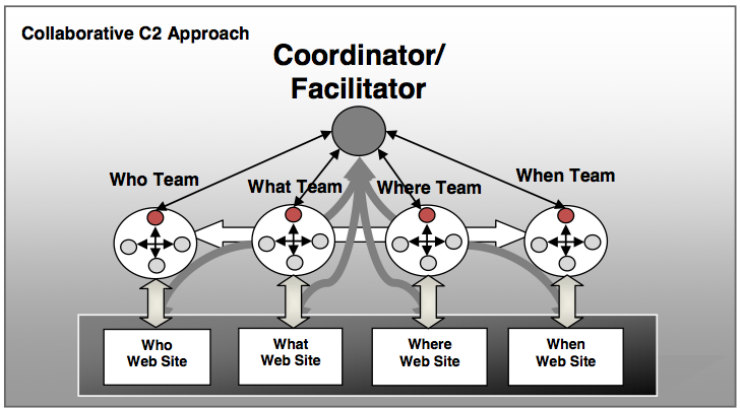
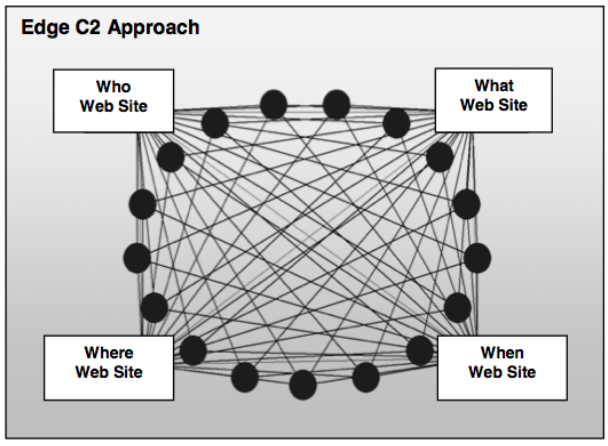
C2 Approach Model	Characteristics:
	ADR-C: Centralized. Three roles defined: CTC, TL and TM. Decision rights are allocated to Coordinator (right to identify in all solution spaces). NCP: Minimum connectivity allowed. Stove-pipe: between TLs and CTC. Teams have exclusive access to their websites and CTC has access to all sites. ITC: Interactions across teams allowed between each TL and CTC. Success Criterion: Organization success depends on the CTC finding the correct solution in all problem spaces. Legend: CTC (grey circle), TL (red circle), TM (light grey circle)
	ADR-C: Distributed and collaborative. Three roles defined: CF, TL and TM. Decision rights allocated to TLs and CF. NCP: Fully connected and interoperable. Existing P2P connectivity between all subjects. Shared team websites. ITC: Interactions allowed between all subjects: CF, TLs and TMs. Success Criterion: Organization success depends on the CF finding the correct solution to all problem spaces OR TLs finding the correct solution to their respective problem space. Legend: CF (grey circle), TL (red circle), TM (light grey circle)
	ADR-C: Fully distributed, not explicit (per individual) and dynamic. One role is pre-defined: TM. TMs choose which part (or parts) of the problem space they work on. NCP: Fully connected and interoperable. Existing P2P connectivity between all individuals. Shared team websites. ITC: interactions allowed between all TMs. Success Criterion: Organization success depends on the individuals' IDs plurality being correct in each problem space. Legend: TM (black circle)

Table 2 – C2 Approach Models and Characteristics

3.4.1 Defining the software-agents parameters (agent calibration)

The software-agent parameters set the ADR-C (actually performed) and ITC of the organization. Therefore, they must be defined properly to obtain the intended C2 approach. For their parameterization, two approaches were considered:

- The first approach consisted in having agents mimic the behavior expected for a given C2 approach. For example, less network-enabled approaches should involve agents with less sharing propensity, whereas more network-enabled approaches should involve agents with more sharing propensity. However, because a success pre-requisite in abELICIT is making all (relevant) information available and having agents with sufficient information and cognitive processing capabilities[7], such configuration could be regarded as a biased one.

[7] This statement is not valid for runs involving human subjects, since even when all relevant information was available sometimes subjects could not fully solve the problem.

- The second approach consisted in defining a common set of agent archetypes and using them in each of the C2 approaches runs. This is the selected approach, for it allows the analysis of the effects of the organizations' approach (e.g., structure, policies and networking) *per se*.

The agents' parameters were first introduced in (Ruddy, Wynn and McEver 2009) and are described in the Software Guide (Ruddy 2011). For this work, they are defined in accordance to the four categories presented in Figure 5 (Stephen *et. al.* 2011), which also illustrates the qualitative approach that is sought per category, namely to define parameters that result in agents that are *low*, *average* or *high* performing (in each category).

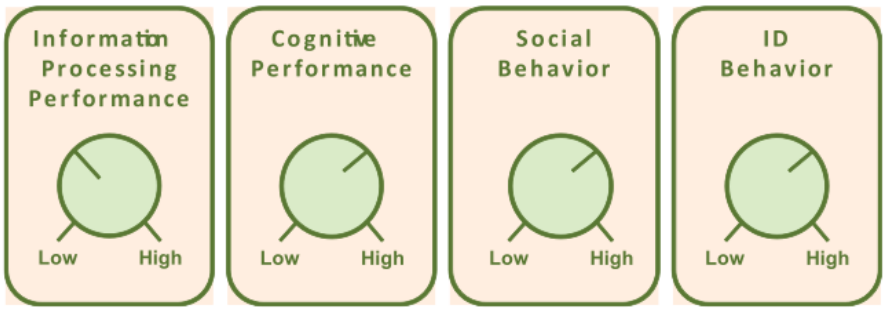


Figure 5 - Categorization of Agent Parameters

The sequence of steps to calibrate the agents is the following:

- Step 1: Define the average agent

  Define an agent archetype with 'average' performance (i.e., number of shares, post, pulls and identifications close to human behavior) and sufficient information processing and cognitive capabilities to solve the problem if the necessary information is made available within a *reasonable* time (i.e. about half the time of a run). This agent does not hoard information. This agent archetype serves as the basis for the modifications made in step 2.

- Step 2: Define agent archetypes

  The agent baseline defined in step 1 is modified to create two additional archetypes: a low-performing agent and a high-performing agent:

  - The low-performing agent has a lower interaction activity (slower or decreased rate of information sharing and seeking) and spends more time processing received factoids (decreased cognitive performance) than the agent baseline.
  - The high-performing agent has a higher interaction activity (faster or increased rate of information sharing and seeking) and spends less time processing received factoids (increased cognitive performance) than the agent baseline.

  Both agent archetypes do not hoard information.

The detailed calibration parameters and results are presented in section 9 (Annex).

3.4.2 ELICIT Runs Plan

3.5 Data Collection and Measurements

The variables measured by data extracted from the ELICIT *datalogs* are presented in Table 3. The detailed list and formulas are presented in Annex 8.4

Domain/Category	Variable	Description
Information	Relevant Information Reached (average and per key role)	Relevant factoids reached: - average amount and percentage across all organization - amount per key role (e.g., CTC and TL)
	Shared Relevant Information	Amount of relevant factoids accessible by all subjects. Measured as number and percentage of factoids.
Interactions/Social	Interactions Activity	Average number of interactions (i.e., total shares, posts and pulls) per subject.
	Average Network Reach	Network reach measures the percentage of subjects that a specific subject interacted with. The average network reach is the average value across all organization and is measured here as a percentage.
Cognitive	Time of First Correct ID	The time to first correct and complete identification by any participant.
	Number of Partially Correct IDs	Measures the number of partially correct IDs, that is, identifications that provided a correct solution in any of the problem spaces.
	Cognitive Self-Synchronization (CSSync)	Measures the degree of self-synchronization of the collective in the cognitive domain. See 8.4 for formula and (Manso and Moffat 2010).
MoM	(Mission) Effectiveness	Measures the degree of effectiveness of the organization, based on the criteria defined in Table 2. It is C2 approach dependent.
	(Mission) Time Efficiency	Measures the efficiency of the organization when using time as indication of cost. See 8.4 for formula.
	(Mission) Effort Efficiency	Measures the efficiency of the organization when using effort as indication of cost. See 8.4 for formula.
	Maximum Timeliness	*The time to first correct and complete identification by any participant relative to the time available* (Alberts 2011, 298).

Table 3 – Key Measurements

Next, the analysis of the experiments is presented.

4 Analysis

In this section the analysis of the N2C2M2 Agent Baseline is presented. It starts by introducing the settings that are common across all runs and then presents the analysis of the N2C2M2 Agent Baseline based on the variables in Table 3.

The following characteristics are common to all runs:

- All runs have the same duration (about 420 time units). Note that a time compression option was setup in abELICIT, thus the time measured in abELICIT is not the absolute time.
- The factoid set used is the same across runs (see annex 10). It consists of 68 factoids in total, in which about half (33) are relevant and the remaining ones (35) are noise. All factoids are distributed to subjects, but no two subjects receive the same factoid.

In this section, the C2 approaches Conflicted C2, De-conflicted C2, Coordinated C2, Collaborative C2 and Edge C2 are numbered as 1, 2, 3, 4 and 5 respectively.

The N2C2M2 Agent Baseline comprises a set of runs with different combinations of the three agent archetypes defined in 3.4.1. Performing the full combination of the 3 types of agents over the 17 members results in an intractable computational problem (the number of runs = 3^17 times 5) and the resulting variety of the dataset would likely be poor regarding the variability of results. Instead the following approach is used: the agents' archetypes are combined according to organization role (three possible positions: top-level, mid-level and bottom-level) and in Edge, where roles are not applicable, the distribution of the same agent types is replicated. The number of possible combinations is 135 (3^3 times 5) as presented in Table 4.

C2 Approach	Agent Type: Top-Level	Agent Type: Mid Level	Agent Type: Bottom-Level	# Possible Combinations*	Run Number
Conflicted C2	1 Coord	4 TLs	12 TMs	27	1 .. 27
De-conflicted C2	1 Deconf	4 TLs	12 TMs	27	28 .. 54
Coordinated C2	1 CTC	4 TLs	12 TMs	27	55 .. 81
Collaborative C2	1 CF	4 TLs	12 TMs	27	82 .. 108
Edge C2	-	-	17 TMs	27**	109 .. 135
			TOTAL	**135**	

* Possible agent types are: (i) baseline, (ii) low-performing and (iii) high-performing.
** Use same combinations of agent types in Edge as for other C2 approaches.

Table 4 – N2C2M2 Agent Baseline

The results obtained in the N2C2M2 Agent Baseline runs for each domain are presented next

4.1 Information Domain

The overall results in the information domain are presented in Table 5.

C2 Approach Number	Relevant Information Reached (Avg: #facts | %)		Shared Information Reached	
	Mean	σ	Mean	σ
1	7.41 | 22%	0	0	0
2	8.29 | 25%	0	0	0
3	11.12 | 37%	0	4	0
4	33 | 100%	0	68	0
5	33 | 100%	0	68	0

Table 5 - Results in the Information Domain

The results obtained in the information domain per C2 approach are not affected by the agent archetypes (the standard deviation was zero for all approaches). For example, for each C2 approach, the amount of information reached, when using high-performing agents was the same as when low-performance agents were used.

However, between the C2 approaches, the following differences are observed:

- The average value for "Relevant Information Reached" increases with the C2 approach: from about 7 to 33 (the maximum value).
- "Shared Information Reached" is zero for the first two levels, low (4) for Coordinated and has maximum value (i.e. 68) for Collaborative and Edge.

Collaborative and Edge approaches achieve the same final scores in the information domain. This is a result of the simple logic used in the agents that behave consistently, in accordance to the parameters set for posting and sharing information, which is role independent. Since the network topology of Collaborative and Edge is the same, the outcomes in the information domain are also the same.

It is also relevant to observe the information accessible per key-role (not applicable for Edge), presented in Table 6.

C2 Approach Number	Top-Level (CTC)	Mid-Level (Who TL)	Mid-Level (What TL)	Mid-Level (Where TL)	Mid-Level (When TL)
1	4	16	16	16	16
2	20	20	20	20	20
3	68	20	20	20	20
4	68	68	68	68	68
5	-	-	-	-	-

Table 6 – Information Reached per Key Role

In Conflicted and De-conflicted approaches, the information accessible for key-roles is low (below 16 facts). In Coordinated, the top-level (i.e., CTC) reaches all factoids, but the middle-levels do not go above 20 factoids. In the Collaborative approach, the top and mid levels have access to all information. Thus, from the information perspective, Coordinated and above meet the necessary conditions for success.

The results obtained sustain the hypothesis that more network-enabled approaches achieve more shared information than less network-enabled approaches.

4.2 Interactions/Social Domain

The results in interactions and social domain are presented in Table 7.

C2 Approach Number	Interactions Activity (Shares, Posts, Pulls)		Team Inward-Outward Ratio	Network Reach (%)	
	Mean	σ		Mean	σ
1	41.28	22.36	1.00	18%	0.00
2	42.74	20.72	0.95	21%	0.00
3	45.95	24.05	0.95	21%	0.00
4	115.68	43.56	0.22	100%	0.00
5	116.39	44.00	-	100%	0.00

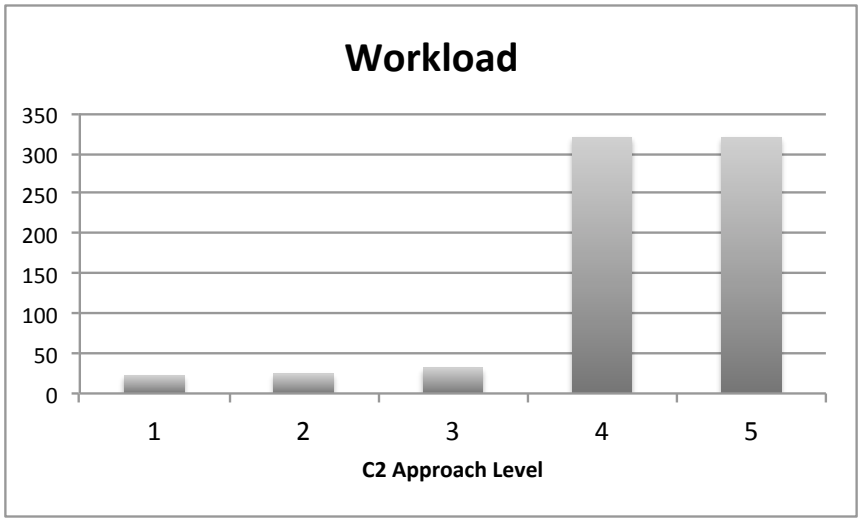
Table 7 – Interactions Measures

The following aspects are noted:

- The first three approaches have similar interactions activity, with a slight increase across approaches (e.g., from Conflicted to De-conflicted approaches, new links are added between the Coordinator and TLs). Collaborative and Edge approaches yield the same results with respect to network activity: agents do not differentiate hard network aspects (i.e., who can communicate with whom) from soft organizational rules (e.g., power difference between team leaders and team members).
- Within each C2 approach, the network activity increases with the agent's performance (i.e. low performing agents perform less interactions than high performing agents).

- Due to the lack of interaction constraints, and the agents' logic being set to share factoids to all nodes within reach, Collaborative and Edge are the C2 approaches displaying the highest network activity. This activity also results in a significant increase in network reach: from 21% in De-conflicted and Coordinated to 100% in Collaborative and Edge.
- The inward-outward ratio (i.e. the ratio of inter and intra team shares) is inward only for Conflicted approaches, mostly inward for De-conflicted and Coordinated approaches and mostly outward for Collaborative approaches. This metric is not applicable for Edge approaches, since there are no teams.

Interaction activities produce workload on agents: each share received and pull made requires subsequent information processing. Thus, more network-enabled approaches have more interactions and, therefore, produce more workload. Agents with low information processing capabilities may have information overload, which in abELICIT is observed when agents do not perform pull actions (since they are busy processing factoids received via shares). Next, an indication of the agents' workload per C2 approach, measured as the number of received shares and pull actions, is presented in Figure 6.



C2 Approach	Agents Archetype	Workload	# Pulls
1	Low	23	166
1	Average	23	311
1	High	23	882
2	Low	24	162
2	Average	24	299
2	High	24	879
3	Low	32	167
3	Average	32	316
3	High	32	943
4	Low	320	**0**
4	Average	320	264
4	High	320	1684
5	Low	320	**0**
5	Average	320	264
5	High	320	1684

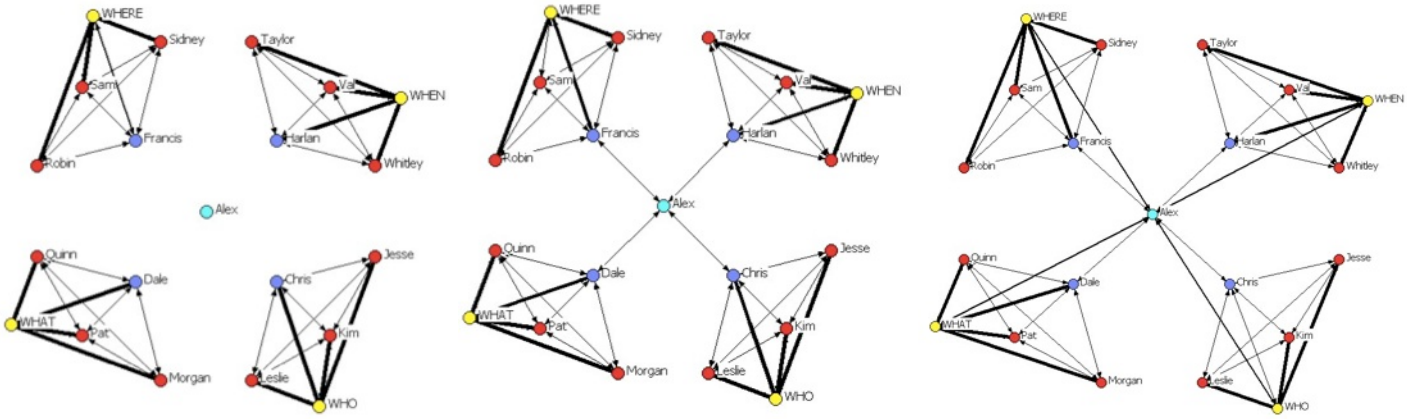
Figure 6 - Agents Workload and Pulling Activity

As configured, Collaborative and Edge approaches have a 900% workload increase over Coordinated approaches. Looking to the table on the right, there are no pulls for low performing agents in Collaborative and Edge C2 approaches indicating that agents were too busy processing the high amount of received information in their inbox (as a result of shares received). The workload effect is further analyzed in 0 (Cognitive Domain) and when discussing efficiency in 4.4.

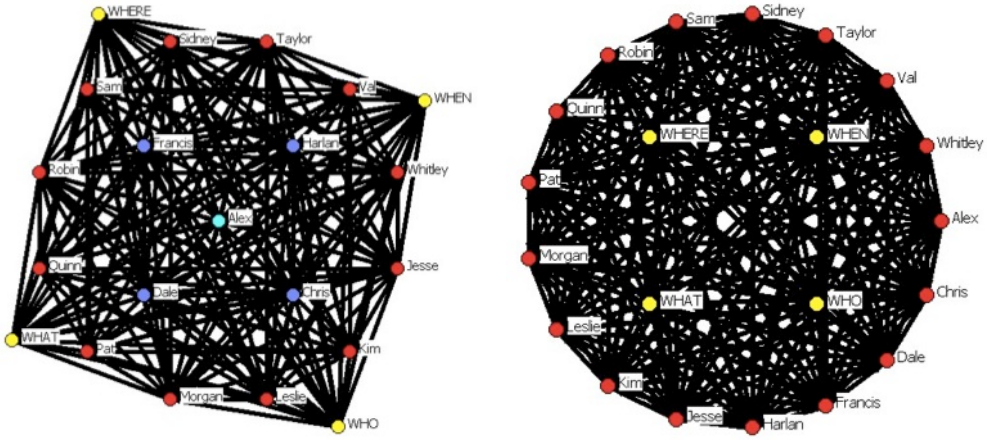
It is concluded that:

- The three less network-enabled approaches have similar activity levels (mean between 40 and 45). These approaches are also inward oriented (i.e. most activity occurs within teams) and their network reach is low (about 20%). They have a low workload (below 32).
- The two more network-enabled approaches have a significant increase in activity (about a 151% increase resulting in a total of 115 actions) and have full network reach (100%). Collaborative inward-outward ratio is low, which indicates that most activity occurs between teams (thus is outward oriented). They have a high workload (320).

We conclude this subsection by presenting in Figure 7 the resulting sociograms for each C2 approach when using average type agents.



Conflicted De-conflicted Coordinated



Collaborative Edge

Figure 7 - Sociograms (approaches 1 to 5 for average run types)

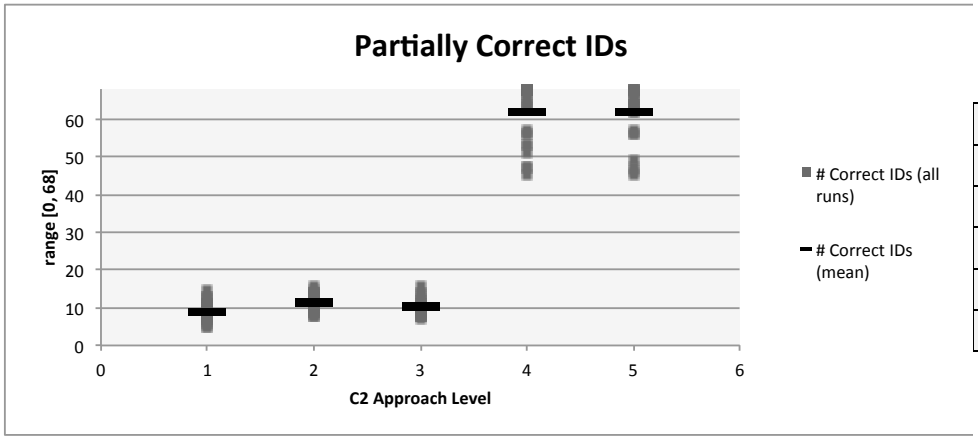
The upper row (Conflicted to Coordinated) and lower row (Collaborative and Edge) result in significantly different social networks as a result of the interactions allowed or constrained: allowed to develop a full peer-to-peer connectivity, the Collaborative and Edge C2 approaches become fully connected networks.

From Conflicted to De-conflicted, the connectivity increases between the top and mid levels. From De-conflicted to Coordinated, the connectivity increases between the top-level and the websites. The sociograms for Collaborative and Edge are equivalent in connectivity, but have subjects and websites positioned in different locations (for Edge has no teams), thus differences are basically on cosmetics.

These sociograms also highlight the symmetric nature of the software agents used. The nodes' activity is almost symmetrical, for these agents treat all nodes and websites equivalently.

4.3 Cognitive Domain

The Number of Partially Correct IDs per C2 approach is presented in Figure 8.



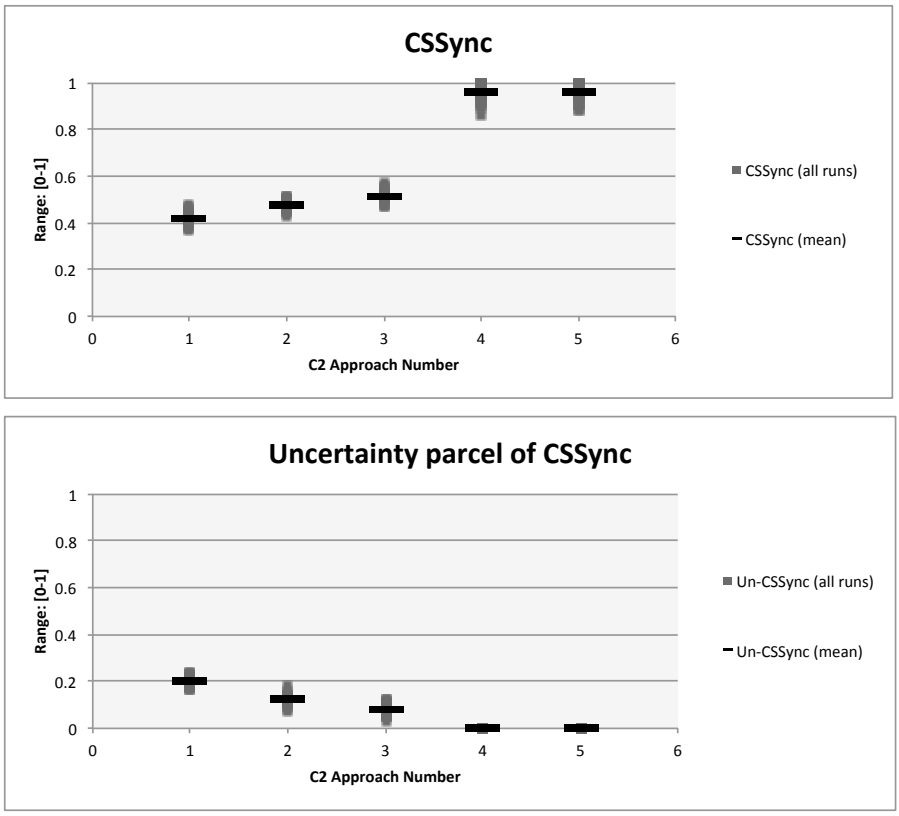
Level	MEAN	STDEV
1	9.11	2.59
2	11.59	2.28
3	10.19	2.14
4	61.85	7.72
5	61.96	7.27

Figure 8 – Partially Correct IDs

Collaborative and Edge yield similar results (about 62 partially correct IDs). De-conflicted presents the second best results (11.6) closely followed by Coordinated (10.2) and then Conflicted (9.1). Two distinct clusters emerge:

- The first, encompassing Conflicted, De-conflicted and Coordinated, with a low amount of information available resulting in low correctness values (below 12), and,
- The second, encompassing Collaborative and Edge, with a high amount of information available resulting in high correctness values above 61). See 7.2 for further information on Edge results.

The CSSync and its associated uncertainty measurement results are presented in Figure 9.



Approach	MEAN	STDEV
1	0.42	0.03
2	0.48	0.02
3	0.52	0.03
4	0.96	0.04
5	0.96	0.04

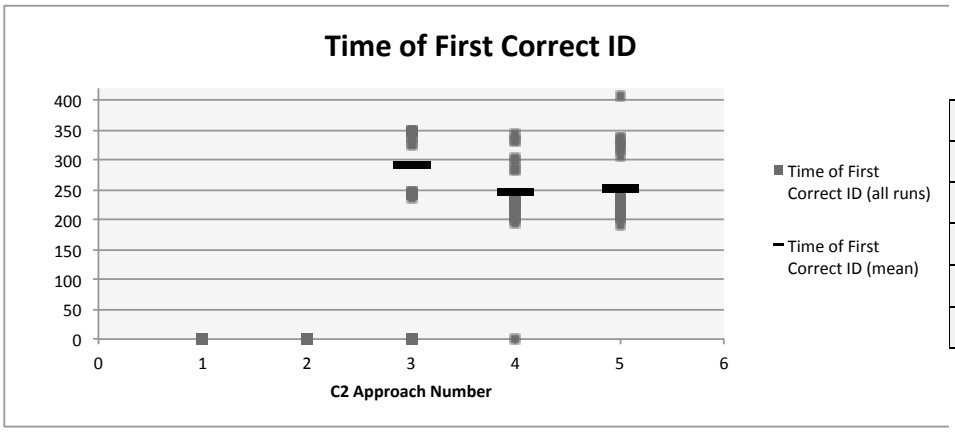
Approach	MEAN	STDEV
1	0.20	0.02
2	0.12	0.02
3	0.08	0.03
4	0.00	0.00
5	0.00	0.00

Figure 9 – CSSync (top) and its uncertainty measurement (bottom)

Once again, two clusters emerge regarding CSSync:

- The first, encompassing Conflicted, De-conflicted and Coordinated, with a low amount of available information resulting in low CSSync values (between 0.42 and 0.52), and,
- The second, encompassing Collaborative and Edge, with a high amount of available information resulting in high CSSync values (at 0.96).
- The uncertainty measure associated with CSSync reduces as the C2 approach becomes more network-enabled. For Collaborative and Edge organizations, uncertainty values are zero (in every run).

The results obtained for Time of First Correct ID (requiring a complete solution) are presented in Figure 10.



Approach	MEAN	STDEV
1	-	-
2	-	-
3	292	49.50
4	247	42.81
5	253	56.68

Figure 10 – Time of First Correct ID

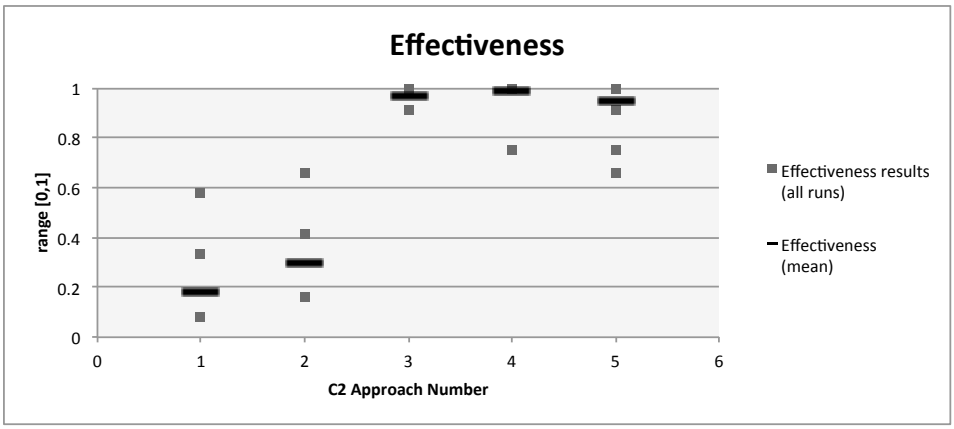
The following is concluded:

- On average, Collaborative is the fastest in reaching the first correct ID (247 seconds), closely followed by Edge (253 seconds) and then by Coordinated (292 seconds). Nonetheless, both Collaborative and Coordinated had runs where no correct complete ID was provided. All Edge runs had a correct complete ID.
- Conflicted and De-conflicted approaches did not provide any correct ID (in any of the solution spaces).

The results obtained sustain the hypothesis that more network-enabled approaches achieve more shared awareness and synchronization than less network-enabled approaches.

4.4 MoMs

The effectiveness results are presented in Figure 11. Detailed results are presented in Table 11 (see annex 7).



Approach	MEAN	STDEV
1	0.18	0.14
2	0.30	0.16
3	0.97	0.04
4	0.99	0.05
5	0.95	0.11

Figure 11 – Effectiveness

Regarding organizational effectiveness, two clusters emerge:

- Coordinated, Collaborative and Edge have the highest scores (above 0.95).
- Conflicted and De-conflicted achieved the lowest scores (below 0.30).

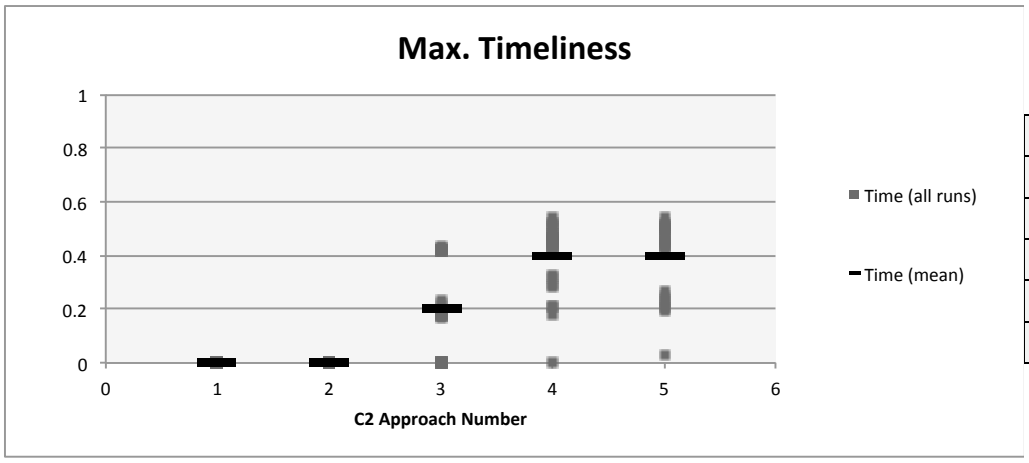
Only Coordinated C2, Collaborative C2 and Edge C2 approaches are effective in abELICIT.

The organization success criterion, which is approach specific as described in Table 2, is an important and differentiating factor. The overall effectiveness results (see Figure 11) are summarized next:

- Coordinated had low scores for the intermediate variables (e.g., information and awareness) and yet, because it was successful in distributing most information to the CTC, it obtained 100% effectiveness whenever the CTC was an average or high performing agent. However, when the CTC was a low performing agent, its results decreased to 91% (still a high score).
- Collaborative had 100% success in all runs, except the one in which all members were low-performing agents.
- Edge failed to reach 100% success in most runs where the majority of members were low-performing agents (7 out of 9 runs with low-performing agents) (see 7.2 in annex for a more detailed view).

When grouping the results in three clusters (high-performing vs. low-performing), the results obtained sustain the hypothesis that more network-enabled approaches are more effective than less network-enabled approaches.

The maximum timeliness results are presented in Figure 12.

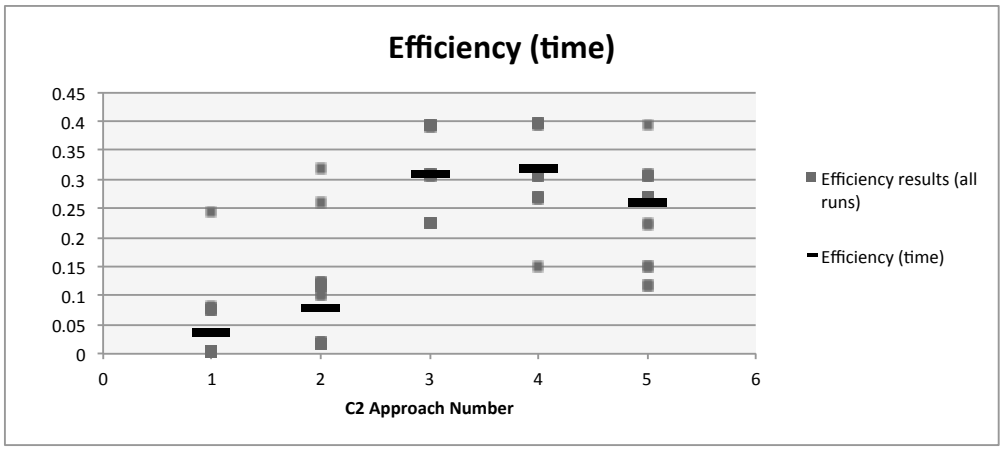


Approach	MEAN	STDEV
1	0.00	0.00
2	0.00	0.00
3	0.20	0.17
4	0.40	0.13
5	0.40	0.13

Figure 12 – Max. Timeliness

Collaborative and Edge achieve the best results (0.40) followed by Coordinated that was two times slower (0.20). Conflicted and De-conflicted, with zero, didn't provide any correct identifies.

The time-efficiency results are presented in Figure 13.



Approach	MEAN	STDEV
1	0.04	0.05
2	0.08	0.08
3	0.31	0.07
4	0.32	0.06
5	0.26	0.06

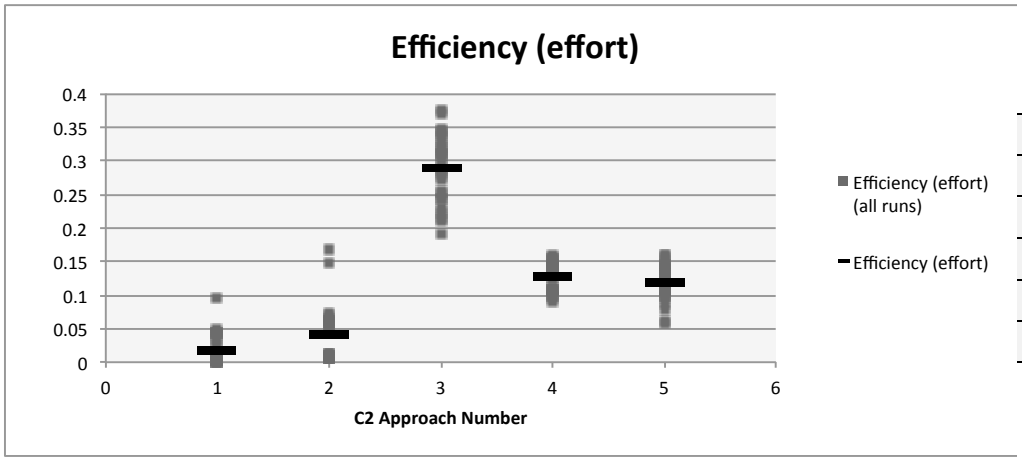
Figure 13 – Efficiency (time)

Two clusters emerge:

- The first comprises Coordinated, Collaborative and Edge with high time-efficiency scores (0.32, 0.31 and 0.26 respectively),
- The second comprises Conflicted and De-conflicted with low time-efficiency scores.

When grouping the results in three clusters (high-performing vs. low-performing), the results obtained sustain the hypothesis that more network-enabled approaches are more (time) efficient than less network-enabled approaches.

The effort-efficiency results are presented in Figure 14.



Approach	MEAN	STDEV
1	0.02	0.02
2	0.04	0.04
3	0.29	0.05
4	0.13	0.02
5	0.12	0.03

Figure 14 – Efficiency (effort)

Herein, three clusters emerge:

- Coordinated was the most efficient organization (0.29 value).
- Collaborative and Edge appear next with 0.13 and 0.12 values respectively.
- Conflicted and De-conflicted were low effort-efficient.

The results obtained DO NOT sustain the hypothesis that more network-enabled approaches are more (effort) efficient than less network-enabled approaches.

An overview of the MoM calculated for the N2C2M2 Agent Baseline, summing the data presented in this section, is presented in Table 8. The best and second best clusters are highlighted in green and yellow background color respectively. The conclusions are drawn in 4.5.

Approach	Effectiveness		Efficiency (time)		Efficiency (effort)		Timeliness	
	Mean	σ	Mean	σ	Mean	σ	Mean	σ
1	0.18	0.14	0.04	0.05	0.02	0.02	0.00	0.00
2	0.30	0.16	0.08	0.08	0.04	0.04	0.00	0.00
3	0.97	0.04	0.31	0.07	0.29	0.05	0.20	0.17
4	0.99	0.05	0.32	0.06	0.13	0.02	0.40	0.13
5	0.95	0.11	0.26	0.06	0.12	0.03	0.40	0.13

Table 8 – N2C2M2 Agents Baseline MoM

4.5 Concluding remarks

By enlarging the N2C2M2 dataset to also include runs using abELICIT, a more reliable view of the C2 approaches emerged.

- **Overall results**

  A graphical depiction of the overall results obtained is presented in Figure 15. Six key measurements are presented that differentiate each C2 approach as follows:

  - The results obtained for Collaborative and Edge approaches are similar: both obtain high values for Shared Relevant Information, Shared Awareness, CSSync, Effectiveness and Time-efficiency.
  - Conflicted, De-conflicted and Coordinated approaches form a cluster with low values for Shared Relevant Information, Shared Awareness and CSSync. However, the first two continue with low scores in the remaining measurements, while Coordinated achieved good scores on Effectiveness, Time-efficiency and Effort-Efficiency.
  - Coordinated obtains the best values for Effort-Efficiency, followed by Collaborative and Edge.
  - Albeit Collaborative and Edge achieve the overall best scores, these approaches also spend more effort and require a higher agent performance across the whole organization. On the other hand, the Coordinated approach has low scores in the information and cognitive domains, the effort concentration in a single entity (i.e., CTC), it is effective and highly efficient.

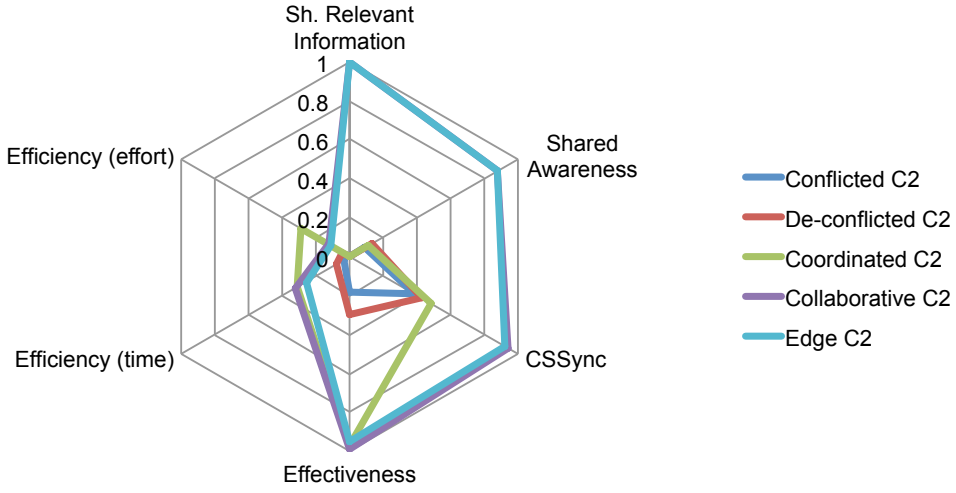


Figure 15 – Overall Results

- **Positioning the C2 approaches**

  The positioning of the C2 approaches followed the design made in the N2C2M2 experiments with human subjects to ensure that a comparison of experiments could be made. However, changing to an agent-based environment produced deviations to the location of the C2 approach space in which each approach should be positioned. The values for ADR-C, DI-C and PI-C (the latter two were calculated from the experiments) are presented in Table **9**. The following deviations are noted:

  - For the first three approaches, ADR-C is zero (no decision right allocated to the collective), placing the organization at the lower left side of the approach space.
  - Collaborative and Edge approaches display the same values for DI-C (2) and PI-C at 100%, positioning the organization at the upper right side of the approach space.

Approach	ADR-C	DI-C(1)*	DI-C(2)**	PI-C***
1	None.	0%	22%	18%
2	None (Within teams only)	0%	25%	21%
3	None (Centralized in CTC)	0%	34%	21%
4	Distributed across CTC and TLs	100%	100%	100%
5	Fully Distributed	100%	100%	100%

* Shared information was used
** Average information accessible was used
*** Average network reach was used

Table 9 **– Results in the C2 key-dimensions**

- **More network-enabled C2 approaches achieve more shared information than less network-enabled C2 approaches**

  More network-enabled approaches (Collaborative and Edge) achieve 100% shared information and less network-enabled approaches (Conflicted and Deconflicted) have low or no shared information. Collaborative and Edge don't restrict interactions amongst agents and fully accessible websites, which is a major advantage that contributes to broad and quick information reach.

  Additional variables used to evaluate the organizational performance in the information domain were (i) average relevant information reached that displayed an increasing value with the increase in C2 approach, and (ii) information accessible per key role (variable not applicable in the Edge approach) that was low for Conflicted and Deconflicted (16 facts out of 68) and maximum for Coordinated and Collaborative (68 out of 68). These variables were relevant for the Coordinated approach that, although it is a constrained model in terms of enabled interactions, was successful in delivering the necessary information to the top-level (CTC), a necessary (but not sufficient) condition for achieving organizational success for this approach

- **More network-enabled C2 approaches achieve more shared awareness and self-synchronization than less network-enabled C2 approaches**

  Regarding shared awareness and self-synchronization, two clusters of results are identified: the first, comprising Conflicted, Deconflicted and Coordinated approaches, achieve low shared awareness values (measured as number of correct IDs) and self-synchronization; while the second, comprising Collaborative and Edge approaches, achieved high values.

- **More network-enabled C2 approaches are more effective and efficient than less network-enabled C2 approaches**

  Regarding effectiveness, two clusters of results are also formed. The first, Conflicted and Deconflicted, are not effective; and the second, Coordinated, Collaborative and Edge approaches, are highly effective.

  For time-efficiency, the same two clusters are formed. The Conflicted and Deconflicted approaches are less time-efficient than the Coordinated, Collaborative and Edge approaches.

  On effort-efficiency, the Coordinated approach achieved the most effort-efficient value, followed by the Collaborative and Edge approaches and then by the low effort-efficient Conflicted and Deconflicted approaches.

  The good performance of the Collaborative and Edge approaches follows expectations, but the results obtained for the Coordinated approach were surprisingly high. In ELICIT, the game strategy set in the Coordinated approach is based in sending all necessary information to a competent decision-maker and not in spending additional effort to develop shared awareness across the organization. It is a highly effective and efficient approach that prevents the sharing of all information to every agent and the allocation of cognitive effort by each agent to solve the problem, as is the Edge approach strategy.

  However, the Coordinated approach is only applicable to problems where all information can be aggregated and processed by a single individual within the available time window. Related agility experiments observe how this strategy performs when disturbances are injected into the system.

A synthesis of the conclusions made for each hypothesis and an indication of their validation is presented in Table 10. Hypotheses not covered in this work were analyzed in (Alberts and Manso 2012).

Hypothesis	Conclusion	Validated (Y/N/C)*
[1]	*For a complex endeavor, more network-enabled C2 approaches are more effective than less network-enabled C2 approaches* The data collected sustain this hypothesis when grouping the results in two clusters: the first, highly effective, comprising Coordinated, Collaborative and Edge and the second one, comprising Conflicted and De-conflicted.	C See 4.4
[2]	*For a given level of effectiveness, more network-enabled C2 approaches are more efficient than less network-enabled C2 approaches*	
	For time-efficiency, the cluster with higher maturity (Coordinated, Collaborative and Edge) was more efficient than the cluster with the lower maturity (Conflicted and De-conflicted). Thus, when grouping results into these two clusters, the results sustain this hypothesis (for time-efficiency)	C (for time-efficiency) See 4.4
	For effort-efficiency, Coordinated was the most efficient approach, followed by Collaborative and Edge and then by Conflicted and De-conflicted. Thus, the results do not sustain this hypothesis (for effort-efficiency).	N (for effort-efficiency) See 4.4
[3]	*More network-enabled C2 approaches have increased agility than less network-enabled C2 approaches*	Not covered.
[4]	*More network-enabled C2 approaches exhibit increased/better levels of **Shared Information** than less network-enabled C2 approaches* The results sustain this hypothesis.	Y See 4.1
[5]	*More network-enabled C2 approaches exhibit increased/better levels of **Shared Awareness** than less network-enabled C2 approaches* The results sustain this hypothesis when grouped into two clusters: Collaborative and Edge (high values) and Conflicted, De-conflicted and Coordinated (low values).	C See 4.3
[6]	*More network-enabled C2 approaches exhibit increased/better levels of **Self-Synchronization** (at cognitive level) than less network-enabled C2 approaches* The results sustain this hypothesis and two clusters are visible: Collaborative and Edge (high values) and Conflicted, De-conflicted and Coordinated (low values).	Y See 4.3
[7]	*A minimum level of maturity is required to be effective in ELICIT* Based on the effectiveness results of Table 8, the following approaches are effective in abELICIT; Coordinated C2, Collaborative C2 and Edge C2.	Y See 4.4
[8]	*Increasing the degree of difficulty in ELICIT requires organizations to increase their network-enabled level to maintain effectiveness in ELICIT*.	Not covered.

* Y=Yes, N=No, C=Conditional Acceptance

Table 10 – Hypotheses Validation

5 Conclusions

The abELICIT runs added additional insights to the human runs and findings in (Manso and B. Manso, 2010). The results reinforce the hypotheses that more network-enabled approaches develop more shared information, shared awareness and self-synchronization than less network-enabled approaches. Additionally, based on each C2 approach's effectiveness criteria, the agent-based Coordinated approach joins the high effectiveness cluster that, for the human runs, only included Collaborative and Edge. Furthermore, the agent-based Coordinated approach is the most effort-efficient of all approaches.

In overall, the agent-based runs improved their effectiveness and time-efficiency scores over the human-based runs when adopting Coordinated, Collaborative and Edge. This improvement is specially pronounced for Coordinated approach. These outcomes result from the simplified environment of abELICIT over ELICIT with human subjects, in which a successful strategy consists in sharing all relevant information to key-roles (e.g., CTC in Coordinated).

Additionally, as opposed to human runs, agent-based Collaborative and Edge runs yield similar results across the measurements made in the information, social and cognitive domains[8], that is, both were located at the top-right of the approach space (i.e., Edge space), but Collaborative should be positioned in areas below that region. The option to use this Collaborative model in abELICIT was to keep backwards comparability with human runs, but a redesign should be considered in future actions.

Based on the presented conclusions and results obtained, the recommendations for future work with the N2C2M2 are the following:

- Extend ELICIT to provide a more dynamic and team-interdependent problem. As is, the abELICIT problem becomes a simple one to solve. Proposed options include increasing the problem dynamics (e.g., create a factoid set that may change depending on certain actions) and interdependencies between teams (e.g., certain key-facts only become accessible after a specific member has access to it).
- Add decisions and actions in ELICIT thus introducing effects in the environment and feedback loops to the organization. Effects in ELICIT may consist in relevant factoids being created or destroyed, thus impacting organizational effectiveness and efficiency.
- Redesign the Collaborative approach in ELICIT so that it is better positioned in the C2 approach space. This Collaborative approach shall require testing using agent-based and human-based runs.
- Further enlarge the N2C2M2 dataset with human runs, to reinforce the findings.
- Explore the use of agent's stochastic parameters to add more uncertainty in the ELICIT runs.

[8] Nonetheless, human subjects did yield different outcomes across several measurements in the C2 domains in the two equally connected Collaborative and Edge (Manso and B. Manso 2010). This is a relevant aspect to further research in social sciences.

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The content herein is deeply intertwined in the work of the SAS-065, a NATO RTO group, which worked from 2006 to 2009 to develop the NATO NEC C2 Maturity Model (N2C2M2), a new model scrutinized through several validation processes, and a subsequent experimentation on the N2C2M2 validation using ELICIT (Manso and B. Manso 2010).

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7 ANNEX – N2C2M2 Detailed Results

7.1 Effectiveness results per run

Coordinated C2 Runs	Effect.	Collaborative C2 4 Runs	Effect.	Edge C2 Runs	Effect.
3-BBBBBBBBBBBBBBBB	1	4-BBBBBBBBBBBBBBBB	1	5-BBBBBBBBBBBBBBBB	1
3-HBBBBBBBBBBBBBBB	1	4-HBBBBBBBBBBBBBBB	1	5-HBBBBBBBBBBBBBBB	1
3-LBBBBBBBBBBBBBBB	0.91	4-LBBBBBBBBBBBBBBB	1	5-LBBBBBBBBBBBBBBB	1
3-BHHHHBBBBBBBBBBB	1	4-BHHHHBBBBBBBBBBB	1	5-BHHHHBBBBBBBBBBB	1
3-HHHHHBBBBBBBBBBB	1	4-HHHHHBBBBBBBBBBB	1	5-HHHHHBBBBBBBBBBB	1
3-LHHHHBBBBBBBBBBB	0.91	4-LHHHHBBBBBBBBBBB	1	5-LHHHHBBBBBBBBBBB	1
3-BLLLLBBBBBBBBBB	1	4-BLLLLBBBBBBBBBB	1	5-BLLLLBBBBBBBBBB	1
3-HLLLLBBBBBBBBBB	1	4-HLLLLBBBBBBBBBB	1	5-HLLLLBBBBBBBBBB	1
3-LLLLLBBBBBBBBBB	0.91	4-LLLLLBBBBBBBBBB	1	5-LLLLLBBBBBBBBBB	1
3-BBBBBHHHHHHHHHHH	1	4-BBBBBHHHHHHHHHHH	1	5-BBBBBHHHHHHHHHHH	1
3-HBBBBHHHHHHHHHHH	1	4-HBBBBHHHHHHHHHHH	1	5-HBBBBHHHHHHHHHHH	1
3-LBBBBHHHHHHHHHHH	0.91	4-LBBBBHHHHHHHHHHH	1	5-LBBBBHHHHHHHHHHH	1
3-BHHHHHHHHHHHHHHH	1	4-BHHHHHHHHHHHHHHH	1	5-BHHHHHHHHHHHHHHH	1
3-HHHHHHHHHHHHHHHH	1	4-HHHHHHHHHHHHHHHH	1	5-HHHHHHHHHHHHHHHH	1
3-LHHHHHHHHHHHHHHH	0.91	4-LHHHHHHHHHHHHHHH	1	5-LHHHHHHHHHHHHHHH	1
3-BLLLLHHHHHHHHHHH	1	4-BLLLLHHHHHHHHHHH	1	5-BLLLLHHHHHHHHHHH	1
3-HLLLLHHHHHHHHHHH	1	4-HLLLLHHHHHHHHHHH	1	5-HLLLLHHHHHHHHHHH	1
3-LLLLLHHHHHHHHHHH	0.91	4-LLLLLHHHHHHHHHHH	1	5-LLLLLHHHHHHHHHHH	1
3-BBBBBLLLLLLLLLLL	1	4-BBBBBLLLLLLLLLLL	1	5-BBBBBLLLLLLLLLLL	0.91
3-HBBBBLLLLLLLLLLL	1	4-HBBBBLLLLLLLLLLL	1	5-HBBBBLLLLLLLLLLL	1
3-LBBBBLLLLLLLLLLL	0.91	4-LBBBBLLLLLLLLLLL	1	5-LBBBBLLLLLLLLLLL	0.91
3-BHHHHLLLLLLLLLLL	1	4-BHHHHLLLLLLLLLLL	1	5-BHHHHLLLLLLLLLLL	0.66
3-HHHHHLLLLLLLLLLL	1	4-HHHHHLLLLLLLLLLL	1	5-HHHHHLLLLLLLLLLL	0.66
3-LHHHHLLLLLLLLLLL	0.91	4-LHHHHLLLLLLLLLLL	1	5-LHHHHLLLLLLLLLLL	0.75
3-BLLLLLLLLLLLLLLL	1	4-BLLLLLLLLLLLLLLL	1	5-BLLLLLLLLLLLLLLL	1
3-HLLLLLLLLLLLLLLL	1	4-HLLLLLLLLLLLLLLL	1	5-HLLLLLLLLLLLLLLL	0.75
3-LLLLLLLLLLLLLLLL	0.91	4-LLLLLLLLLLLLLLLL	0.75	5-LLLLLLLLLLLLLLLL	1

Table 11 - Effectiveness results per run

7.2 Identification results for two Edge runs

Subjects / ID...	WHO	WHAT	WHERE	WHEN
Alex	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Chris	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Dale	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Francis	VIOLET	FINANCIAL INSTITU...	OMEGALAND	APRIL 5 AT AM
Harlan	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Jesse	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Kim	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Leslie	VIOLET	FINANCIAL INSTITU...	OMEGALAND	APRIL 5 AT AM
Morgan	VIOLET	FINANCIAL INSTITU...	OMEGALAND	APRIL 5 AT AM
Pat	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT 11:00AM
Quinn	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Robin	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Sam	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Sidney	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Taylor	VIOLET	FINANCIAL INSTITU...	OMEGALAND	APRIL 5 AT AM
Val	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Whitley	VIOLET	FINANCIAL INSTITU...	OMEGALAND	APRIL 5 AT 11:00AM

L5 run ID 5-HLLLLLLLLLLLLLLL @ 395 seconds: only the high-performing agent has 100% correctness

Subjects / ID...	WHO	WHAT	WHERE	WHEN
Alex	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Chris	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Dale	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Francis	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT 11:00AM
Harlan	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Jesse	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Kim	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Leslie	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT AM
Morgan	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Pat	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT 11:00AM
Quinn	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Robin	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Sam	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Sidney	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Taylor	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Val	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Whitley	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM

L5 run ID 5-HLLLLLLLLLLLLLLL @ 421 seconds (final ID state): substantial improvement but only the high-performing agent has 100% correctness

Subjects / ID...	WHO	WHAT	WHERE	WHEN
Alex	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Chris	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Dale	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Francis	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Harlan	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Jesse	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Kim	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Leslie	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT AM
Morgan	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Pat	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Quinn	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Robin	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Sam	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Sidney	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT AM
Taylor	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Val	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT AM
Whitley	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT 11:00AM

L5 run ID 5-LLLLLLLLLLLLLLLL @ 395 seconds: no 100% correctness

Subjects / ID...	WHO	WHAT	WHERE	WHEN
Alex	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Chris	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Dale	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT 11:00AM
Francis	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Harlan	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT 11:00AM
Jesse	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Kim	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Leslie	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Morgan	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Pat	VIOLET	FINANCIAL INSTITU...	TAULAND	APRIL 5 AT 11:00AM
Quinn	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Robin	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT AM
Sam	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Sidney	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Taylor	VIOLET	FINANCIAL INSTITU...	EPSILONLAND	APRIL 5 AT 11:00AM
Val	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM
Whitley	VIOLET	FINANCIAL INSTITU...	PSILAND	APRIL 5 AT 11:00AM

L5 run ID 5-LLLLLLLLLLLLLLLL @ 421 seconds (final ID state): substantial improvement being the plurality 100% correct

Table 12 – Identification results for two Edge runs

Identification results for two Edge runs at 395 and 421 seconds: in the first row (run ID 5-HLLLLLLLLLLLLLLL) all except one are low-performing agents and, in the second row (run ID 5-LLLLLLLLLLLLLLLL), all agents are low performing. Contrary to expectations, the low-performing run had a better score.

8 ANNEX – abELICIT Configuration

8.1 C2 Approach Configuration

Conflicted

Filename	organization-N2C2M2-level1.txt

```
n|Role|Team|Country|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|website1|website2|website3|website4|
<begin actual table>
1|Isolated Coordinator  ||Chiland|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|0|
2|Team leader           |Who|Chiland|0|0|0|0|0|1|1|1|0|0|0|0|0|0|0|0|1|0|0|0|
3|Team leader           |what|Psiland|0|0|0|0|0|0|0|0|1|1|1|0|0|0|0|0|0|1|0|0|
4|Team leader           |where|Omegaland|0|0|0|0|0|0|0|0|0|0|0|1|1|1|0|0|0|0|0|1|0|
5|Team leader           |when|Deltaland|0|0|0|0|0|0|0|0|0|0|0|0|0|0|1|1|1|0|0|0|1|
6|Team member           |Who|Chiland|0|1|0|0|0|0|1|1|0|0|0|0|0|0|0|0|1|0|0|0|
7|Team member           |Who|Chiland|0|1|0|0|0|1|0|1|0|0|0|0|0|0|0|0|1|0|0|0|
8|Team member           |who|Chiland|0|1|0|0|0|1|1|0|0|0|0|0|0|0|0|0|1|0|0|0|
9|Team member           |what|Psiland|0|0|1|0|0|0|0|0|1|1|0|0|0|0|0|0|1|0|0|
10|Team member          |what|Psiland|0|0|1|0|0|0|0|0|1|0|1|0|0|0|0|0|0|1|0|0|
11|Team member          |what|Psiland|0|0|1|0|0|0|0|0|1|1|0|0|0|0|0|0|0|1|0|0|
12|Team member          |where|Omegaland|0|0|0|1|0|0|0|0|0|0|0|0|1|1|0|0|0|0|0|1|0|
13|Team member          |where|Omegaland|0|0|0|1|0|0|0|0|0|0|0|1|0|1|0|0|0|0|0|1|0|
14|Team member          |where|Omegaland|0|0|0|1|0|0|0|0|0|0|0|1|1|0|0|0|0|0|0|1|0|
15|Team member          |when|Deltaland|0|0|0|0|1|0|0|0|0|0|0|0|0|0|0|1|1|0|0|0|1|
16|Team member          |when|Deltaland|0|0|0|0|1|0|0|0|0|0|0|0|0|0|1|0|1|0|0|0|1|
17|Team member          |when|Deltaland|0|0|0|0|1|0|0|0|0|0|0|0|0|0|1|1|0|0|0|0|1|
Conflicted
Who
What
Where
When
<end actual table>
```

De-conflicted

Filename	organization-N2C2M2-level2.txt

```
n|Role|Team|Country|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|website1|website2|website3|website4|
<begin actual table>
1|Information Broker    ||Chiland|0|1|1|1|1|0|0|0|0|0|0|0|0|0|0|0|0|0|0|
2|Team leader           |Who|Chiland|1|0|0|0|0|1|1|1|0|0|0|0|0|0|0|0|1|0|0|0|
3|Team leader           |what|Psiland|1|0|0|0|0|0|0|0|1|1|1|0|0|0|0|0|0|1|0|0|
4|Team leader           |where|Omegaland|1|0|0|0|0|0|0|0|0|0|0|1|1|1|0|0|0|0|0|1|0|
5|Team leader           |when|Deltaland|1|0|0|0|0|0|0|0|0|0|0|0|0|0|1|1|1|0|0|0|1|
6|Team member           |Who|Chiland|0|1|0|0|0|0|1|1|0|0|0|0|0|0|0|0|1|0|0|0|
7|Team member           |Who|Chiland|0|1|0|0|0|1|0|1|0|0|0|0|0|0|0|0|1|0|0|0|
8|Team member           |who|Chiland|0|1|0|0|0|1|1|0|0|0|0|0|0|0|0|0|1|0|0|0|
9|Team member           |what|Psiland|0|0|1|0|0|0|0|0|1|1|0|0|0|0|0|0|1|0|0|
10|Team member          |what|Psiland|0|0|1|0|0|0|0|0|1|0|1|0|0|0|0|0|0|1|0|0|
11|Team member          |what|Psiland|0|0|1|0|0|0|0|0|1|1|0|0|0|0|0|0|0|1|0|0|
12|Team member          |where|Omegaland|0|0|0|1|0|0|0|0|0|0|0|0|1|1|0|0|0|0|0|1|0|
13|Team member          |where|Omegaland|0|0|0|1|0|0|0|0|0|0|0|1|0|1|0|0|0|0|0|1|0|
14|Team member          |where|Omegaland|0|0|0|1|0|0|0|0|0|0|0|1|1|0|0|0|0|0|0|1|0|
15|Team member          |when|Deltaland|0|0|0|0|1|0|0|0|0|0|0|0|0|0|0|1|1|0|0|0|1|
16|Team member          |when|Deltaland|0|0|0|0|1|0|0|0|0|0|0|0|0|0|1|0|1|0|0|0|1|
17|Team member          |when|Deltaland|0|0|0|0|1|0|0|0|0|0|0|0|0|0|1|1|0|0|0|0|1|
De-conflicted
Who
What
Where
When
<end actual table>
```

COORDNATED

Filename	organization-N2C2M2-level3.txt

```
n|Role|Team|Country|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|website1|website2|website3|website4|
<begin actual table>
1|Cross Team Coordinator||Chiland|0|1|1|1|1|0|0|0|0|0|0|0|0|0|0|0|1|1|1|1|
2|Team leader            |who|Chiland|1|0|0|0|0|1|1|1|0|0|0|0|0|0|0|0|1|0|0|0|
3|Team leader            |what|Psiland|1|0|0|0|0|0|0|0|1|1|1|0|0|0|0|0|0|0|1|0|0|
4|Team leader            |where|Omegaland|1|0|0|0|0|0|0|0|0|0|0|1|1|1|0|0|0|0|0|1|0|
5|Team leader            |when|Deltaland|1|0|0|0|0|0|0|0|0|0|0|0|0|0|1|1|1|0|0|0|1|
6|Team member            |who|Chiland|0|1|0|0|0|0|1|1|0|0|0|0|0|0|0|0|1|0|0|0|
7|Team member            |who|Chiland|0|1|0|0|0|1|0|1|0|0|0|0|0|0|0|0|1|0|0|0|
8|Team member            |who|Chiland|0|1|0|0|0|1|1|0|0|0|0|0|0|0|0|0|1|0|0|0|
9|Team member            |what|Psiland|0|0|1|0|0|0|0|0|0|1|1|0|0|0|0|0|0|0|1|0|0|
10|Team member           |what|Psiland|0|0|1|0|0|0|0|0|0|1|0|1|0|0|0|0|0|0|1|0|0|
11|Team member           |what|Psiland|0|0|1|0|0|0|0|0|0|1|1|0|0|0|0|0|0|0|1|0|0|
12|Team member           |where|Omegaland|0|0|0|1|0|0|0|0|0|0|0|0|1|1|0|0|0|0|0|1|0|
13|Team member           |where|Omegaland|0|0|0|1|0|0|0|0|0|0|0|0|1|0|1|0|0|0|0|0|1|0|
14|Team member           |where|Omegaland|0|0|0|1|0|0|0|0|0|0|0|0|1|1|0|0|0|0|0|0|1|0|
15|Team member           |when|Deltaland|0|0|0|0|1|0|0|0|0|0|0|0|0|0|0|1|1|0|0|0|0|1|
16|Team member           |when|Deltaland|0|0|0|0|1|0|0|0|0|0|0|0|0|0|0|1|0|1|0|0|0|1|
17|Team member           |when|Deltaland|0|0|0|0|1|0|0|0|0|0|0|0|0|0|0|1|1|0|0|0|0|1|
Coordinated
who
what
where
when
<end actual table>
```

Collaborative

Filename	organization-N2C2M2-level4.txt

```
n|Role|Team|Country|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|website1|website2|website3|website4|
<begin actual table>
1|Coordinator-Facilitator||Chiland|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
2|Team leader             |Who|Chiland|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
3|Team leader             |what|Psiland|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
4|Team leader             |where|Omegaland|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
5|Team leader             |when|Deltaland|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
6|Team member             |Who|Chiland|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
7|Team member             |Who|Chiland|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
8|Team member             |who|Chiland|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|
9|Team member             |what|Psiland|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|
10|Team member            |what|Psiland|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|
11|Team member            |what|Psiland|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|
12|Team member            |where|Omegaland|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|
13|Team member            |where|Omegaland|1|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|
14|Team member            |where|Omegaland|1|1|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|
15|Team member            |when|Deltaland|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|
16|Team member            |when|Deltaland|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|
17|Team member            |when|Deltaland|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|
Collaborative
Who
What
Where
When
<end actual table>
```

Edge	
Filename	organization-N2C2M2-level5.txt

```
n|Role|Team|Country|1|2|3|4|5|6|7|8|9|10|11|12|13|14|15|16|17|website1|website2|website3|website4|
<begin actual table>
1|Coordinator-Facilitator||Chiland|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
2|Team leader             |Who|Chiland|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
3|Team leader             |what|Psiland|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
4|Team leader             |where|Omegaland|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
5|Team leader             |when|Deltaland|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
6|Team member             |Who|Chiland|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
7|Team member             |Who|Chiland|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
8|Team member             |who|Chiland|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|1|
9|Team member             |what|Psiland|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|1|
10|Team member            |what|Psiland|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|1|
11|Team member            |what|Psiland|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|1|
12|Team member            |where|Omegaland|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|1|
13|Team member            |where|Omegaland|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|1|
14|Team member            |where|Omegaland|1|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|1|
15|Team member            |when|Deltaland|1|1|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|1|
16|Team member            |when|Deltaland|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|1|
17|Team member            |when|Deltaland|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|1|0|1|1|1|1|1|
Collaborative
Who
What
Where
When
<end actual table>
```

8.2 Reference batch file for agent runs

The batch file allows to specify the configuration of multiple ELICIT runs and to schedule it as a background process run in the ELICIT server. This results in an important tool to conduct a large number of trials with minimum effort for the researcher.

An excerpt of a reference batch file pertaining to a single run and used as basis to setup the ELICIT N2C2M2 agent experiments is presented in the next table. The 'X' symbol in background yellow contains information that is specific for each run.

Namely:

- In the 'group' field, it specifies the C2 approach used (e.g., 1 to 5).

  For example, for the C2 approach Coordinated the group field will contain the following value: 'organization-N2C2M2-level3.txt'

- In the 'role' field, it specifies the agent archetype to use. This field is used to cover the possible combinations of agent archetypes across three organization levels.

  For example, when using low-performing for all agents except the team leaders that are high-performing, the role field will contain the following value:
  'SenseMaking_Agent2.4_N2C2M2_LHHHHLLLLLLLLLLL.txt'

- In the 'runName', it specifies the name of the run.

Filename	agent-batch-N2C2M2.txt (excerpt for one run)

```
<start trialset>
interval|5
waves|3
trial|60|factoidset1a5-17.txt|countries1.txt
names|names17.txt
group|organization-N2C2M2-levelX.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
```

```
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
role|SenseMaking_Agent2.4_N2C2M2_X.txt
agentauditing|false
teamtableauditing|false
numberofidentifies|-1
agentcompression|0.1
startAgentDelay|0
runName|abN2C2M2-X
country|Portugal
institution|WEAREIT
researcher|MarcoManso
researcherContactInfo|marco.manso@edisoft.pt
natureOfParticipants|agent
experienceOfParticipants|agent
baselineExperiment|no
```

8.3 Agents Configuration Template (2.4 Sample)

The agent configuration file used as basis to set the agents' archetypes (i.e., low, average and high performing) is presented next.

Filename	SenseMaking_Agent2.4Sample.txt

```
SenseMaking_Agent_1
<begin agent configuration parameters>

SenseMaking_Agent_1.jar
net.parityinc.ccrp.web.agent.impl.SenseMaking_Agent_1
readyIntervalDelay|Time interval to click Ready button|10000
```

Processing / Cognitive Characteristics

```
messageQueueCapacity|Capacity of queue (-1 means unlimited)|-1
messageQueueTimeRemainInQueue|Time a factoid can remain in queue (-1 means unlimited)|-1
messageQueueNewerBeforeOlder|If true then newer messages are selected before older|false
selectMessageFromQueueDelay|Select message from queue delay|1000
screeningSelectedMessageDelay|Screening selected message (message processing) delay|1000
informationProcessingDelay|Information Processing delay|3000
awarenessProcessingDelay|Awareness Processing delay|3000
determiningKnowledgeNeedsDelay|Determining Knowledge Needs delay|3000
primary|Primary areas of interest. Possible values: who, what, where, when)|who,what,where,when
secondary|Secondary areas of interest. Possible values: who, what, where, when)|
awarenessProcessingThreshold|If cumulative value of the perceived message value is more or equal to
this variable, then start awareness processing.|4
inactivityPeriod|Period of agent inactivity before used for logging and ending|300000
```

Social Characteristics – outward (Sharing / Posting)

```
shareBeforeProcessing|If true then share message before Processing|false
postedTypes|PostedTypes|who,what,where,when
postFactor|PostFactor|1
postOutOfArea|PostOutOfArea|true
shareWithFactor|ShareWithFactor|1
sharedTypes|SharedTypes|who,what,where,when
shareRelevantAccordingToSiteAccess|ShareRelevantAccordingToSiteAccess|false
shareAccordingToSiteAccess|ShareAccordingToSiteAccess|true
isCompetitiveHoarder|IsCompetitiveHoarder|false
pullFactor|PullFactor|1
propensityToShare|PropensityToShare possible values (low, moderate, high, very high)|moderate
shareModalChoice|ShareModalChoice possible values (both, post dominant, post only, peer to peer
dominant, peer to peer only)|post dominant
```

```
socialProcessingDelay|Social Processing delay|4000
sharingPostingMessageDelay|Sharing/Posting each Message delay|5000
shareWith|List of players with whom agent must share (-1 means share with all from organization
configuration file)|-1
shareWithWebSites|List of websites with whom agent must share|
minTimeBetweenShares|If the time since the last Share is not >= minTimeBetweenShares, the agent
should wait before it Shares (in milliseconds, -1 means ignoring this parameter)|-1
trustInIndividuals|List of initial values of TrustInIndividual for players in agent's team.
Possible values (high, medium, distrust, no opinion)|
trustInWebSites|List of initial values of Trust for web sites. Possible values (high, medium,
distrust, no opinion)|
trustInSources|List of initial values of Trust for sorces. Possible values (high, medium, distrust,
no opinion)|
reciprocity|Reciprocity possible values (high, low, medium, na, none)|
propensityToShareExternal|If message is not in area of interest, then agent shares it according to
sharing preferences with probability = propensityToShareExternal|1
postBetweenSitesDelay|Post between sites delay|500
provideRelevance|Provide relevance for posted and shared messages|false
provideTrust|Provide trust for posted and shared messages|false
```

Social Characteristics – inward / information seek (Pull)

```
webRequestDelay|Web Request (Pull)|9000
propensityToSeek|PropensityToSeek possible values (low, moderate, high, very high)|moderate
minTimeBetweenPullsForPropensityToSeekLow|It is used to set minTimeBetweenPulls, if
propensityToSeek is low. If the time since the last pull is not >= minTimeBetweenPulls, do not Pull
(in milliseconds)|300000
minTimeBetweenPullsForPropensityToSeekModerate|It is used to set minTimeBetweenPulls, if
propensityToSeek is moderate. If the time since the last pull is not >= minTimeBetweenPulls, do not
Pull (in milliseconds)|180000
minTimeBetweenPullsForPropensityToSeekHigh|It is used to set minTimeBetweenPulls, if
propensityToSeek is high. If the time since the last pull is not >= minTimeBetweenPulls, do not
Pull (in milliseconds)|60000
minTimeBetweenPullsForPropensityToSeekVeryHigh|It is used to set minTimeBetweenPulls, if
propensityToSeek is very high. If the time since the last pull is not >= minTimeBetweenPulls, do
not Pull (in milliseconds)|60000
pullBetweenSitesDelay|Pull between sites delay|1000
```

ID Characteristics

```
timeBeforeFirstIdentify|Time before the agent does its first identify (in minutes)|1
minSolutionAreas|The minimum number of ID tables with some data|1
hasSeenEnoughToIdentify|HasSeenEnoughToIdentify|1
isGuesser|IsGuesser|true
isFrequentGuesser|IsFrequentGuesser|true
idConfidencelevel|IdConfidencelevel|1
partialIdentify|Identify if there are no some answers|true
idAttemptDelay|ID Attempt delay|20000
```

8.4 Data Collection and Measurements

The data collected and measurements obtained from the ELICIT *datalogs* are presented in the next tables.

Name	Value Type	Description
Duration	Number	Duration of a run (in agent's time, measured in Minutes).
Compression factor	Number	Compression of time used to accelerate agent runs (e.g., 0.1 means 1 minute in agents time is 10 minutes in human's time).
Total Shares	Number	Number of shares performed by all members.
Total Posts	Number	Number of posts performed by all members.
Total Pulls	Number	Number of pulls performed by all members.
Total IDs	Number	Number of IDs performed by all members.
List of SenseMaking agent files	Text	Filename of agents file configuration.
Workload	Number	Measured as the number of actions requiring information processing work, that is, number of share received actions and pull actions.

Table 13 – ELICIT measurements: general

Name	Value Type	Description
Relevant facts accessible (number of)	[0..#KES factoids]	Number of K/E/S factoids accessible to organization (currently, the ELICIT platform makes all existing factoids accessible).
Facts accessible (number of)	[0..#factoids]	Number of factoids accessible to organization (currently, the ELICIT platform makes all existing factoids accessible).
Percentage of shared relevant information reached*	[0..100%]	Percentage of K/E/S factoids that were reached by all members.
Relevant information reached per key-role	[0..#KES factoids]	Number of K/E/S factoids that were reached (i.e., shared received or pull) by specific subjects (in key-roles).
Relevant information reached* (mean value)	[0..#KES factoids]	Mean value of K/E/S factoids reached by members of the organization.

#KES factoids = 33, #factoids = 64
(*) reached refers to information that a subject potentially has access to after a (i) pull action or (ii) share received.

Table 14 – ELICIT measurements: information-related

Name	Value Type	Description
Interactions activity (mean value)	Number	Mean value of interaction activities (i.e., number of shared, posts and pulls) per subjects.
Team inward-outward ratio	Number [0..1]	The ratio of inter and intra team interactions (i.e., shares) divided by total number of interactions.
Network reach (mean value)	Percentage	Mean value of the percentage of network reach by subjects.

Table 15 – ELICIT measurements: social-related

Name	Value Type	Description
Number of Partially Correct IDs	[0..4 * nbrSubjects]	Number of partially correct identifications provided by subjects (accounts correct answers in WHO, WHAT, WHERE and WHEN).
Time of First Correct ID	Number	The time to first correct and complete identification by any participant.
CSSync (Cognitive Self-Synchronization)	Number [0..1]	Cognitive self-synchronization value (Marco and Moffat 2011).
CSSync Uncertainty	Number [0..1]	Uncertainty measurement associated with CSSync (Marco and Moffat 2011).

nbrSubjects = 17

Table 16 – ELICIT measurements: awareness-related

Name	Value Type	Description
Effectiveness	[0..1]	Effectiveness score of the organization (Manso and B. Manso 2010)
Time efficiency	Number	Efficiency based on time (Manso and B. Manso 2010) – scaled to 1 hour (3600 seconds): $Efficiency_{time} = Effectiveness_{score}^{2} \times \log_{10}(1+3600/Effectiveness_{time})$
Effort efficiency	Number	Efficiency based on effort (Manso and B. Manso 2011) – scaled to 1000 actions: $Efficiency_{effort} = Effectiveness_{score}^{2} \times \log_{10}(1+1000/totalNumberOfActions)$ Being: totalNumberOfActions = total(shares+pulls+posts+IDs)
MAX timeliness*	Number	*The time to first correct and complete identification by any participant relative to the time available* (Alberts 2011, 298). $MaxTimeliness = 1-\frac{timeFirstCorrectID}{durationOfRun}$

* Concept, variable and formula: (Alberts 2011).

Table 17 – ELICIT measurements: MoMs

9 ANNEX – Calibration of Agent Archetypes

9.1 Reference Values

For the calibration of the agent parameters, past measurements conducted in the N2C2M2 human runs are used as reference. The values are presented in Table 18.

C2 approach	#shares (per hour)	#posts (per hour)	#pulls (per hour)	#IDs (per hour)	# correct answers
MAX	455	372	1443	105	7
MIN	69	78	69	40	1

Table 18 – Average Agent Results

Note that the measurements are not discriminated per C2 approach since what is intended is to obtain agent archetypes that cover all the C2 approaches.

9.2 The Average-Performing Agent

For the definition of the *average agent* parameters, the starting point used is the ELICIT sample file "SenseMaking_Agent2.4Sample.txt" (see 8.3) provided by the ELICIT platform. This configuration, however, defines agents displaying an above *average* performance, that is, agents that actively share and post information with other agents and are fast in determining the solution in all problem spaces (if the necessary information is available).

Thus, an average agent for this study consists in an agent displaying less activity and cognitive performance than the sample file agent, but that is still able to identify correctly (if the necessary information and time are available). The average agent shall also present a credible behavior across all five C2 approaches.

A number of tests were performed with different parameters and the chosen configuration is presented in Table 19.

Parameter	Sample file value	Modified Value	Rational
idConfidencelevel	1	0.5	Allows identify attempts when agent confidence on solution is above 0.5.
HasSeenEnoughToIdentify	1	10	Reduces the number of early identification attempts.
IsFrequentGuesser	True	False	Reduces the number of identification attempts.
IdAttemptDelay	20000	5000	Reduces the delay between identification attempts.
InformationProcessingDelay	3 000	5 000	Increases the delay in processing information (delays generation of awareness).
AwarenessProcessingDelay	3 000	5 000	Increases the delay in developing awareness from the information available.
SocialProcessingDelay	4 000	8 000	Increases the delay in social activities to reduce the sharing activity between subjects.
SharingPostingMessageDelay	5 000	10 000	Increases the delay in sharing and posting messages to reduce the sharing and posting activity.
ShareWithWebsites	Not specified	Who, What, Where, When	Allows posting to all websites (if allowed by NCP).
PropensityToShare	Moderate	Low	Reduce sharing activity.
ShareAccordingToSiteAccess	True	False	Does not restrict posting.

Table 19 – Average Agent parameters

The results obtained with the average-type agents are presented in Table 20.

C2 approach	#shares	#posts	#pulls	#IDs	# correct answers
Conflicted	192	64	311	108	1.25
De-conflicted	224	64	299	139	3.5
Coordinated	224	80	316	235	2
Collaborative	1088	272	264	1003	17
Edge	1088	272	264	1003	17

Table 20 – Average Agent Results

9.3 The High-Performing Agent

The high-performing agent is one that (i) shares and seeks more information and (ii) spends less time processing information than the average agent. The expected implications are (i) accelerate the amount of information shared across time (ii) increase the amount of information reached across time (iii) increase the agent's cognitive process. This should (a) reduce task time-efficiency and (b) delay or compromise task effectiveness.

The parameters that were modified from the average agent to obtain the high-performing agent are presented in Table 21.

Parameter	Average-perf. value	Modified Value	Rational
InformationProcessingDelay	5 000	1 000	Faster in processing information.
SocialProcessingDelay	8 000	4 000	Faster in handling social activities (increases the sharing activity between subjects).
SharingPostingMessageDelay	10 000	5 000	Faster in sharing and posting messages.
AwarenessProcessingDelay	5 000	1 000	Faster in developing awareness from the information available.
PropensityToSeek	moderate	High	Increase the agent's propensity to seek (pull), therefore accessing more information across time.

Table 21 – High-performing Agent parameters

The results obtained with the average-type agents are presented in Table 22.

C2 approach	#shares	#posts	#pulls	#IDs	# correct answers
Conflicted	192	64	882	113	2.25
De-conflicted	224	64	879	139	2.25
Coordinated	224	80	943	235	3.5
Collaborative	1088	272	1684	1003	17
Edge	1088	272	1684	1003	17

Table 22 – High-Performing Agent results

9.4 The Low-Performing Agent

The low-performing agent is one that (i) shares and seek less information and (ii) takes more time processing information than the average agent. The expected implications are (i) slow the information shared across time (ii) slow the amount of information reached across time (iii) slow the agent's cognitive process. This should (a) reduce task time-efficiency and (b) delay and/or decrease task effectiveness.

The parameters that were modified from the average agent to obtain the low-performing agent are presented in Table 23.

Parameter	Average-perf. value	Modified Value	Rational
InformationProcessingDelay	5 000	9 000	Slower in processing information.
SocialProcessingDelay	8 000	12 000	Slower in handling social activities (reduces the sharing activity between subjects).
SharingPostingMessageDelay	10 000	15 000	Slower in sharing and posting messages.
AwarenessProcessingDelay	5 000	9 000	Slower in developing awareness from the information available.
PropensityToSeek	moderate	low	Decrease the agent's propensity to seek (pull), therefore accessing less information across time.

Table 23 – Low-performing Agent parameters

The results obtained with the average-type agents are presented in Table 24.

C2 approach	#shares	#posts	#pulls	#IDs	# correct answers
Conflicted	192	64	166	112	3.25
De-conflicted	224	64	162	139	2.75
Coordinated	224	80	167	230	2.25
Collaborative	1088	272	0	908	12.75
Edge	1088	272	0	903	15.5

Table 24 – Low-Performing Agent results

9.5 Agent Calibration Baseline

The **Agent Calibration Baseline** comprises runs covering all approaches and all archetypes using agents with the same archetypes. This results in a baseline comprising 15 runs, as presented in Table 25.

C2 Approach	Agent Type	Run Number
Conflicted C2	Low Average High	1 2 3
De-conflicted C2	Low Average High	4 5 6
Coordinated C2	Low Average High	7 8 9
Collaborative C2	Low Average High	10 11 12
Edge C2	Low Average High	13 14 15

Table 25 – Agent Calibration Baseline

The results of the Agent Calibration Baseline runs are presented next.

9.5.1 Information Domain

The results in the information domain are presented in Table 26.

C2 Approach Number	Agents Archetype	Relevant Information Reached (Avg: #facts | %)	Shared Information Reached
1	Low	7.41 | 22%	0
1	Average	7.41 | 22%	0
1	High	7.41 | 22%	0
2	Low	8.29 | 25%	0
2	Average	8.29 | 25%	0
2	High	8.29 | 25%	0
3	Low	11.12 | 37%	4
3	Average	11.12 | 37%	4
3	High	11.12 | 37%	4
4	Low	33 | 100%	68
4	Average	33 | 100%	68
4	High	33 | 100%	68
5	Low	33 | 100%	68
5	Average	33 | 100%	68
5	High	33 | 100%	68

Table 26 - Results in the Information Domain

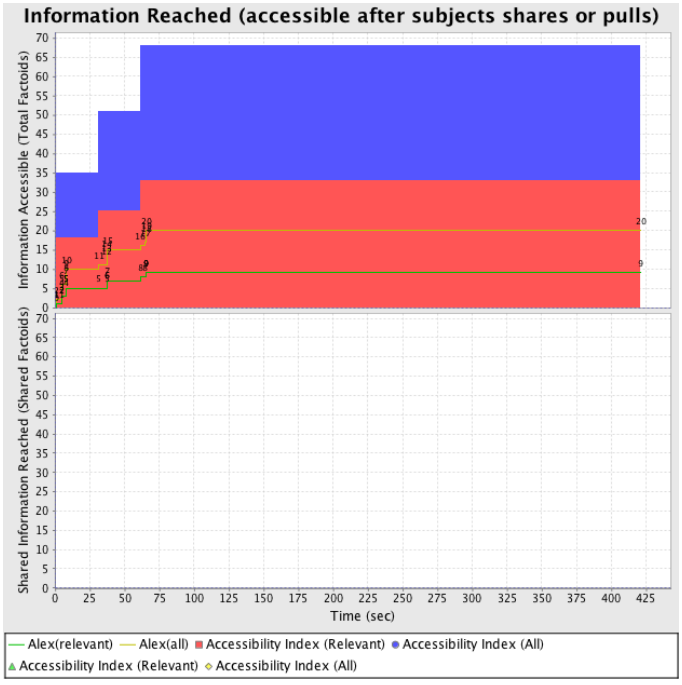
See analysis in 4.1.

Figure 16 presents time charts in which:

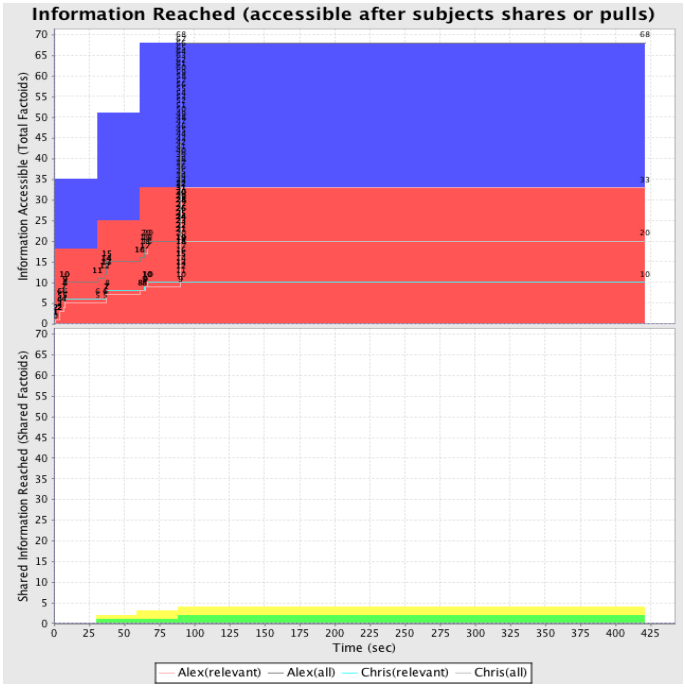
- The top chart presents the amount of information accessible (as a result of the factoids published by the ELICIT server): the increases in 'number of factoids' (i.e. red bar) and 'number of relevant factoids' (blue bar) correspond to each factoid wave (i.e., first at 0, second at 30 and third at 60 time units) and are the same for all approaches.
- The bottom chart presents the amount of shared information (i.e., number of factoids accessible by all subjects): the green bar refers to the 'number of relevant factoids' and the yellow bar to 'number of factoids' (all).

For De-conflicted and Coordinated, the information reached by the top-level entity (i.e. Alex) is presented in the top chart: for De-conflicted, it reaches 20 (out of 68) factoids at about 65 time units, while in Coordinated all factoids become accessible after 80 time units. The bottom chart shows no or very low values for shared information.

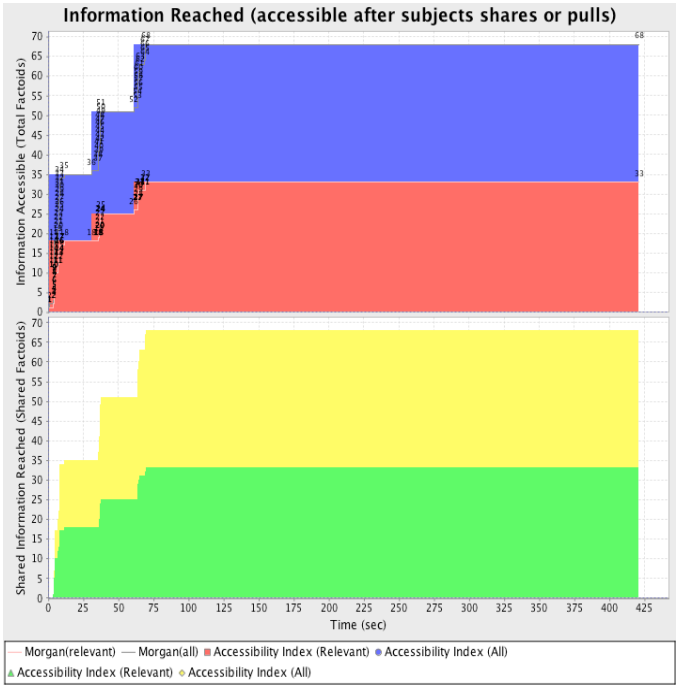
For Collaborative and Edge, all information becomes quickly accessible to all subjects, as shown in the bottom chart (i.e., green and yellow bars). For example, Morgan team-member reached all information at about 70 time units.



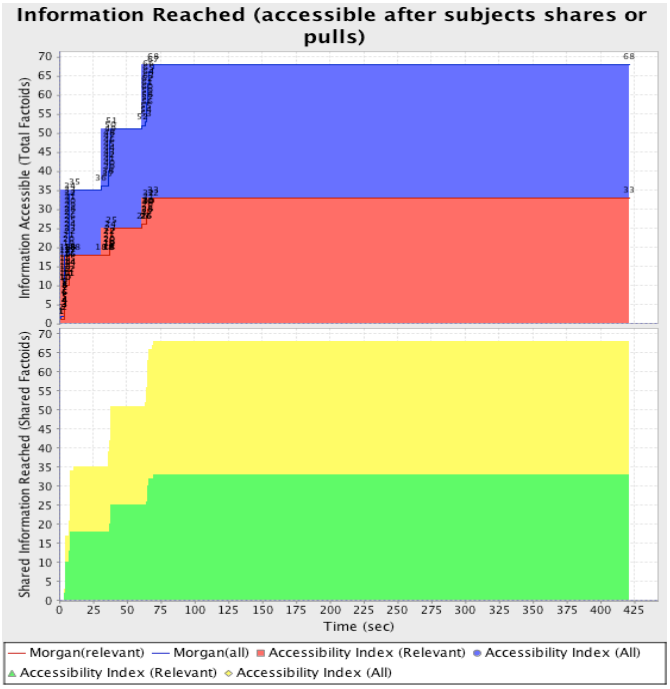
De-conflicted C2



Coordinated C2



Collaborative C2



Edge C2

Figure 16 - Information reached throughout time (average type runs)

A further aspect to mention is the linear logic of agents that can be demonstrated by presenting the amount of share and post actions per factoid (see Table 27). All factoids have the same number of shares and posts, thus agents do not have any selection criteria for sharing factoids.

Ac...	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Shares	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
Posts	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
S + P	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
(clas.)	E	E	E	E	S	S	S	K	N	K	N	N	K	K	N	N	N	N	N	N	N	K	N	S	S	S	S	S	K	N	K	N	N

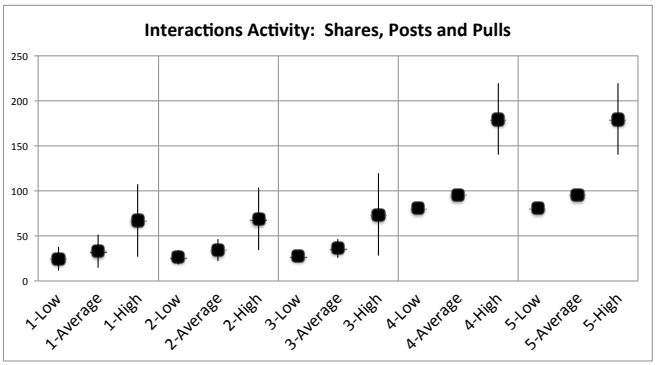
Table 27 – Sample of factoids distributed by subjects (Edge run using average agents)

9.5.2 Interactions/Social Domain

The interactions and social domain results are presented in Table 28 and depicted in Figure 17.

C2 Approach Number	Agents Archetype	Interactions Activity (Shares, Posts, Pulls)		Team Inward-Outward Ratio	Network Reach	
		Mean	σ		Mean	σ
1	Low	25	6.64	1.00	0.18	0.04
1	Average	33	9.20	1.00	0.18	0.04
1	High	67	20.06	1.00	0.18	0.04
2	Low	26	3.85	0.93	0.21	0.03
2	Average	35	6.13	0.95	0.21	0.03
2	High	69	17.35	0.97	0.21	0.03
3	Low	28	2.82	0.93	0.21	0.03
3	Average	36	5.20	0.95	0.21	0.03
3	High	73	22.73	0.97	0.21	0.03
4	Low	80	0.00	0.20	1.00	0.00
4	Average	96	1.88	0.21	1.00	0.00
4	High	179	19.76	0.25	1.00	0.00
5	Low	80	0.00	-	1.00	0.00
5	Average	96	1.88	-	1.00	0.00
5	High	179	19.76	-	1.00	0.00

Table 28 - Measures of Interactions



The thick dot marks the mean value and the lines above and below it are two times the standard deviation

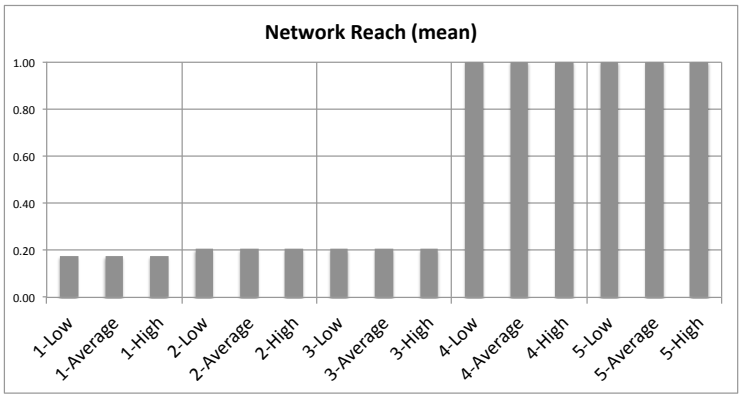
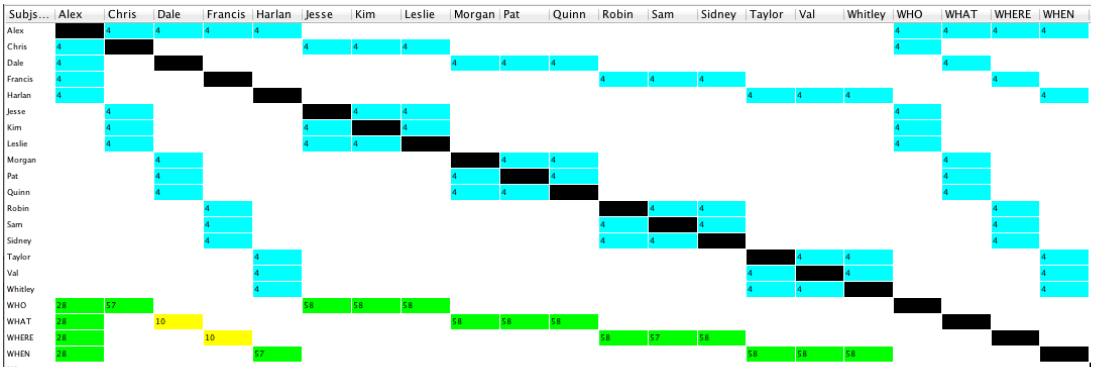
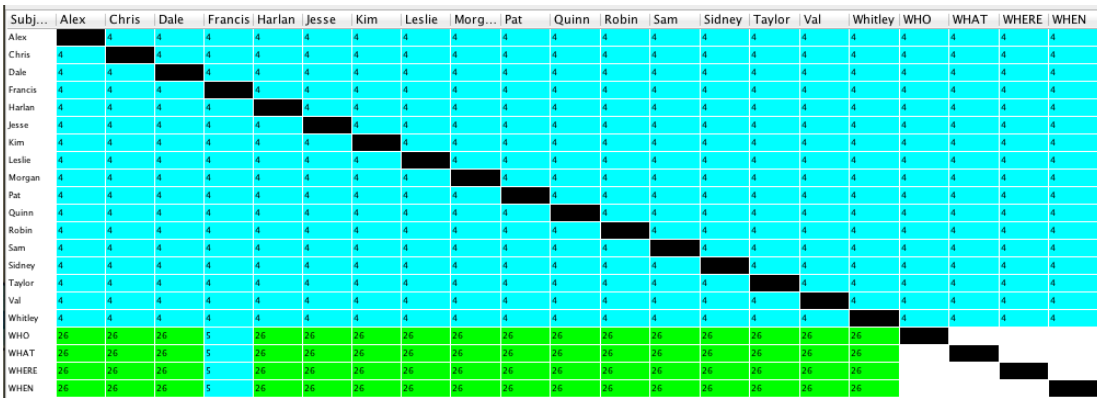


Figure 17 – Interactions activity (left) and network reach (right) results



Run: Coordinated-High

Abnormal pull behavior observed for Dale and Francis.



Run: Collaborative-High

Abnormal pull behavior observed for Francis.

Table 29 - Social matrix and abnormal behaviors observed in agents

9.5.3 Cognitive Domain

The results in the cognitive domain are presented in Table 30.

C2 Approach Number	Agents Archetype	Time of First Correct ID*	Number of Partially Correct IDs					CSSync	
			Overall	WHO	WHAT	WHERE	WHEN	Value	Uncert.
1	Low	-	13	7	6	0	0	0.47	0.21
1	Average	-	5	3	1	1	0	0.38	0.20
1	High	-	9	5	3	1	0	0.38	0.20
2	Low	-	11	5	3	3	0	0.46	0.11
2	Average	-	14	7	6	1	0	0.49	0.10
2	High	-	9	3	3	3	0	0.43	0.13
3	Low	-	9	4	3	2	0	0.51	0.06
3	Average	349	8	2	2	3	1	0.50	0.08
3	High	237	14	5	4	4	1	0.53	0.09
4	Low	-	51	17	17	0	17	0.95	0.00
4	Average	303	68	17	17	17	17	1.00	0.00
4	High	193	68	17	17	17	17	1.00	0.00
5	Low	408	62	17	17	12	16	0.92	0.00
5	Average	338	68	17	17	17	17	1.00	0.00
5	High	204	68	17	17	17	17	1.00	0.00

* Measures the time in which the first correct ID in all problem spaces occurred.

Table 30 - Results in the Cognitive Domain

Time charts regarding Number of Partially Correct IDs (scaled to 0-17), covering all approaches for average type runs, are presented in Figure 18.

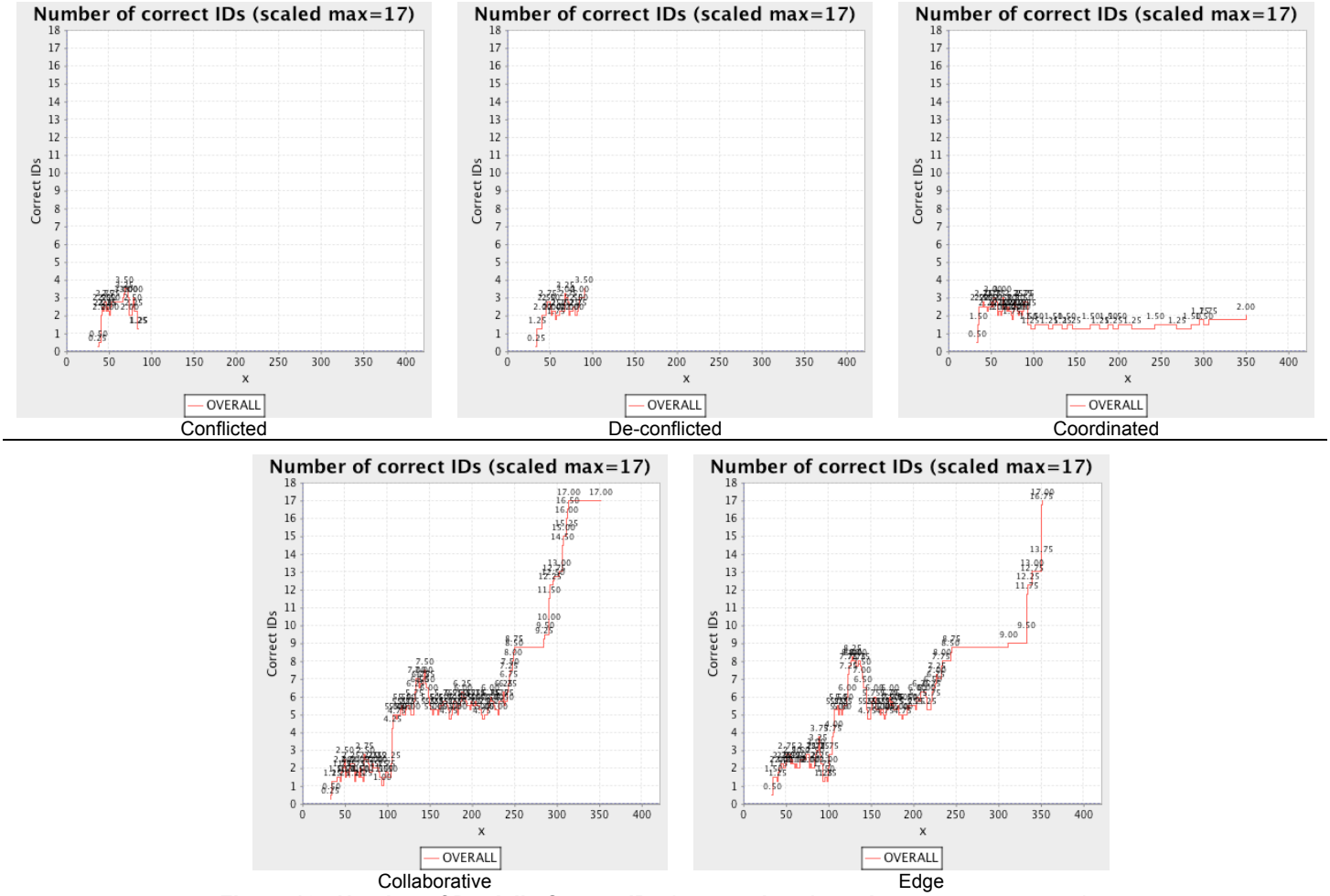


Figure 18 - Number of Partially Correct IDs (approaches 1 to 5 in average type runs)

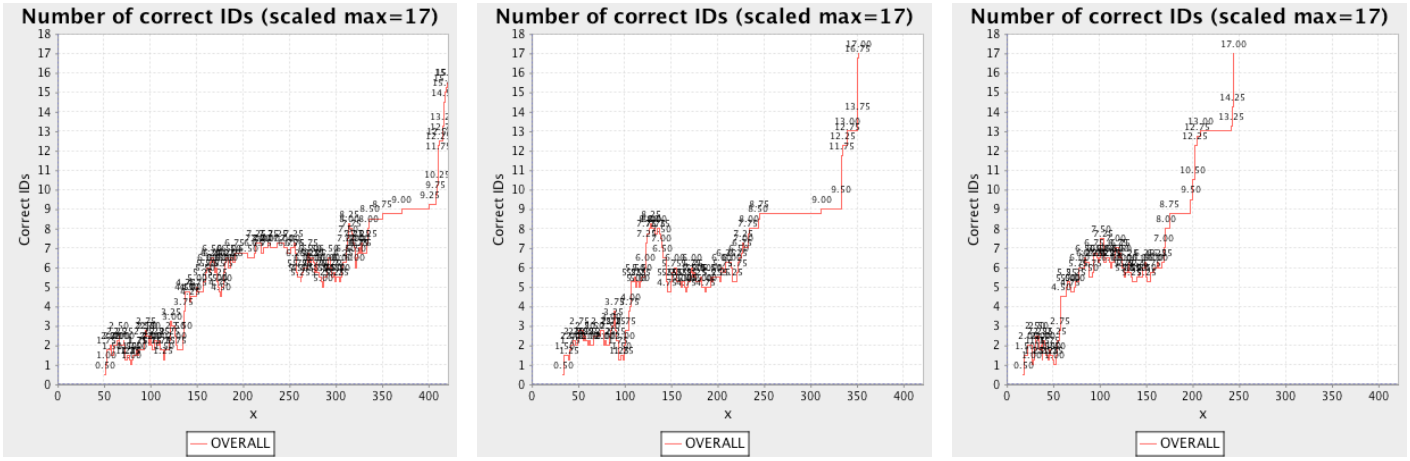
For all approaches, correct IDs only start after 35 seconds (i.e. after wave 2 when a minimum set of factoids is accessible).

Conflicted and De-conflicted reach a low value for Number of Partially Correct IDs and their identification activity ends soon (at about 100 seconds) since no new factoids are circulated between teams.

Coordinated reaches low but stable values after 100 seconds.

Collaborative and Edge have an irregular trend until 100 seconds, where it has a steep increase to stabilize again after 150 seconds. Then, Collaborative has a second steep increase around 250 seconds and reaches its maximum value at about 310 seconds. Edge second steep increase occurs after 300 seconds and reaches maximum value at about 350 seconds.

Time charts regarding the Number of Partially Correct IDs (scaled to 0-17) for all Edge runs are presented in Figure 19.



Low performing Average Performing High performing

Figure 19 - Number of Partially Correct IDs for Edge runs

As expected, by increasing the agents' performance the time to reach a given Number of Partially Correct IDs decreases. The best awareness scores and precise time they were achieved are presented in 'Scores' subsection.

The Cognitive Self-Synchronization results are presented in Figure 20.

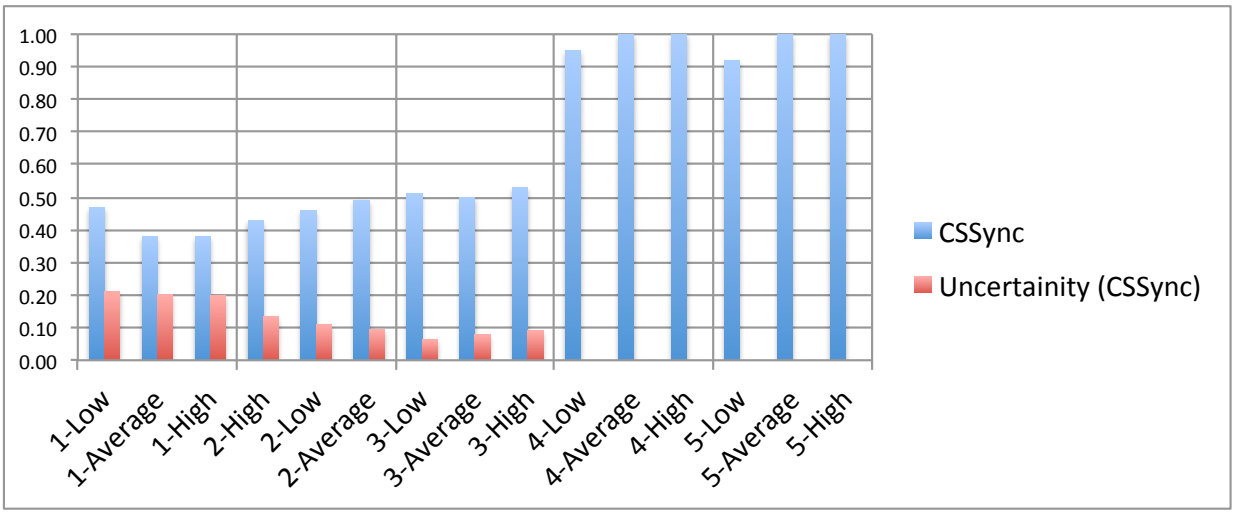


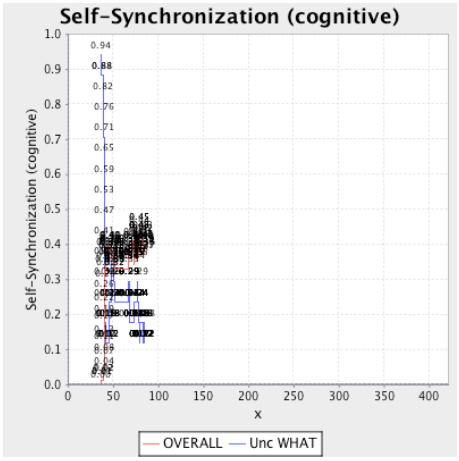
Figure 20 - Cognitive Self-Synchronization and related uncertainty measure

Figure 21 presents the time evolution of CSSync from Conflicted to Edge using the average type agent.

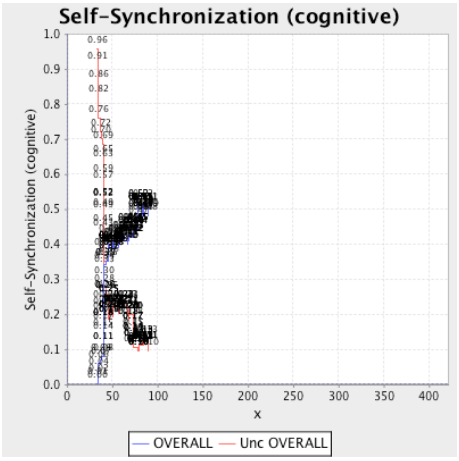
Self-synchronization starts forming (and its associated uncertainty decreases) after 30 seconds. While in Conflicted the final CSSync value varies around 0.4, in De-conflicted the value is slightly increasing until it reaches 0.5. In Coordinated, on the other hand, it reaches the final values for CSSync and its associated uncertainty at 100 seconds, with minor fluctuations after this.

Both Collaborative and Edge have steep increases in self-synchronization after 100 seconds until it reaches its maximum value after 300 seconds. Their uncertainty level decreases very soon to low levels.

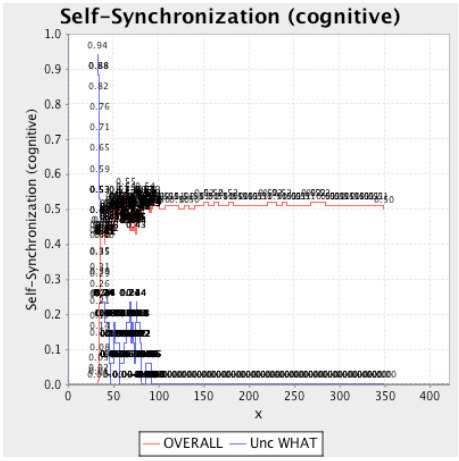
A key differentiating aspect between the first three levels (Conflicted, De-conflicted and Coordinated) and the last two levels (Collaborative and Edge) consists of the amount of shared information across the organization. For the first case it is always low, and for the later cases it is high. By having all information available, agents develop high levels of shared awareness and CSSync (and no uncertainty).



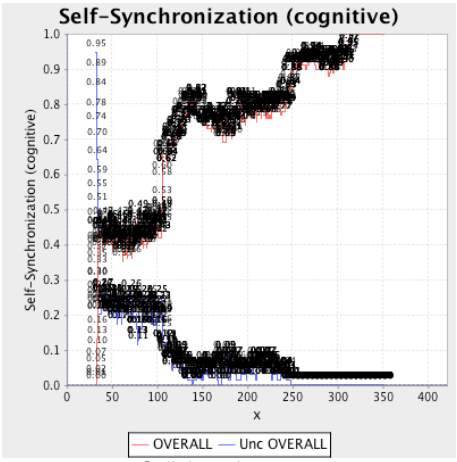
Conflicted



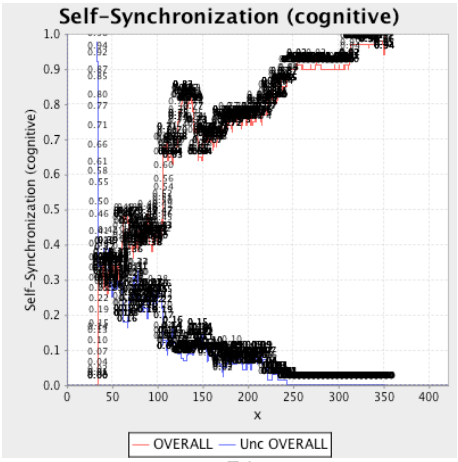
De-conflicted



Coordinated



Collaborative



Edge

Figure 21 - CSSync evolution over time and its associated uncertainty

9.5.4 MoMs

Results for time-efficiency and effort-efficiency are presented in Figure 22.

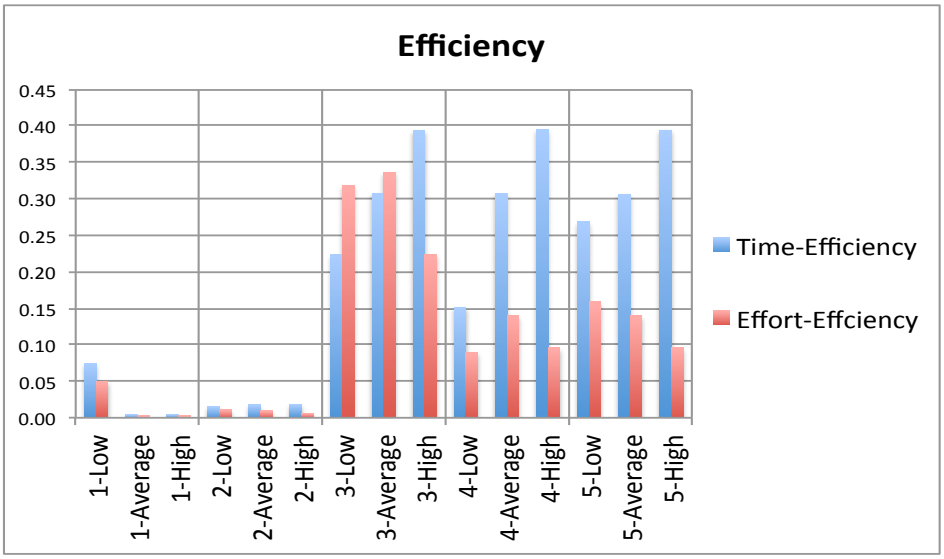


Figure 22 - Time-Efficiency and Effort-Efficiency Results

10 ANNEX - Factoid Set

Filename: factoidset1a5-17.txt

Content:

```
1|E|1|2|1|1|The Lion is involved
2|E|2|6|1|1|Word has it that an unprotected target is preferred to ensure the likelihood of success (can assume is true)
3|E|3|10|1|1|The Lion doesn't operate in Chiland
4|E|4|14|1|1|The Lion attacks in daylight
5|S|1|1|3|1|The Azure, Brown, Coral, Violet, or Chartreuse groups may be planning an attack
6|S|1|8|2|2|The Azure and Violet groups use only their own operatives, never employing locals
7|S|1|17|1|3|The Chartreuse group is not involved
8|K|1|3|3|1|The Lion is known to work only with the Azure, Brown, or Violet groups
9|N|1|13|1|1|The Purple or Gold group may be involved
10|K|1|9|1|2|All of the members of the Azure group are now in custody
11|N|1|4|3|2|Reports from the Coral group indicate a reorganization
12|N|1|5|1|3|There is a lot of activity involving the Violet group
13|K|1|11|1|3|The Brown group is recruiting locals - intentions unknown
14|K|1|15|2|4|The Lion will not risk working with locals
15|N|1|14|2|4|The Jackal has been seen in Tauland
16|N|1|10|1|5|Members of the Purple group have been visiting Omegaland
17|N|1|6|3|6|The Chartreuse group has close ties with local media
18|N|1|7|1|7|The Azure group has a history of attacking embassies
19|N|1|12|3|8|The Purple and Gold groups have blood ties
20|N|1|16|3|9|The Brown group has been known to use IED's
21|N|2|1|2|1|Only the Coral and Violet groups have a capacity to hit protected targets
22|K|2|8|3|1|All high value targets belonging to Tauland and Epsilonland are well protected
23|N|2|9|1|2|The attackers are focusing on a high visibility target
24|S|2|4|1|1|Caches of explosives have recently been found in Epsilonland, Chiland, and Psiland
25|S|2|2|1|2|Financial institutions in Tauland, Chiland, and Omegaland were recently attacked there is evidence of more attacks
26|S|2|15|3|3|Reports that uniforms were stolen in Tauland, Epsilonland and Psiland
27|S|2|11|1|4|Bloggers are discussing the role of financial institutions in oppressing the Coral, Violet and Chartreuse groups
28|S|2|13|1|5|Members of the Violet and Chartreuse groups were active in planning protests at a recent financial summit
29|K|2|16|1|2|Security forces are providing highly visible, around the clock protection to all visiting dignitaries in the region
30|N|2|14|3|3|Dignitaries in Epsilonland employ private guards
31|K|2|12|2|3|Tau, Epsilon, Chi, Psi and Omega-lands are providing visible, around the clock protection to their own dignitaries at home
32|N|2|17|1|4|A new train station is being built in the capital of country Tauland
33|N|2|5|2|5|Tauland's embassy in Epsilonland has a flat roof
34|N|2|3|1|6|Until recently most of the dignitaries in Tauland rode in Mercedes
35|N|2|10|1|7|Dignitaries in Chiland have motorcycle escorts
36|N|2|7|3|8|Epsilonland's embassy in Tauland has two helicopter pads
37|S|3|9|3|1|The Azure,  Brown, Coral, and Violet groups have the capacity to operate in Tau, Epsilon, Chi, Psi and Omega-lands
38|N|3|2|3|1|Locals in Tauland, Epsilonland and Omegaland are being recruited
39|K|3|4|2|1|Countries Chiland, Psiland and Omegaland are taking steps to protect their embassies abroad
40|N|3|5|3|2|The Brown group members have entered Tauland and Epsilonland
41|N|3|6|2|3|Reports from Tauland, Chiland and Psiland indicate surveillance ongoing at coalition embassies
42|K|3|7|2|2|The target is a coalition member embassy, visiting dignitary, or financial institution (Tau, Epsilon, Chi, Psi or Omega-lands)
43|N|3|14|1|4|No traces of members from the Coral group have been found in countries Psiland or Omegaland
44|S|3|16|1|2|Chiland is in the process of deploying troops to protect the embassies of coalition partners
45|N|3|1|1|5|The Azure, Brown, and Coral groups want to attack the interests of Tauland, Epsilonland or Chiland
46|S|3|3|2|3|The Coral and Violet group operatives have entered Psiland
47|K|3|13|3|3|All high value targets of Omegaland are well protected
48|S|3|12|1|4|There has been an increase in messages intercepted in Psiland
49|N|3|15|1|6|The Lion was born in Tauland
50|N|3|8|1|7|There is no new information about Brown group operations in Chiland
51|N|3|11|2|8|Epsilonland is mountainous
52|N|3|17|2|9|Tauland is land locked
53|K|4|17|3|1|The attack will be at 11:00
54|N|4|2|2|1|The Azure and Brown groups prefer to attack at night
55|N|4|3|1|2|The Tauland embassy in Epsilonland is hosting a international conference on the 10th
56|N|4|11|3|3|The Chartreuse, Purple and Gold groups are known to attack at any time of the day
57|S|4|6|1|1|Attacking buildings when there are many people present increases casualties
58|N|4|15|1|4|The Coral, Chartreuse and Purple groups are capable of attacking year round
59|K|4|5|1|2|The Lion is planning something in April on the anniversary of his father's death
60|S|4|10|3|2|There are fewer attacks in the dead of winter (January thru March)
61|S|4|16|2|3|The Violet and Chartreuse groups want to attach the interests of Chiland, Psiland and Omegaland
62|K|4|1|1|3|The Violet group is planning something big on the 5th
63|S|4|7|1|4|The Violet group prefers to operate in daylight
64|N|4|8|1|5|The lion was born in June
65|N|4|9|2|6|The Coral group prefers to attack at night
66|N|4|12|1|7|The Purple group prefers to attack in daylight
67|N|4|4|1|8|The Brown group needs time to regroup
68|N|4|13|2|9|The Azure group does not attack on its holy days
69|A|0|0|0|0|The Violet group plans to attack a financial institution in Psiland on April 5 at 11:00 AM
```