19th ICCRTS

"C2 Agility: Lessons Learned from Research and Operations"

Information Quality Evaluation of C2 Systems at Architecture Level

Paper ID Number:

077

Topics:

Topics 4: Experimentation, Metrics, and Analysis

Topics 3: Data, Information and Knowledge

Topic 5: Modeling and Simulation

Authors:

Dr Luo Xu, NCI

Dr Zhiqiang Fan, NCI

Research Fellow Zhongliang Ai, NCI

Point of Contact:

Dr Zhiqiang Fan

North China Institute of Computer Technology (NCI)

No. 211 Beisihuan Middle Road, Beijing, P. R. China

Tel:

+86 10 89056348

E-mail:

g.fanzhiqiang@gmail.com

Abstract

As C2 systems become larger and more complex, architecture plays a more essential role during the whole life-cycle of the systems. Thereby, capability evaluation of C2 systems at architecture level becomes necessary and important for improving the system capability at the stage of architecture design. This paper proposes a method for information quality evaluation of C2 system at architecture level. First, the information quality model is proposed, including measures of information quality and methods of weights assignment and synthesis of the measures. Second, a framework for systematically conducting architecture-level information quality evaluation is provided. Finally, based on the framework, an experiment is conducted to validate the proposed information quality evaluation method. Experiment results show that our proposed method can effectively evaluate the information quality based on architecture models of C2 systems, which can help to identify key factors impacting information quality and improve the system capability at the stage of architecture design of C2 system.
Keywords: Information Quality, Measures, Architecture

1 Introduction

Control and Command (C2) systems are composed of hardware and software subsystems for gathering information from various sensors, processing and displaying information, and commanding and controlling various weapons to attack threatening targets. C2 systems are often large-scale, complex, real-time and software-intensive systems. It has long been recognized that "architecture" has a strong influence throughout the development life cycle of a system [1], especially for the development of large-scale and complex systems, in which the development process often involves multiple stakeholders, various and complicated activities, and multiple development stages. With the development of network centric warfare (NCW), C2 systems become larger and more complex, architecture of C2 system plays a more essential role during the whole life-cycle of the systems. Therefore, capability evaluation of C2 systems at the stage of architecture design becomes necessary and meaningful.

In the environment of NCW, information quality/superiority plays a very important role for winning the war [2]. Hence, information quality/superiority is usually an important measure of C2 system capabilities [3]. There already exist many literatures to evaluate the information quality/superiority of C4ISR system or its subsystems. Qiu [4], Liu [5] and Chen [6] proposed several methods for evaluating the information quality or information superiority of C4ISR system. Yang [7], Zhao [8], Zhao [9] and Greg [10] respectively provided the methods to evaluate the information quality/superiority of Data Link Communication Subsystem, Military Communication Network, Communication Subsystem, and Tactical Military Networks in C4ISR system. Besides, Quan [11] provided the evaluation index of information superiority and discussed several evaluation methods. Zhu [12] and Zhang [13] evaluated the information superiority of Near Space Information System and Command Automation System, respectively. Sangheun [14] analyzed the information exchange capability of battlefield networks. Though these works have provided many effective methods to evaluate information quality/superiority, there still lacks a method that can evaluate the information quality based on the architecture design of C2 systems. Therefore, in this paper, we propose a method for information quality evaluation of C2 system at architecture level. First, we propose an information quality model that qualitatively establishes the relations between architecture design and measures of information quality. Second, a framework is provided to conduct the architecture-level information quality evaluation of C2 system. Finally, an experiment is conducted to validate our proposed method. Via results analysis in the experiment, it shows that our method can help designers to identify key factors in architecture design which significantly impacts the information quality of C2 system and improve the architecture designs.

The rest of paper is organized as follow: Section 2 describes the information quality model. Section 3 provides a framework (named as DSEA) to systematically evaluate the information quality of C2 systems at architecture level. In Section 4, based on the DSEA framework, a case study used to validate our proposed information quality model is presented. Finally, the paper is concluded and the future work is discussed in Section 5.

2 Information Quality Model

2.1 Measures of Information Quality

According to the hierarchical view of measure of effectiveness proposed in [16], we provide the measures of information quality as shown in Fig.1. At the level of measure of C2 effective (MOCE), we define the measure *Information Quality*. At the level of measure of performance (MOP), we define five measures: *Completeness*, *Correctness*, *Currency*, *Relevance* and *Shared Extent*. At the level of dimensional parameter (DP), as this paper focus on the information quality evaluation at architecture level, we define the static and dynamic parameter of architecture of C2 systems. Such parameters may cause remarkable impact on system's MoP or MoCE under certain circumstances. For example, the *Average Hops of Information Transmission* between systems is an important parameter when conducting time-critical attacks. In Fig. 1, it is worth noting that *Relevance* and *Shared Extent* can be measured statically while *Completeness*, *Correctness* and *Currency* need to be dynamically measured. That is, the dynamic parameter are measured by executing architecture (i.e., via simulation). These parameters are usually calculated based on the collected data during the execution of architecture.

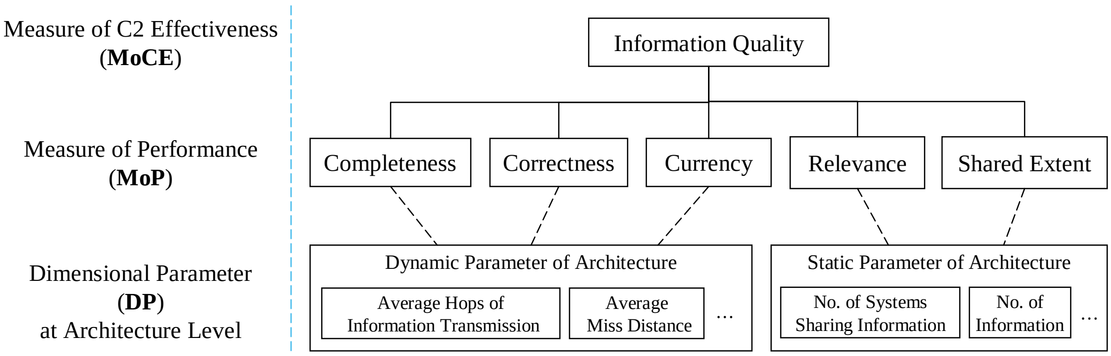


Figure 1. Measures of Information Quality

We use I_{Com}, I_{Cor}, I_{Cur}, I_{Rel}, I_{SE} to represent the *Completeness*, *Correctness*, *Currency*, *Relevance* and *Shared Extent*, respectively.

- *Completeness* is the percentage of detected targets to the entire targets. *Completeness* is a function of time, which is defined as:

$$I_{Com}(t) = \frac{\text{number of the detected targets at time } t}{\text{number of the entire targets at time } t}$$

- *Correctness* is the degree to which the detected targets agree with ground truth. Like *Completeness*, *Correctness* is also a function of time. Assuming there are N detected targets, and each target has M information items (such as velocity and location), using $G_i(t)$ and $P_i(t)$ to respectively represent the actual feature and the detected feature of ith target at time t, $G_i(t)$ and $P_i(t)$ are respectively defined as:

$$G_i(t) = [g_{ij}(t)] \quad i \in \{1, 2, \cdots, n\} \quad j \in \{1, 2, \cdots, m\}$$
$$P_i(t) = [p_{ij}(t)] \quad i \in \{1, 2, \cdots, n\} \quad j \in \{1, 2, \cdots, m\}$$

Therefore, the error of jth information item of ith target at time t is defined as:

$$ER_{ij}(t) = | p_{ij}(t) - g_{ij}(t) |$$

The correctness of ith target at time t can be defined as:

$$I_{Cor}^{i}(t) = 1 - \sum_{j=1}^{m} SER_{ij} \Big/ M$$

where, SER_{ij} is the standardization of ER_{ij}. Then average correctness at time t is defined as:

$$I_{Cor}(t) = \sum_{j=1}^{n} I_{Cor}^{i}(t) \Big/ N$$

- *Currency* is the delay from the time at which a target is detected to time at which the target is taken to users. *Currency* is defined as:

$$I_{Cur} = \sum_{j=1}^{n} I_{Cur}^{i} \Big/ N \qquad \text{where, } I_{Cur}^{i} \text{ is the currency of } i\text{th target.}$$

- *Relevance* is the proportion of detected targets that are related to the tasks at hand. Assuming there are N detected targets and K tasks, *Relevance* is defined as:

$$I_{\mathrm{Re}l} = \sum_{i=1}^{n}\sum_{j=1}^{k} I_{\mathrm{Re}l}^{ij} \Big/ N \cdot K \qquad \text{where, } I_{\mathrm{Re}l}^{ij} = \begin{cases} 1 & \text{if the } i\text{th target is related to } j\text{th task} \\ 0 & \text{if the } i\text{th target is unrelated to } j\text{th task} \end{cases}$$

- *Shared Extent* is the ratio of number of system/nodes that shared the detected targets to the number of system/nodes that can share these detected targets. Assuming there are N detected targets, *Shared Extent* is defined as:

$$I_{SE} = \sum_{i=1}^{n} I_{SE}^{i} \Big/ N \qquad \text{where, } I_{SE}^{i} = \frac{\text{number of systems/nodes that shared the } i\text{th target}}{\text{number of systems/nodes that can share the } i\text{th target}}$$

2.2 Weights Assignment of Measures

Assuming $W=(w_1, w_2, \ldots, w_j, \ldots, w_n)^T$ is the weight of the five measures, $\sum_{j=1}^{n} w_j = 1, w_j \geq 0, n = 5$. w_1, w_2, w_3, w_4 and w_5 represent the weights of *Completeness*, *Correctness*, *Currency*, *Relevance* and *Shared Extent*, respectively. The weights of the five measures can be calculated based on the methods provided in Appendix A.

2.3 Synthesis of Measurers

To evaluate information quality, it is needed to synthesize the five measures defined in Section 2.1, with experts' preferences on them (i.e., the weights of the five measures). We choose the marginal substitution method of multi-attribute decision making theory [15] to synthesize the five measures. In addition, the indifference curve of Cobb-Douglas preferences is picked for the marginal substitution method. The utility function of Cobb-Douglas preferences is used to obtain the synthetic value of the five measures. Formula (1) is the function prototype of Cobb-Douglas preferences. Three indifference curves are shown in Fig. 2. X and Y can be regarded as two measures. a and b are the user's preferences of measures. U is the synthetic value. Different points in an identical curve are equivalent. That is why it is named as indifference curve. From Fig. 2, we know that U will be unchanged by increase in X if Y is reduced. The arrow in figure indicates the increase direction of U. The values on curve $U=3$ are better than the values on curves $U=2$ or $U=1$. The parameter a and b reflect the user's preference of measures.

$$U(X,Y)=X^aY^b, a>0, b>0 \qquad (1)$$

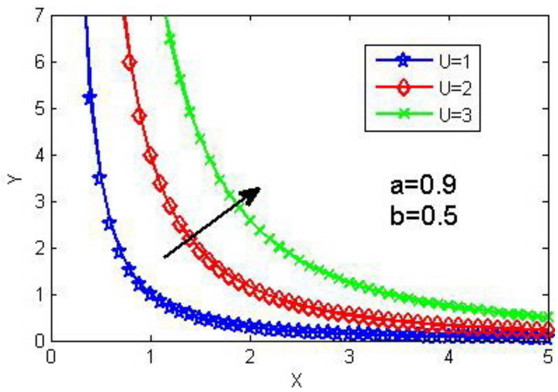


Figure 2. Examples of Indifference curve of Cobb-Douglas preferences

Based on the function prototype of Cobb-Douglas preferences (i.e. Formula (1)), the five measures can be synthesized using formula (2). It is worth noting that the effectiveness type of measures and the cost type of measures need to be respectively standardized using formulas (3) and (4) before synthesizing them.

$$I = I_{Com}^{w_1} I_{Cor}^{w_2} I_{Cur}^{w_3} I_{\mathrm{Re}l}^{w_4} I_{SE}^{w_5} \qquad (2)$$

$$r_j = \frac{x_j}{x_j^+}, x_j^+ = \max x_j \qquad (3)$$

$$r_j = \frac{x_j^-}{x_j}, x_j^- = \min x_j \qquad (4)$$

3 Architecture-level Information Quality Evaluation Framework

To systematically evaluate and analyze the information quality of C2 system at architecture level, we provide a framework, including architecture Design, Simulation, Evaluation and Analysis (DSEA), as shown in Fig. 3. First, it is needed to design and describe the architecture of C2 systems. It is worth noting that only the part of architecture that is related to information quality (IQ) is required. Architecture can be described using different architecture modeling methods or ADLs. We recommend describing the architecture using standard modeling methods or languages, such as DoDAF [20] and UML [22]. Measures of *Relevance* and *Shared Extent* need to be refined in this step. Second, with the described architecture of C2 systems, it is needed to select or develop a simulation platform to execute the described architectures under specific scenarios. Before execution, it is usually required to transform the architecture models to simulation models which can be executed by the selected or developed simulation platform. In this step, there is a need of determining the data that need to be collected during simulation and then specify the measures of *Completeness*, *Correctness* and *Currency*, based on the simulation platform. Third, according to the information quality model proposed in Section 2, information quality of systems can be calculated based on the simulation results. Finally, via analyzing the evaluation result, we can find the key factors impacting information quality and/or make the decision of architecture design.

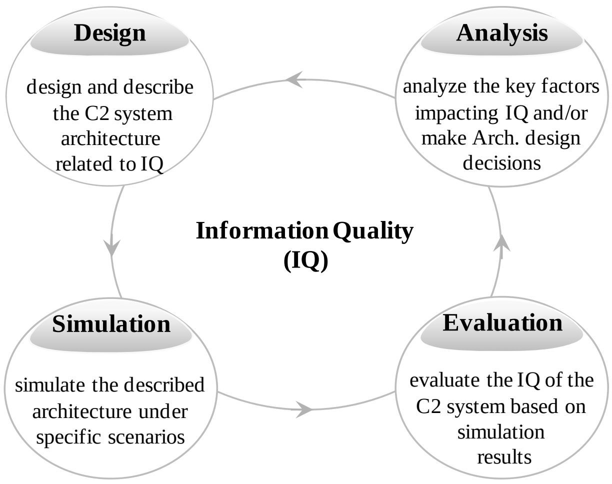


Figure 3. The DSEA Framework

4 Experiment and Analysis

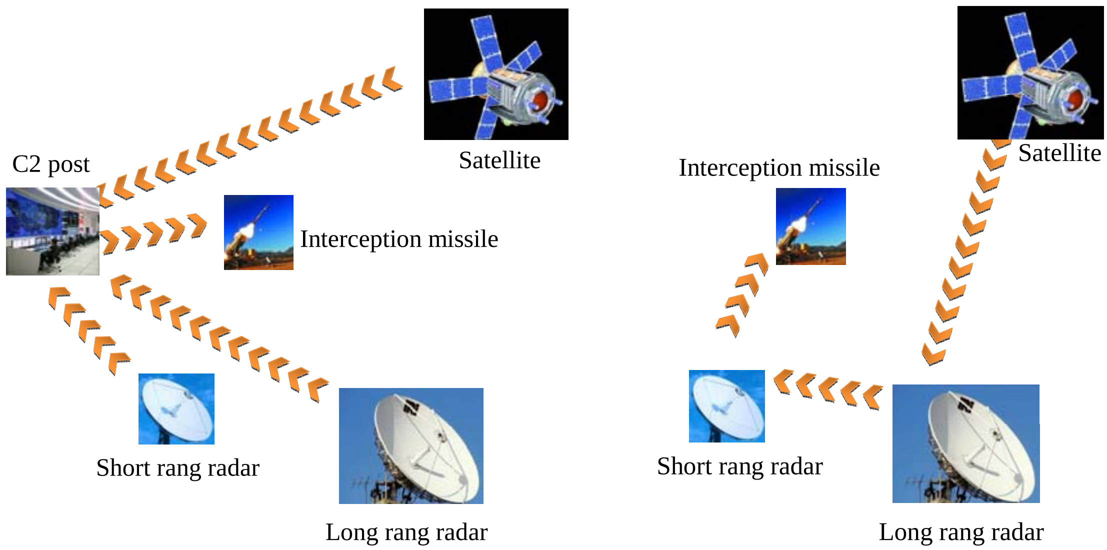
To validate our proposed information quality model, we conducted an experiment which includes three parts: planning and design of the experiment (Section 4.1) which introduces the selected C2 systems and scenario, experiment execution (Section 4.2) which is further divided into architecture description, model transformation and simulation execution, and analysis of experiment result (Section 4.3) which analyzes and discusses the collected experiment results.

4.1 Planning and Design

4.1.1 Experiment Design

In this experiment, we selected two C2 systems with different architecture designs for evaluating their information qualities. More specifically, these two systems respectively use center-collaboration mode and sensor-to-shooter-collaboration (shorten as S2S-collaboration) mode in their architecture design. In this experiment, we designed a scenario of heading off missile. In center-collaboration mode, when sensors (such as radar) detects the threatening targets (e.g. enemy missile), they send information to command and control posts. The command and control posts then make decision and assign weapon system (such as interception missile site) to intercept the enemy missile(s), as shown in Fig. 4a. Differing from center-collaboration model, sensors can send information to weapon system directly in sensor-to-shooter-collaboration model. Based on the information, the weapon's control system can independently determine how to intercept the enemy missile, as shown in Fig. 4b.

In this scenario, there are one enemy missile, three sensors (i.e., a satellite, a long rang radar and a short rang radar), a command and control post and an interception missile site. The experiment was conducted in two conditions: **noninterference** and **with electronic interference**. In the condition of electronic interference, we added an interference source.



a. center-collaboration model b. S2S-collaboration mode

Figure 4. two kinds of collaboration mode for heading off enemy missile

4.1.2 Participants

Two kinds of participants took part in this experiment. The first kind of participant, including a PhD student, two master students and an engineer, finished the architecture description. The second kind of participant, including three business experts, gave the weight of the five measures defined in Section 2.1 and confirmed the experiment results, which will be described in detail in Section 4.3.2. It is worth noting that the simulation is a constructive simulation. No participants take part in it.

4.2 Execution

4.2.1 Architecture Description

At the beginning of this experiment, architectures of the two systems were described. First, one PhD student and two master students studied the system design documents within in a week. Second the two master students captured the architecture element in the design documents and described them as DoDAF models using IBM RSA modeling tool [21], within three days. The characteristics of the architecture description are listed in Table 1.

4.2.2 Model Transformation and Simulation Execution

To simulate the architecture models, we built a simulation platform which integrates OPNET [17] and Simulink [18] via MAK/RTI [19] in this experiment. It is needed to transform the architecture model to simulation models. Based on the defined rules in our previous work [23], architecture models conducted in Section 4.2.1 were automatically transformed into the models which can be directly inputted to the built simulation platform. As mentioned in Section 4.1.1, the whole simulation was divided into two groups (i.e., noninterference and interference). In each groups, 30 times simulations were executed.

Table 1. Characteristics of Architecture Descriptions

Models	Descriptions	
	Center-Collaboration Mode	S2S-Collaboration Mode
OV-2	5 nodes and 7 connections among them	4 nodes and 4 connections among them
OV-4	5 nodes and 4 relationships among them	4 nodes and 3 relationships among them
OV-5	8 activities and 23 flows among them	7 activities and 14 flows among them
OV-6b	20 states and 27 transitions among them	16 states and 22 transitions among them
OV-6c	6 systems and 14 events among them	5 systems and 15 events among them
OV-7	9 data	7 data
SV-1	6 systems and their 16 interactions	5 systems and their 12 interactions
SV-2	5 systems and their 4 communications	4 systems and their 3 communications
SV-4	27 functions	24 functions
SV-5	39 mappings between 8 activities and 27 functions	32 mappings between 7 activities and 24 functions
SV-10b	16 states and 22 transitions among them	14 states and 19 transitions among them
SV-10c	6 systems and 29 events among them	5 systems and 19 events among them

4.3 Results and Analysis

4.3.1 Results Collection

After each simulation, the I_{Com}, I_{Cor}, and I_{Cur} were calculated. In this experiment, since there is only one enemy missile, the I_{Com} was calculated by averaging the detection rate of the three sensors (i.e., the satellite, the long rang radar and the short rang radar). For I_{Cor}, we only calculated one information item “distance precision of the enemy missile” which is the average of distance precisions reported by the three sensors. The standardized simulation results in noninterference group and in interference group are respectively listed in Table 6 and Table 7, Appendix B

4.3.2 Analysis and Discussion

Using the average results in Table 6 and Table 7, Appendix B, we compare the I_{Com}, I_{Cor}, and I_{Cur} of center-collaboration mode and S2S-collaboration mode, as shown in Fig. 5, Fig.6 and Fig. 7, respectively. From Fig. 5 to Fig.7, one can see that, in the condition of noninterference, the completeness (I_{Com}) and correctness (I_{Cor}) of these two kinds of mode are almost the same, while for the timeliness (I_{Cur}), S2S-collaboration mode is better than center-collaboration mode because sensors can directly send information to weapons in the S2S-collaboration mode. In the condition of interference, from Fig. 5 to Fig. 7, we can see that I_{Com}, I_{Cor}, and I_{Cur} in both center-collaboration mode and S2S-collaboration mode become worse. Especially, I_{Com} in S2S-collaboration mode is reduced much more than which in center-collaboration, as shown in Fig. 5.

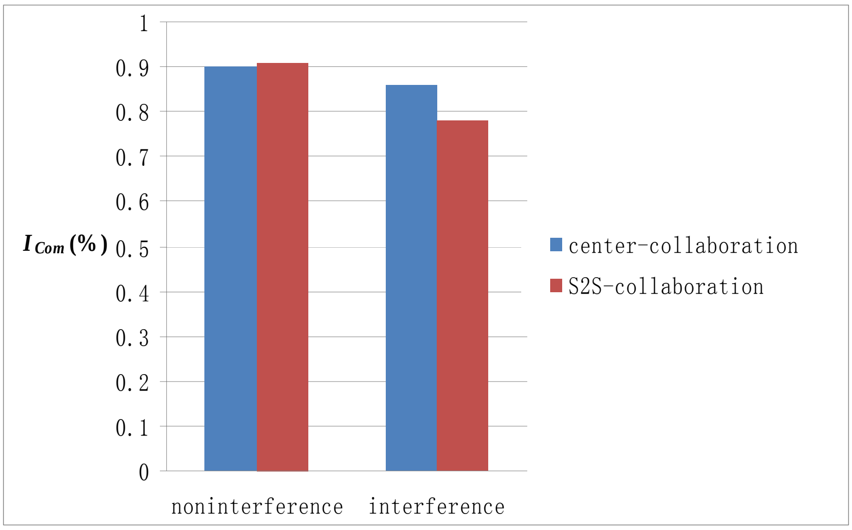


Figure 5. Comparison of completeness in center-collaboration and self-collaboration

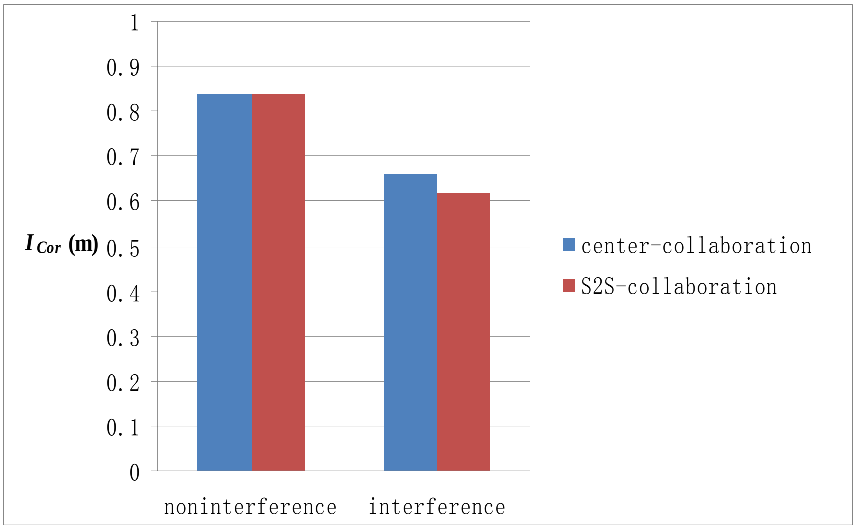


Figure 6. Comparison of correctness in center-collaboration and self-collaboration

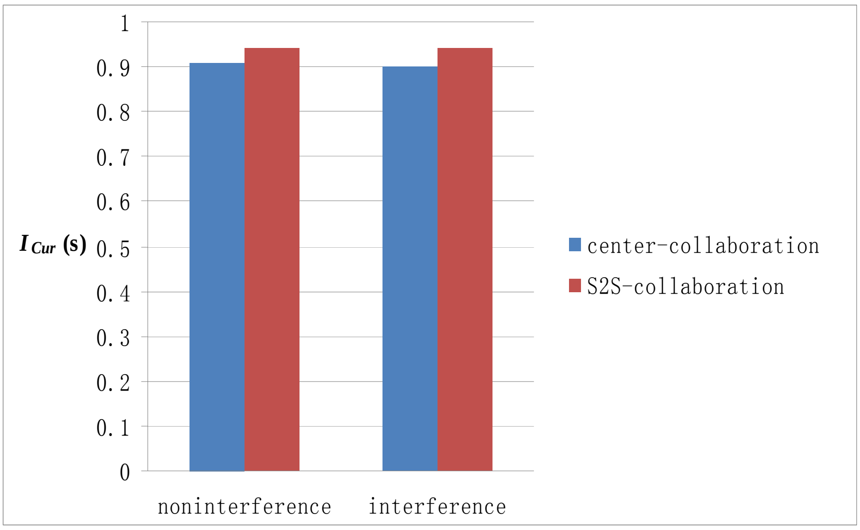


Figure 7. Comparison of currency in center-collaboration and self-collaboration

To calculate the information quality, we first derived the weights of the five measures from participated experts, as listed in Table 2 (see also Appendix A). Second, we calculated the values of relevance (I_{Rel},) and shared extent (I_{SE},) by analyzing the architecture design of the two systems (described in Section 4.1.1). Finally, the information qualities were calculated based on the method proposed in Section 2.3, as listed in Table 3.

Table 2. Weights of the five Measures

	I_{Com}	I_{Cor}	I_{Cur}	I_{Rek}	I_{SE}
Weights	9	7	8	5	3
Standardized Weights	0.28	0.22	0.25	0.16	0.09

Table 3. Results of Information Quality

		I_{Com}	I_{Cor}	I_{Cur}	I_{Rek}	I_{SE}	I
Noninterference	Center-collaboration	0.90	0.84	0.91	1	0.57	0.87
	S2S-collaboration	0.91	0.84	0.94	1	0.6	0.88
Interference	Center-collaboration	0.86	0.66	0.90	1	0.57	0.81
	S2S-collaboration	0.78	0.62	0.94	1	0.6	0.79

From the column "I_{Cur}" of Table 3, we can see that S2S-collaboration mode performs better than Center-collaboration mode, either in the condition of noninterference or in the condition of interference. Via analysis of the architecture design described in Table 1 in Section 4.1, we can see the fact that less interactions among nodes/systems in the S2S-collaboration mode save the transmission time and lead to high currency. For example, in OV-5 and SV-10C, activities/systems and flows/events among them in the S2S-collaboration mode are obviously fewer than those in the Center-collaboration mode. In other words, target information are transmitted and processed through a longer path and more systems in the Center-collaboration mode, which leads to the low currency. For the measures completeness (I_{Com}) and correctness (I_{Cor}), by analyzing the described architecture, we found that these two measures are mainly influenced by the ability of detecting and identifying targets. According to the architecture design presented in Section 4.1.1, only the C2 post equips the multi-sensor information fusion system. In the Center-collaboration mode, all situation awareness information gathered by different sensors are converged into the C2 post and then used to calculate target position. Via information fusion and revision, such mode can significantly improve the completeness and correctness in the condition of interference. Oppositely, in S2S-collaboration mode, the weapon system highly depends on a single sensor (i.e. short range radar) to gain the target position. Hence, the interference to the sensor can seriously reduce the information quality of weapon system and even cause it to lose the target.

Evaluating information quality of C2 systems at architecture level aims at providing suggestions for improving and/or making decision of the architecture design of C2 system. Based on the above analysis and the results listed in Table 3, we can conclude that using S2S-collaboration mode could provide a little higher information quality in condition of noninterference whereas using center-collaboration mode could provide higher information quality in the condition of interference. The evaluation conclusion was supported by the participated experts.

5 Conclusion and Future Work

Control and Command (C2) systems are large-scale, complex, real-time and software-intensive systems. As C2 systems become larger and more complex, architecture plays a more essential role during the whole life-cycle of the systems. Information quality is usually an important measure of C2 systems effectiveness. However, in existing literatures, there is a lack of a method that can evaluate the information quality of C2 system based on architecture designs. Therefore, in this paper, we propose a method for architecture-level information quality evaluation, including measures of information quality and the methods for weights assignment and synthesis of measures. Moreover, a framework is provided to systematically conducting information quality evaluation of C2 system at architecture level. With our proposed information quality model, one can effectively evaluate the information quality based on architecture models of C2 systems. In next work, we intend to extend the experiment by launching multiple enemy targets and apply our proposed method to more cases.

Appendix A Two Kinds of Weight Assignment Model

Experts can give their preferences of the five measures via two methods: 1) directly giving out the importance of each measure. In this case, w_j can be gained by $w_j = \frac{x_j}{\sum_{j=1}^{n} x_j}$, where, x_j is the importance of the *jth* measure, which can be given according to Table 4; 2) giving the importance ratio of two measures as matrix *A*. The Least square method can be used to calculate the subjective weight by $\min z = \sum_{i=1}^{n}\sum_{j=1}^{n}(x_{ij}w_j - w_j)^2$, $st.\sum_{j=1}^{n} w_j = 1, w_j \geq 0$ (The detailed description is presented in section 3.1.2 of Ref. [15]). x_{ij} is the importance ratio of measure *i* to measure *j*, which can be given according to Table 5.

$$A = \begin{bmatrix} x_{11} & x_{12} & & x_{1n} \\ x_{21} & x_{22} & & x_{2n} \\ & & & \\ x_{n1} & x_{n2} & & x_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & & w_1/w_n \\ w_2/w_1 & w_2/w_1 & & w_2/w_n \\ & & & \\ w_n/w_1 & w_n/w_2 & & w_n/w_n \end{bmatrix}$$

Table 4. Qualitative concept of users' preferences

MI	VI	I	LI	NI	LUI	UI	VUI	MUI
9	8	7	6	5	4	3	2	1

M, V, I, L, N and U are respectively used for Most, Very, Important, Little, Normal and Un

Table 5. Qualitative ratio of users' preferences

GI	VI	I	LI	SI	LUI	UI	VUI	GUI
5	4	3	2	1	1/2	1/3	1/4	1/5

G, V, I, L, S and U are respectively used for Great, Very, Important, Little, Same and Un

The first method compares importance of all measures and assigns an importance to each of them. On the other hand, the second method only compares measure *j* with measure *i* ($i \neq j$) in matrix *A*. If there are fewer measures, the first method is easier for experts than the second one. But second method is easier than the first, in that, experts can give preferences if there are many measures. It is indicated by psychology experiments that ordinary people can distinguish five to nine grades, and researchers suggest using nine grades and selecting the integer between 0 and 10 to quantify the qualitative value [15]. Thereby, nine grades (i.e. from 1 to 9) are used in Table 4 and Table 5.

Appendix B Standardized Simulation Result in Experiment

Table 6. Standardized Simulation Results (noninterference)

No.	Center-Collaboration Mode			S2S-Collaboration Mode		
	I_{Com}	I_{Cor}	I_{Cur}	I_{Com}	I_{Cor}	I_{Cur}
1	1.00	0.83	0.89	1.00	0.86	0.93
2	1.00	0.83	0.90	0.33	0.98	0.93
3	1.00	0.88	0.90	1.00	0.96	0.93
4	1.00	0.95	0.91	1.00	0.87	0.94
5	1.00	0.94	0.90	1.00	0.89	0.94
6	1.00	0.88	0.89	1.00	0.66	0.93
7	1.00	0.81	0.90	1.00	0.67	0.93
8	1.00	0.94	0.90	1.00	0.84	0.94
9	1.00	0.81	0.90	1.00	0.86	0.96
10	1.00	0.80	0.90	0.33	0.98	0.93
11	0.33	0.50	0.93	1.00	0.82	0.96
12	0.67	0.85	0.93	1.00	0.87	0.93
13	1.00	0.88	0.89	1.00	0.94	0.94
14	1.00	0.89	0.91	1.00	0.91	0.96
15	1.00	0.82	0.89	1.00	0.87	0.94
16	1.00	0.84	0.90	1.00	0.90	0.94
17	1.00	0.82	0.89	1.00	0.89	0.94
18	1.00	0.79	0.89	1.00	0.91	0.94
19	1.00	0.93	0.90	0.33	0.47	0.93
20	0.67	0.97	0.93	1.00	0.90	0.94
21	1.00	0.81	0.90	1.00	0.94	0.94
22	0.33	0.47	0.93	0.67	1.00	0.93
23	1.00	0.85	0.90	1.00	0.88	0.94
24	1.00	0.78	0.89	1.00	0.79	0.94
25	1.00	0.81	0.90	1.00	0.77	0.96
26	0.67	0.87	0.93	0.67	1.00	0.93
27	1.00	0.79	0.89	1.00	0.75	0.96
28	1.00	0.91	0.92	1.00	0.84	0.94
29	1.00	0.91	0.92	1.00	0.50	0.94
30	0.33	0.95	0.90	1.00	0.73	1.00
Average	0.90	0.84	0.91	0.91	0.84	0.94

Table 7. Standardized Simulation Results (interference)

No.	Center-Collaboration Mode			S2S-Collaboration Mode		
	I_{Com}	I_{Cor}	I_{Cur}	I_{Com}	I_{Cor}	I_{Cur}
1	1.00	1.00	0.93	0.33	0.62	0.96
2	0.67	0.60	0.89	1.00	0.46	0.78
3	1.00	0.62	0.90	1.00	0.60	0.94
4	0.33	0.68	0.93	0.67	0.69	0.93
5	1.00	0.62	0.91	1.00	0.69	0.93
6	0.33	0.64	0.93	0.67	0.69	0.93
7	1.00	0.63	0.93	0.33	0.58	0.96
8	1.00	0.67	0.93	0.33	0.58	0.96
9	1.00	0.61	0.90	1.00	0.65	0.96
10	0.67	0.61	0.90	1.00	0.70	0.93
11	1.00	0.62	0.89	1.00	0.58	0.94
12	1.00	0.57	0.90	1.00	0.65	0.93
13	1.00	0.69	0.92	1.00	0.64	0.93
14	1.00	0.69	0.93	0.33	0.57	0.94
15	1.00	0.64	0.90	1.00	0.61	0.94
16	0.67	0.60	0.90	1.00	0.69	0.93
17	1.00	0.73	0.93	0.67	0.62	0.96
18	1.00	0.60	0.90	1.00	0.68	0.96
19	0.33	0.62	0.92	1.00	0.72	0.93
20	1.00	0.63	0.90	1.00	0.59	0.94
21	0.33	0.94	0.78	0.67	0.66	0.93
22	1.00	0.61	0.91	1.00	0.64	0.93
23	1.00	0.58	0.90	1.00	0.67	0.93
24	1.00	0.80	0.90	1.00	0.56	0.96
25	1.00	0.65	0.93	0.33	0.59	0.94
26	0.33	0.68	0.93	0.33	0.47	0.93
27	1.00	0.66	0.93	0.33	0.64	0.93
28	1.00	0.62	0.92	1.00	0.55	0.96
29	1.00	0.69	0.93	0.33	0.66	0.96
30	1.00	0.65	0.89	1.00	0.63	0.96
Average	0.86	0.66	0.91	0.78	0.62	0.94

References

[1] ISO/IEC/IEEE 42010:2011(E): System and software engineering -- Architecture description. Dec. 1, 2011

[2] Hyun Seok Yoon, Dong Hwi Lee, Gangtaek Lee, etc. A study on the Information Superiority of Network Centric Warfare for Future battlefield. 2008 International Conference on Information Science and Security. 2008, pp:224-231

[3] Perry W, Signori D, Boon J. Exploring information superiority - a methodology for measuring the quality of information and its impact on shared awareness. RAND Corporation, 2004.

[4] Qiu hang-ping, Wang Ling-ling, Quan Ji-chuan, etc. Research on Evaluation Index of Information Superiority Based on Information Quality. Computer Technology and Development. 2010, 20(5):128-131.

[5] Liu Dong-po, Fei Ai-guo, Li Ge. Research on C4ISR Information Superiority Measurement. Computer Simulation. 2007, 24(6):27-30.

[6] Cheng Shao-qin, Zhang Jin-ming, Zhou Yan, etc. Research on the Evaluation Method of Information Superiority and Information Dominance. Journal of System Simulation. 2004, 16(5):1060-1063

[7] Yang Guang, Zhao Zhao, Zhou Jing-lun, etc. Research on Evaluation Method of Information Superiority of Data Link Communication Subsystem in C4ISR. Journal of System Simulation. 2011, 23(1):25-28.

[8] Zhao Xin-kai, Guo Jing. Research on the Evaluation Index of Information Superiority for Military Communication Network. Command Control & Simulation. 2008, 30(2):78-82

[9] Zhao Ce, Liu Qian-li. Research on the Evaluation Index of Information Superiority for Communication Sub-System of C4ISR. Command Control & Simulation. 2006, 28(6):79-82

[10] Greg Cirincione, Srikanth Krishnamurthy, Thomas F. La Porta. Impact of Security Properties on the Quality of Information in Tactical Military Networks. 2010 Military Communications Conference on Cyber Security and Network Management. pp:1-6, 2010

[11] Quan Ji Chuan, He Ming, Liu Yong. Discusses on Evaluation Methods of Information Superiority. 2011

[12] Zhu Canbin, Cheng Jian. Research on the Evaluation of Information Superiority in Near Space Information System. 2009

[13] Zhang Lie, Guo Jing, Jiang Xiaoyuan, etc. Research on Information Superiority Evaluation Model of Command Automation System. Proceedings of the 5m World Congress on Intelligent Control and Automation. 2004, pp:3155-3159

[14] Sangheun SHIM, Jaeyoung CHEON, Myunggil AHN. The Analysis of Information Exchange Capability for Battlefield Networks using M&S techniques of the NetSPIN. 18th International Command and Control Research and Technology Symposium. 2013.

[15] Xu Jiuping, Wu Wei. Multiple Attribute Decision Making Theory and Methods, Tsinghua University Press, Beijing, 2006.

[16] NATO Code of Best Practices (COBP) for C2 Assessments, 2002, page 5 and 94.

[17] OPNET Technologies, Inc. OPNET. www.opnet.com
[18] MathWorks. Simulink. www.mathworks.cn/products/simulink/
[19] VT MAK. HLA RTI – Run Time Infrastructure: MÄK RTI. http://www.mak.com/products/link-simulation-interoperability/hla-rti-run-time-infrastructure.html
[20] DoD Architecture Framework Working Group. DoD Architecture Framework Version 1.0 Volume I. February 2004. http://links.enterprisearchitecture.dk/links/files/DoDAF_v1_Volume_I.pdf
[21] IBM. Ration Software Architect. http://www-01.ibm.com/software/rational/products/swarchitect/
[22] OMG. OMG Unified Modeling Language (OMG UML), Superstructure, V2.1.2. http://www.omg.org/docs/formal/07-11-02.pdf
[23] Xia Xiao-kai, Wu Ji, Xu Luo, etc. Model driven simulation and validation of system architecture. Systems Engineering and Electronics. 2013.