# 19th ICCRTS

## Title of Paper:

## *A Method to Measure the Amount of Battlefield Situation Information*

## Paper ID: 086

### Topic(s)

Topic 2: Organizational Concepts and Approaches
Topic 3: Data, Information and Knowledge
Topic 4: Experimentation, Metrics, and Analysis


### Authors:

**Zhang Dongge**
College of Command Information Systems
PLA University of Science and Technology
Nanjing City, Jiangsu Province
China

**Meng Hui**
PLA Military Representative Office of Taiyuan Railway Bureau
Taiyuan City, Shan'xi Province
China

**Tao Jiuyang**
College of Command Information Systems
PLA University of Science and Technology
Nanjing City, Jiangsu Province
China

**Point of Contact:**

Zhang Dongge
College of Command Information Systems
PLA University of Science and Technology
No.1 Haifuxiang Road, Qinhuai District
Nanjing City, Jiangsu Province
Postcode: 210007
China
E-mail: DongGeZhang@hotmail.com

# A Method to Measure the Amount of Battlefield Situation Information*

ZHANG Dongge [1] ， MENG Hui [2] ， TAO Jiuyang [1]

College of Command Information Systems，PLA University of Science and Technology，Nanjing 210007，China.；2.Military Representative Office of Taiyuan Railway Bureau，Taiyuan 030013，China）

**Abstract:** One of the essential issues in C4ISR is to properly measure the amount of Battlefield Situation Information (BSI), which is a key concept in the research of Situation Awareness and decision-making. BSI contains two mutually independent contributions from current status information, which describes objective state of a certain battlefield situation element at the moment, and from trends information, which expresses changes of element's state that may occur in the future. But measure the amount of BSI has not been thoroughly studied before. Here we report a novel method that precisely measures the amount of BSI on the basis of Shannon's information theory. Our method gives the first accurate quantification on current status information as well as trends information contained in BSI. Necessary conditions for two C2 nodes to reach a consensus in the process of Situation Awareness are also provided in current work.

**Keywords:** battlefield cooperation; command and control; the amount of situation information; analysis definition; formal method.

## 1. Introduction

Proper measurement of the amount of Battlefield Situation Information (BSI) is foundation of researches like evaluating commanders' Situation Awareness (SA) workload and assessing information-processing ability of C4ISR. In order to assess SA, generally Common Operation Picture (COP) [1] is applied as one of the main forms to depict battlefield environment [2]. However, sufficient information is usually necessary for COP approach. With insufficient information it prevents a comprehensive understanding of the real status. On the other hand, excessive information can lead to inefficient decision making because of the additional time consumed in handling the information. Thus, it is an urgent request to provide an efficient method that precisely measures the amount of

* Supported by the National Natural Science Foundation of China (Grant No. 61174198), Supported by PLA Military Graduate Students Foundation (Grant No. 2011JY002-163).

BSI contained in a COP.

BSI contains two mutually independent contributions from current status information, which describes objective state of a certain battlefield situation element at the moment, and from trends information, which expresses changes of element's state that may occur in the future. To correctly and accurately understand the BSI, both current status information and trend information have to be described comprehensively. In previous reports, most studies have only focused on current status information while neglecting trends information, the latter of which actually consumes the largest part of commanders' cognitive resources. A model that describes the current status information as well as the trends information has not been reported to the best of our knowledge.

In current work, we provide formal definitions of current status information and trends information, and then propose a method to accurately measure the amount of BSI on the basis of Shannon's information theory [3]. Necessary conditions for two C2 nodes to reach a consensus in the process of Situation Awareness are also provided. Our study generates a solid theoretical foundation for analytical calculation about SA capability and paves the road for future in-depth consideration.

## 2. Description of BSI

Effective SA on the battlefield is the basis of decision making. According to the views of Riley and other researchers, the Ergonomics defined SA as "receiving sufficient warning information continuously" in 2006[4-6], and definitions of SA all point to "knowing what is going on", written by Endsley in 1995[7]. And people may have some questions: how much information can be considered as sufficient and how much information must be provided in order to know what is going on? To answer these questions, the first problem is to measure the amount of BSI. The problem can be divided into three main parts: to measure the amount of information (1) that is collected from objective environment, (2) that operators can process, and (3) that describes the environmental trends.

Therefore, we need to study the process of SA and learn what kind of information is collected and what the content of operator's cognition is, and whether it is possible to measure the amount of different kinds of information. In this regard, we need to establish a BSI processing model in the first place.

### 2.1 BSI processing model oriented to decision making

Commanders' SA is based on repeated collection of information on the environment. Suppose we use "snapshots" to observe the battlefield situation, which means that after each time unit, a snapshot is taken to collect values of various parameters of the situation elements, and then the system or commanders need to comprehend these values. We consider this process as a discrete SA process. Parameters of the situation elements are named as "objective situation", and they can be regarded as "Source" in Shannon's information theory. Commanders or operators are "Destination". Certain amount of information can be obtained from source via snapshot. If destination can correctly comprehend all the information, we believe that battlefield situation is completely comprehended. Details of BSI processing are shown in Figure 1.

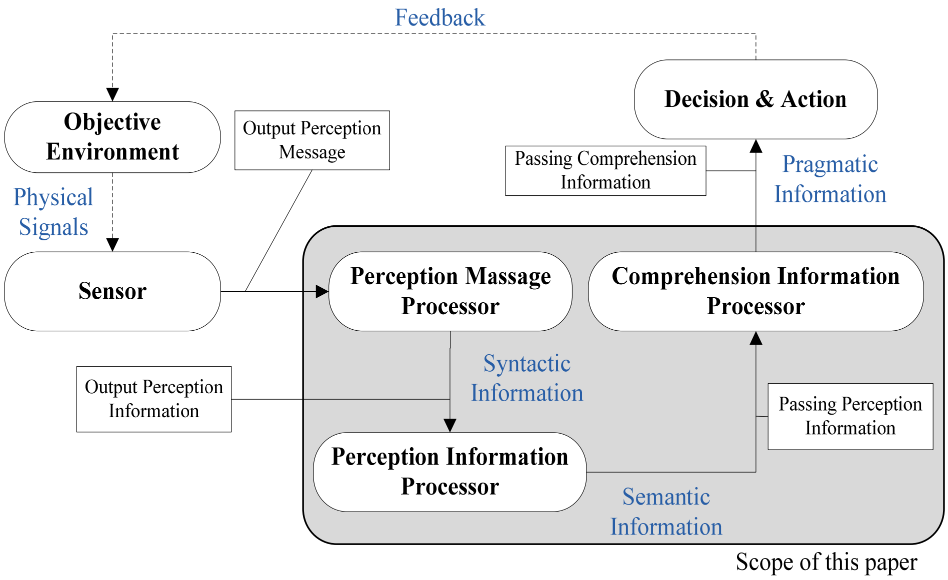


**Fig. 1 Internal relations of situation information processing system**

Although terms in Shannon's information theory are used in this paper, there are intrinsic differences between SA research and information theory. Our research focuses on the amount of information sent by source and information processing ability of destination, such as the amount of information that needs to be sent, when to send the information, the amount of information that destination needs to process, and how much information can be processed. In addition, the characteristics and rules of BSI processing need to be discussed as well.

## 2.2 Definition of BSI

Different operators have different purposes in SA, and operators may obtain different information from the same situation element. Therefore, it makes less sense for us to generally discuss the information contained in source. We define those parameters, which operators really care about, as BSI and ignore others, so that we can get some results of universal significance.

**Def. 1 BSI** Suppose A is a COP containing multiple situation information, and operator B is a SA subject interested in A. Total number of parameters in A that B cares about is $\alpha$ , and values of these parameters at time $t$ are indicated as $Q(w_1(t), w_2(t), \cdots, w_\alpha(t))$ (these parameters are scalars). We use $w_k(t)(1 \le k \le \alpha)$ to represent value of *k*-th situation elements, and sequence $w(t) =< w_1(t), w_2(t), \cdots, w_\alpha(t) >$ is a piece of BSI that B obtains at time *t*. This piece of BSI can be formally expressed as:

$$w(t) \in W = \{< w_1(t), w_2(t), \cdots, w_\alpha(t) > | Q(w_1(t), w_2(t), \cdots, w_\alpha(t))\}$$

Assume that there are tanks moving on the road (figure 2). Operator is interested in the position and velocity of *n*-th tank, so there are three parameters that this operator cares about, $\alpha = 3$. Figure 2 is a sketch showing the position of *n*-th tank in one-dimensional condition. If there is only one tank on the road and the operator only needs to know the position of this tank, $\alpha = 1$.

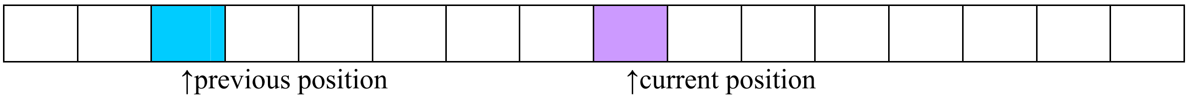

**Fig.2 Schematic diagram for situation information in one-dimensional Conditions**

In one-dimensional condition as Figure 2, there are 16 positions (numbered from 1 to 16) on the road. When it comes to two-dimensional condition like Figure 3, there are totally 64 positions and each position has its own number, too.

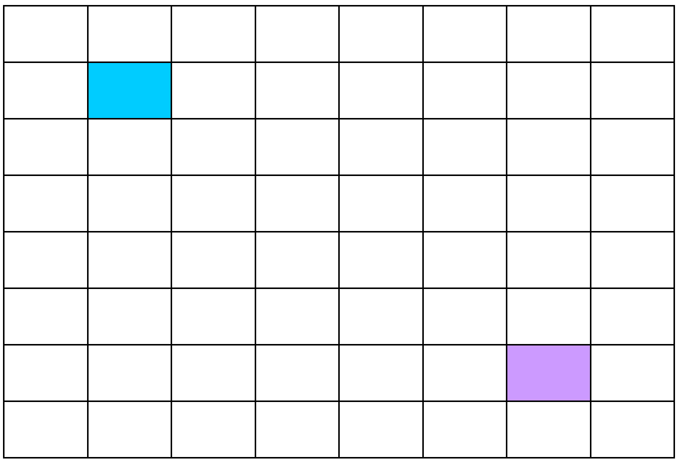
**Fig.3 Schematic diagram for situation information in two-dimensional Conditions**

## 3. BSI Measurement

Situation describes both current status of elements at the moment and the trends which express changes of elements' state that may occur in the future. Therefore, we should analyze situation from two aspects: current status and trends. For instance, position of a tank at the moment is current state, and possible positions at next moment are trends. Therefore, only knowing current position of the tank is not enough. Furthermore, current status information is perception information, and trend is comprehension information. Combine these two kinds of information with prior knowledge, then we can get projection information.

### 3.1 Measurement of current status information

In Figure 2, position of a tank at present is current status information. Suppose a tank is at position *a* at the moment, we can identify *a* by asking questions like "Is it between 1 to 8 or not". Since there are 16 possible positions, we can determine *a* in asking 4 times.

*S* is the amount of current status information. According to calculation method mentioned in Shannon's information theory, for position information of the tank in Figure 2, $S = \log_2 a = \log_2 16 = 4$ . Equation $S = \log_2 a$ is used to measure the amount of current status information. This means, in Figure 2, an operator can get right position of a tank if he has the ability to process no less than 4bit information in a time unit.

**Def. 2 The amount of current status information.** At time $t_0$, if there are *a* possible values of $w_k(t)(1 \le k \le \alpha)$ (one parameter of a situation element), the amount of current status information S about this situation element is:

$$S(t_0) = \log_2 a \qquad (1)$$

### 3.2 Measurement of trends information

Kierkegaard once said "Life can only be understood backwards, but it must be lived forwards" [8]. Therefore, we need to compare the past moment and present time in order to analyze trends information, otherwise trends of situation elements cannot be understood.

Suppose a tank in Figure 2 is at position 3, and it moves to position 9 after one time unit. In order to understand trends of this tank's movement, we need to analyze changes turned out in this time unit. *b* is the number of possible changes. In this scenario, changes are ranged from 0 to 15, so $b = 16$ (In figure 3, *b* is Euclidean distance between the two positions, $b = \max\sqrt{(x - x_0)^2 + (y - y_0)^2}$ ). It will take no more than 4 times asking to determine *b* if we use questions like "Is it between 0 to 7".

**Def. 3 The amount of trends information.** In time period $\Delta t$, the number of possible changes of $w_k(t)(1 \le k \le \alpha)$ is *b*, and then the amount of trends information in this period is $T$ (the dimension is *bit*):

$$T(\Delta t) = \log_2 b \qquad (2)$$

**Discussion 1:** In definition 3, it's easy to understand that *b* is related to time period. In case of long observation time, range of possible changes is large, and vice versa. Therefore, for a uniform changed situation element, longer observation time makes larger *b*, and the amount of trends information is larger as well. In practice, observation time is tightly related to the response time requirements for a certain situation. This paper assumes that update cycle of BSI is fixed, and then the amount of trends information is equivalent in each update cycle.

**Discussion 2:** As BSI in this paper is scalar, information measurement method proposed in the paper is not suitable for vectors. Nevertheless, we can decompose a vector into two or more scalars and each scalar changes over time. So we can measure the amount of information in these scalar components at first and then combine them together, in order to determine the amount of information in the vector.

### 3.3 Measurement of BSI

Commanders should process both current status information and trends information to have right SA. In fact, people's awareness of something is not completed at once but step by step. For example, when we observe a pedestrian, we may firstly observe his position and then concentrate on his velocity. Although there are some relationships between these two processes which decide results of your observation, the processes to get current status information and trends information are separated from each other. So we make hypothesis as below:

**"Merger and Separation" Hypothesis of SA (M-S Hypothesis):** Assuming there are series elements in a situation, and awareness of these elements is divided into two parts: awareness of "current status" and that of "trends". After these independent awareness processes are completed, all the cognition results can be combined at once, on the basis of experience and relations between elements, by operator's brain.

According to M-S hypothesis, we assume that outcomes of current status awareness and trends awareness can be linear superimposed.

**Def. 4 The amount of BSI.** Suppose an operator is interested in *n* elements. The amount of "current status" information of element *i* is $S_i$, and the amount of "trends" information of the element is $T_i$. According to M-S hypothesis, the amount of BSI that this operator needs to process can be expressed as:

$$SA=\sum_{i=1}^{n} SA_i=\sum_{i=1}^{n} S_i+\sum_{i=1}^{n} T_i \qquad (3)$$

In the above-mentioned tank movement example, the amount of BSI $SA=S+T=2\log_2 a=8bit$. That means the operator cannot get right and complete SA if he isn't able to process $8bit$ information in a time unit.

If awareness processes of "current status" and "trend" are different (i.e. one is directly reading of data and the other requires complicated computing), we add different weight values to $S_i$ and $T_i$ in formula 3 to solve this problem.

**Def. 5 Average BSI processing speed** Suppose an operator can process $\Delta SA\, bits$ information in time period $\Delta t$, then average BSI processing speed is $v$.

$$v=\frac{\Delta SA}{\Delta t} \qquad (4)$$

$v$ can be used to assess the basic SA ability of operators. In some complicated cases, $\Delta SA$ can be expressed as superposition of increment about current status information and trends information.

## 4. Demo

Suppose there is a sports car moving on the road. Total number of possible positions is 64 because the average velocity of a sports car is higher than that of a tank. Then range of current status information $a=64$ and range of trends information $b=64$. Hence the amount of BSI is $SA=S+T=2\log_2 64=12bit$. That means operator needs to process at least $12bit$ information to correctly understand the situation of the sports car.

If there are 4 sports cars on the road, new information is added into the situation since operator needs to distinguish among cars. Code these 4 cars with 00, 01, 10 and 11, and then it takes no more than 2 times to tell which car it is.

Generally speaking, if there are $m$ cars on the road, the amount of information is $M$, $M=\log_2 m$. In scenarios above, $m=4$, so $M$ equals $2bit$.

In conclusion, the amount of BSI to describe situation of a car in this scenario is:

$$SA=S+T+M=\log_2 64+\log_2 64+\log_2 4=14bit$$

The result of $SA$ shows that operator has to process no less than $14bit$ information in a time unit, otherwise he cannot obtain effective awareness of the situation. In other words, he can’t precisely describe the situation of a certain car.

For a COP which includes 4 cars and the number of positions for each car is 64, the amount of BSI in it is:

$$SA = (S + T + M) \cdot M = (\log_2 64 + \log_2 64 + \log_2 4) \cdot \log_2 4 = 28bit$$

## 5. Necessary conditions for dual-agent collaboration

Relying on definition and calculation methods above, we can analyze requirement of information processing ability for multi-agent collaboration. Suppose there are two decision-making nodes in a C2 relationship network [9], here we call it C2 node, and these two C2 nodes need to collaborate with each other. Each C2 node may have different requirements for SA during collaboration. For example, in the above-mentioned cases, for one C2 node it needs 16 position units to correctly describe position of a situation element because its tasks require high accuracy. But the other C2 node only needs 8 position units. Under the circumstances, two C2 nodes have different demands for information processing speed, and there’s no need for these C2 nodes to process the same bits information in a time unit.

If the amount of BSI that node *i* has to process is $SA_i$, and average BSI processing speed of *i* is $v_i$, $SA_j$ and $v_j$ for C2 node *j*, the amount of information to be exchanged is $SA_{ij}$, then conditions for these C2 nodes to collaborate effectively are:

**Condition 1**: difference of information processing time between two C2 nodes is less than $\delta$,

$$\left| \frac{SA_i + SA_{ij}}{v_i} - \frac{SA_j + SA_{ij}}{v_j} \right| \le \delta \qquad (5)$$

$\delta$ is the maximum difference in information processing time of two C2 nodes that can be accepted during collaboration. This condition reflects degree of synchronization between two C2 nodes. If one C2 node processes BSI much faster than the other, they cannot have efficient collaboration.

Weighting methods can be used to modify formula 5 if processing speeds of current status information and trends information are different.

Besides Condition 1, it is required that the time for SA and mutual communication must be less than the circle of situation information updating so that mutual collaboration can be achieved..

**Condition 2:** time to exchange information is less than BSI updating circle $t_0$,

$$\left|\frac{SA_i + SA_{ij}}{v_i}\right| \le t_0 \quad \text{and} \quad \left|\frac{SA_j + SA_{ij}}{v_j}\right| \le t_0 \qquad (6)$$

This condition indicates that if operators haven't finished processing previous BSI but new BSI has already arrived, then the operators won't get right awareness of the situation.

And weighting methods can also be used here to modify the formula if processing speeds of current status information and trends information are different. .

## 6. Conclusion

Measurement of the amount of BSI is an essential issue needed to be solved in research about second command and control. It is lack of standardized indicators and description of trends in previous researches, and these defects prevent in-depth analysis of rapid SA. Using ideology in Shannon's information theory and relying on the experience that "more complex, more difficult to understand", we propose a method to measure the amount of BSI. This paper lays a solid foundation for calculating and analyzing operators' SA ability.

## Reference


[1] HU Hong-bo, GUO Hui-dong, "Architecture and Techniques of Common Operational Situation Picture". COMMAND CONTROL & SIMULATION. Vol. 28(5), pp28-32, 2006.

[2] HI HUI-jie, GU Hao, DU Yang-hua, "Research in Measurement if Sea Battlefield Situation Awareness". COMMAND CONTROL & SIMULATION, Vol.32 (3), pp28-34, 2010.

[3] C. E. Shannon, "A Mathematical Theory of Communication", Bell System Technical Journal, Vol. 27, pp 379-423, 623-656,1948

[4] J. M. Riley, M. R. Endsley, C. A. Bolstad, & H. M. Cuevas. "Collaborative planning and situation awareness in army command and control". Ergonomics, Vol. 49(12-13), pp 1139 – 1153, 2006.

[5] P. Salmon, N. Stanton, G. Walker, & D. Green, "Situation awareness measurement: A review of applicability for C4i environments". Journal of Applied Ergonomics, Vol. 37(2), pp. 225-238, 2006.

[6] N. A. Stanton, "Hierarchical task analysis: Developments, applications and extensions". Applied Ergonomics, Vol. 37(1), pp55-79, 2006.

[7] M.R. Endsley, "Towards a theory of situation awareness in dynamic systems", Human Factors, Vol.

37(2), pp32-64, 1995.

[8] Kierkegaard, Soren, “The Journals of Soren Kierkegaard”, A selection and translated by Alexander – Dru , Oxford: Oxford University Press (1938). pp465

[9] ZHOU Dao-an, ZHANG Dong-ge, CHANG Shu-chun, “Formal Description of Command and Control Relationships”, COMMAND CONTROL & SIMULATION, Vol. 30(4), pp13-17, 2008.