Study on CPS Credibility of Coal Preparation Plant Based on Improved D-S Evidential Theory

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***Abstract* — In order to fulfill the requirement of ensuring the security and stability of the cyber physical system, the CPS credibility calculation based on the improved D-S evidential theory is put forward. The credibility of the nodes is initialized by the historical interaction between nodes, and the direct credibility is weighted by applying the proportional relationship between the numbers of historical interaction. The overall credibility is obtained with Dempster rule and is modified with real-time environmental deviation. Moreover, considering the dynamic nature of the credibility, the time function is introduced into the credibility calculation and the credibility attenuation equation is obtained. The reasonability and effectiveness of the method is proved through experiments.**

Keywords - Cyber physical system, D-S evidential theory, Credibility, Environmental function, Credibility attenuation equation

I. INTRODUCTION

With the development of information technology and network technology, the intelligent network technology is getting more and more attention. Systems Cyber-physical (CPS), as a kind of heterogeneous large information system, plays an irreplaceable role in future cyber development and has a bright future for application.

CPS is involved in various types of calculation methods, such as P2P, grid computing, cloud computing. There are diverse network systems, too, such as distributed systems, hybrid systems, pervasive systems, wireless sensor networks. Or, it can be divided into discrete and continuous network [1,2]. In order to pass information among all entities with reliability and high efficiency, and provide secure service, the credibility among entities is the basic of analysis. In this paper, a research on CPS credibility model is conducted. The model is improved based on the traditional D-S evidential theory and factors influencing the CPS credibility of coal preparation plant. It puts forward the credibility calculation method of CPS based on improved D-S evidential theory. By providing more reliable indexes, the information interaction between each node in the system is more secure.

II. CPS CREDIBILITY AND ITS MODEL

A. CPS Credibility

The rapid development of information technology has brought a lot of initiative for the CPS development [3,4]. Dr. Ashford Lee Edward from University of California at Berkeley believes that CPS is a system that combines physical processes and computational processes (information processing), which uses both embedded systems and networks to monitor the physical processes, and along with feedbacks from physical process to the computational process [5]. Michael S. Branicky professor from Case Western Reserve University says CPS, combined with Computation, Communication, Control (3C), will change people's understanding of the physical world. Insup Lee from the Institute of Engineering and Applied Sciences, Department of Computer and Information Science in University of Pennsylvania also considers CPS as a deep integration of 3C technology. He Jifeng from Chinese Academy of Sciences considers CPS is based on environmental perception, achieve deep integration and real-time interaction through the calculation of the periodic feedback of mutual influence between physical processes and computational processes. It's a network physical device system deeply integrated with 3C technology [6,7]. The definition of CPS in Wikipedia is that it is a system of collaborating computational elements controlling physical entities, differs from other calculation methods in that the physical world is closely coupled with the calculation process.

Credibility is the quantitative expression of trust, also known as trust, trust value or trust level [8]. Credibility means the trust degree on a certain thing according to one's objective experience or recommended experience. There are a lot of factors affecting the credibility of the information, such as the working experience of the information transmitter and the surrounding environment, etc. Different experts and organizations have different definitions on reliability, and the credibility computing organization believes that if an entity's behavior always achieve the expected goal, then it is credible [9].

In CPS, credibility can be understood as the trust degree on the information provided by an entity to another in a system. With the further development of CPS research, the problem of information transmission will bring serious consequences if only considering the feasibility and completeness of the transmission method, yet without paying attention to the credibility of the nodes that provide information. In the complicated system or under severe

circumstance, the credibility of the nodes is more important for the validity and credibility of the transmission information [10]. In order to improve the credibility, self adaptability and high self adjustment ability of CPS, more and more researchers are devoted to the research of the credibility evaluation of the mutual connected nodes, which makes credibility evaluation as one of the hot topics at present.

B. CPS Credibility Model

This paper does not consider the existence of malicious nodes for now, it only conducts a preliminary study on the credibility calculation method in CPS. According to the trust management and trust measurement, the historical interaction between nodes, CPS internal environment, node's own characteristics and credibility releasing time are considered in designing the calculation method. Simply build a suitable CPS credibility model, as shown in Figure 1. The appropriate network equipment is chosen as the regional agent in different regions, and the credibility of each node in the area is calculated, and finally a regional credibility table is formed.

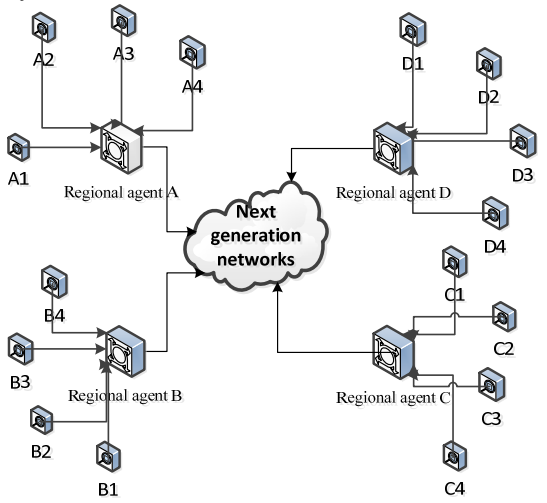

Figure 1. CPS model of coal preparation plant

In the above models, the system is divided into four regions, each region has a regional agent, the four types of nodes connecting to which are separately: sensor nodes, actuator nodes, computing processing equipment and monitoring equipment. Considering the advantages of Layered Architecture the CPS credibility model can be divided into three layers: the bottom layer is the physical world in which sensors and actuators exist, that is A1, A2, B1, B2, C1, C2, D1, D2 in the figure; the middle layer is a part of the information world in which regional agents located, that is A, B, C, D in the figure; the top layer is the next cyber that collects all information.

When calculating the credibility with the above model, object's credibility on the subject is divided into two parts, one is called the direct credibility; the other is called the overall credibility or indirect credibility or recommendation credibility [11]. In the concrete calculation, the subject and object can also be referred to as the trustor and the trustee, and the system can also be called the trusting node and the trusted node. The nodes in the CPS might be a sensor node, or an embedded system, or even a small network.

According to the trust management and trust measurement, this paper mainly considers the historical interaction experience between the nodes, the environment, the node's own characteristics, the credibility releasing time and so on during calculation.

III. IMPROVED D-S EVIDENTIAL THEORY

A. Credibility Calculation Process

The factors affecting the credibility of CPS include the experience of the historical interaction between the nodes, the physical environment, the node's own characteristics, credibility releasing time, etc. It is necessary to apply credibility function, weighted array, environmental function, Dempster synthesis algorithm, etc.. After a comprehensive consideration about the above factors, this paper puts forward the calculation method the CPS credibility based on the improved D-S evidential theory. Specific design process is shown as in Fig. 2.

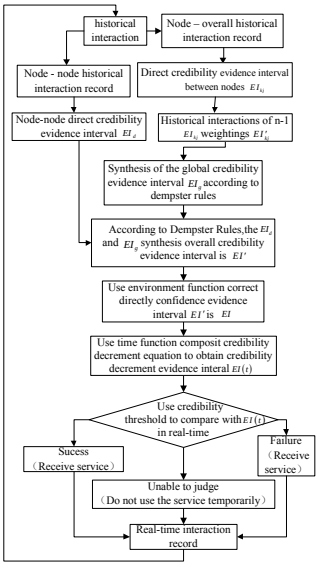

Figure 2. CPS credibility calculation process based on improved D-S

B. Improved D-S Evidential Theory Algorithm

1) Node - node historical interaction record

The total number of historical direct interaction between the trust node and the trusted node:

$$Sum_d = T_d + F_d + ToF_d \tag{1}$$

Where, T_d denotes the times of successful direct historical interaction between the trusting nodes and the trusted nodes; F_d denotes the times of failed direct historical interaction between the trusting nodes and the trusted nodes;

ToF_d denotes the uncertain direct historical interaction between the trusting nodes and the trusted nodes.

2) Node - overall historical interaction record

The total times of the direct historical interaction between trusted nodes and all nodes in CPS:

$$Sum_g = T_g + F_g + ToF_g \tag{2}$$

Where, Tg denotes the times of successful direct historical interaction between the trusted nodes and all nodes; Fg denotes the times of failed direct historical interaction between the trusting nodes and the trusted nodes; ToFg denotes the uncertain direct historical interaction between the trusting nodes and the trusted nodes.

3) Direct credibility assessment method

The credibility function can be obtained by reviewing the historical interaction record between nodes and nodes.

$$\begin{aligned} Bel(\{T_d, F_d\}) &= 1 - Bel(\{T_d\}) - Bel(\{F_d\}) \\ &= \frac{Sum_d - T_d - F_d}{Sum_d} \end{aligned} \tag{3}$$

$$Pl(\{T_d\}) = 1 - Bel(\{F\}) = \frac{Sum_d - F_d}{Sum_d} = \frac{T_d + ToF_d}{Sum_d} \tag{4}$$

Thus the direct credibility evidence interval can be written as:

$$EI_d = [Bel(\{T_d\}), Pl(\{T_d\})] = \left[\frac{T_d}{Sum_d}, \frac{Sum_d - F_d}{Sum_d}\right] \tag{5}$$

4) Overall credibility assessment method

$$Bel_g(\{T\}) = \frac{1}{1-k}\begin{pmatrix} Bel_1(\{T\}) \times Pl_2(\{T\}) \\ +Bel_2(\{T\}) \times Pl_1(\{T\}) \\ -Bel_1(\{T\}) \times Bel_2(\{T\}) \end{pmatrix} \tag{6}$$

$$Pl_g(\{T\}) = \frac{1}{1-k} Pl_1(\{T\}) \times Pl_2(\{T\}) \tag{7}$$

Where, $1-k = 1 - Bel_1(\{T\}) - Bel_2(\{T\}) + A_1 + A_2$

$A_1 = Bel_1(\{T\}) \times Pl_2(\{T\})$, $A_2 = Bel_2(\{T\}) \times Pl_1(\{T\})$

After obtaining the integrated evidence interval, integrate which with the third interval according to the mentioned rule, the rest can be done in the same way and the overall credibility can be written as:

$$EI_g = [Bel_g, Pl_g] \tag{8}$$

5) Credibility integration

Integrate direct credibility

$$EI_d = [Bel(\{T_d\}), Pl(\{T_d\})] = \left[\frac{T_d}{Sum_d}, \frac{Sum_d - F_d}{Sum_d}\right]$$

with overall credibility $EI_g=[Bel_g, Pl_g]$ according to the Dempster rule, the overall evidence interval of credibility can be written as *EI'*.

C. The Credibility Modification With Environmental Awareness

1) Environmental function

In order to improve the real-time performance and credibility of the evidence interval, this paper introduces an environmental function to modify the current interval, and obtain a new evidence interval. When the information interaction conducted among the nodes, the regional agent will inform the trusting node the real-time evidence interval of trusted node by advanced calculation.

The environment function is a collection, which includes the routes environment (temperature, humidity, air pressure, noise, vibration, etc.) and the node's own characteristics. It can be used to calculate the real-time environmental deviation by taking factors affecting nodes credibility as variables, and therefore modify the current overall evidence interval. The calculation of environmental deviation is as follows:

Environmental deviation

$$\eta = \frac{\left|E_c(a, b, \cdots) - E_{th}(a, b, \cdots)\right|}{E_{th}(a, b, \cdots)} \tag{9}$$

where, $E_c(a, b,\ldots)$is the current environmental function, $E_{th}(a, b,\ldots)$ is the threshold environmental function, which can be a range.

2) The credibility modification with environmental awareness

Here, evidence interval $EI=[Bel(\{T\}), Pl(\{T\})]$ represents the evidence interval of direct credibility or the overall credibility. After introducing the environmental function, the overall evidence interval of credibility can be modified as:

$$Bel(\{T\}) = Bel'(\{T\}) \cdot (1-\eta) \tag{10}$$

$$Pl(\{T\}) = 1 - Bel(\{F\}) = 1 - (1 - Pl'(\{T\})) \cdot (1-\eta) \tag{11}$$

The modified overall evidence interval of credibility can be:

$$\begin{aligned} EI &= [Bel(\{T\}), Pl(\{T\})] \\ &= [Bel'(\{T\}) \cdot (1-\eta), 1 - Pl'(\{T\})) \cdot (1-\eta)] \end{aligned} \tag{12}$$

The modification of the evidence interval is only suitable for the entities that are vulnerable to external environment or have been in severe environment for a long time, for those entities who have been in a stable environment for a long time, modification is not necessary to avoid the waste of resources.

3) The credibility life cycle

In this paper, we use the exponential function as the life cycle function.

4) The credibility attenuation equation

In summary, we can get the credibility of the time attenuation function, as shown below:

$$Bel(\{T\},t) = Bel(\{T\}) \times f(t) = Bel(\{T\}) - Bel(\{T\}) \times (1 - f(t)) \quad (13)$$

$$Pl(\{T\},t) = Pl(\{T\}) \times f(t) = Pl(\{T\}) - Pl(\{T\}) \times (1 - f(t)) \quad (14)$$

Thus, the evidence interval of credibility attenuation can be obtained. It can be seen from the equation that with the time increasing, the trust function (i.e., the minimum e evidence interval) gradually decreases, and the likelihood function (i.e., the maximum evidence interval) is gradually reduced, which shows that the weight of complete distrust is increasing. As time goes by, the credibility is advancing towards distrust till the trust function and attenuation function reduce to zero, when the overall evidence interval of credibility becomes zero, that is, complete distrust. In this case, the interaction may not be reported to the regional agent nor recorded.

5) The credibility threshold

In order to recognize the credibility more effectively and quickly, this paper sets up a confidence threshold in the regional agent. Apply $EI_{th} = [Bel_{th}(\{T\}), Pl_{th}(\{T\})]$ as credibility threshold and make following judgments:

a) If trusting node's evidence interval on trusted node is completely within $EI_{th} = [Bel_{th}(\{T\}), Pl_{th}(\{T\})]$, then trusting node will adopt the information provided by trusted node;

b) If $Bel(\{T\}) < Bel_{th}(\{T\}), Pl(\{T\}) < Pl_{th}(\{T\})$, judgment is impossible;

c) If $Bel(\{T\}) < Bel_{th}(\{T\}), Pl(\{T\}) > Pl_{th}(\{T\})$, judgment is impossible;

d) If $Bel(\{T\}) > Bel_{th}(\{T\}), Pl(\{T\}) > Pl_{th}(\{T\})$, judgment is impossible;

e) If $Bel(\{T\}) < Bel_{th}(\{T\}), Pl(\{T\}) < Bel_{th}(\{T\})$, failure,

that means the information provided by trusted node cannot be adopted;

f) If $Bel(\{T\}) > Pl_{th}(\{T\}), Pl(\{T\}) > Pl_{th}(\{T\})$, failure.

IV. EXPERIMENTS AND ANALYSIS

There are four types of nodes in each region in the CPS credibility model, which are sensor nodes, actuator nodes, computing processing equipment and monitoring equipment, and a regional agent is set up to collect the interaction between nodes irregularly. It is assumed that in each region, there are 50 sensor nodes, 10 actuator nodes, 5 processing equipments, 5 monitoring equipments, and totally 280 nodes in CPS system, the comparison between the traditional calculation method and the method based on the improved D-S evidential theory is conducted, from which it is concluded that the latter is more suitable to the CPS characteristics.

A. The effect of weighting

TABLE 1. EXPERIMENTAL SAMPLE

Interaction nodes	Number of interactions	Number of successes	Number of Unknowns	Number of failures
A3	200	150	30	20
A4	100	75	20	5
B3	5	0	3	2
B4	5	0	3	2
C4	20	5	5	10

Assuming that the trusted node is a sensor node in the region A, that is, A1, the trusting node is a computing processing equipment C3, the nodes interacted by trusted node A1 are A3, A4, B3, B4 ,C3, C4, where, C3 is trusting node, then in the calculation of overall credibility, C3 can be ignored, the calculation is only restricted to the remaining 5 nodes' direct credibility on A1. Specific sample parameters are shown as in table 1.

Firstly, the direct calculation is conducted by using the D-S evidential theory without the weighted link, and then the overall credibility evidence interval is obtained as shown in Table 2.

TABLE 2. DIRECT CALCULATION ON THE OVERALL CREDIBILITY EVIDENCE INTERVAL (1)

Interaction nodes	A3	A4	B3	B4	C4
Number of interactions	200	100	5	5	20
Number of successes	150	75	0	0	5
Number of Unknowns	30	20	3	3	5
Number of failures	20	5	2	2	10
Evidence interval	[0.75, 0.9]	[0.75, 0.95]	[0,0.6]	[0,0.6]	[0.25, 0.5]
Synthesized Evidence interval	[0.93,0.96]		[0,0.36]		[0.25, 0.33]
Overall credibility evidence interval	[0.5166,0.5179]				

From table 2, it can be concluded that with traditional D-S evidential theory, the overall credibility evidence interval is [0.5166, 0.5179], the support degree for the credibility is [0.5166, 0.5179], the value is greatly deviated from the credibility evidence interval provided by the nodes with many interactions.

From table 3, it can be seen that the weighted overall evidence interval of credibility is [0.5239, 0.9124], namely, the support degree for node A1 is [0.5239, 0.9124], which can tell that this evidence interval is getting more close to the interval provided by A3. Therefore, the weighted nodes can reflect the credibility of the experienced nodes.

B. The effect of the environmental function

From table 4, assuming that the direct credibility of trusting node C3 on trusted node A1 is [0.6, 0.9], after the integration of the mentioned overall credibility evidence interval [0.5239, 0.9124] , it is possible to calculate the overall credibility of D3 on A1 is [0.5239,0.9124]. The environmental deviation(1-η) is obtained after inspecting the internal and external characteristics of C3 and A1. Assuming the deviation is 0.5, which means that the current route environment is relatively poor, and the modified overall evidence interval of credibility is [0.3936,0.9587].

TABLE 3. WEIGHTED CALCULATIONS OVERALL CREDIBILITY EVIDENCE INTERVAL (1).

Interaction nodes	A3	A4	B3	B4	C4
Number of interactions	200	100	5	5	20
Number of successes	150	75	0	0	5
Number of unknowns	30	20	3	3	5
Number of failures	20	5	2	2	10
Evidence interval	[0.75, 0.9]	[0.75, 0.95]	[0,0.6]	[0,0.6]	[0.25, 0.5]
Weighting	200/360	100/360	5/360	5/360	20/360
Evidence interval after Weighting	[0.4167, 0.9444]	[0.208, 0.9861]	[0, 0.9944]	[0, 0.9944]	[0.0139, 0.9722]
Overall credibility evidence interval	[0.5239,0.9124]				

TABLE 4 THE CREDIBILITY OF THE CALCULATION OF THE ENVIRONMENTAL DEVIATION

Evidence interval	Overall credibility evidence interval	Environ mental deviation	Overall credibility evidence interval after correction
$EI_d = [0.6,0.9]$	[0.7872,0.9174]	0.5	[0.3936,0.9587]

TABLE 5 DIRECT CALCULATION ON THE OVERALL CREDIBILITY EVIDENCE INTERVAL (2).

Evidence interval	Number of interactions	Weighted Evidence interval	Synthesized Evidence interval
[0.8,0.9]	1	[0.0533,0.9933]	[0.2057,0.5645]
[0.2,0.3]	10	[0.1333,0.5333]	
[0.4,0.5]	2	[0.0533,0.9933]	
[0.4,0.5]	2	[0.0533,0.9933]	

C. Weighted simulation of overall credibility

The overall credibility is processed with weighted simulation and the simulation sample parameters are shown as Table 5.

The weighted overall evidence interval is calculated as Table 6 .

TABLE 6 WEIGHTED CALCULATIONS OVERALL CREDIBILITY EVIDENCE INTERVAL (2)

Evidence interval	Number of interactions	Weighted Evidence interval	Synthesized Evidence interval
[0.8,0.9]	10	[0.5333,0.9333]	[0.5693,0.9160]
[0.2,0.3]	1	[0.0133,0.9533]	
[0.4,0.5]	2	[0.0533,0.9933]	
[0.4,0.5]	2	[0.0533,0.9933]	

TABLE 7 THE CALCULATION ON CREDIBILITY EVIDENCE INTERVAL WITH CHANGING WEIGHTING VALUES

Evidence interval	Number of interactions	Weighted Evidence interval	Synthesized Evidence interval
[0.8,0.9]	1	[0.0533,0.9933]	[0.2057,0.5645]
[0.2,0.3]	10	[0.1333,0.5333]	
[0.4,0.5]	2	[0.0533,0.9933]	
[0.4,0.5]	2	[0.0533,0.9933]	

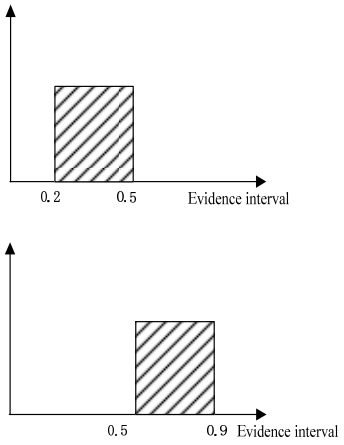

Figure 3. the overall credibility of the before-(up) and after-(down)weighting

Simulation is shown in Figure 3, from which it can be concluded that nodes with more interactions would have more contributions to the credibility evidence interval, which reflects the role of historical experience in the assessment of credibility.

D. Credibility environmental deviation simulation

TABLE 8 CALCULATION ON THE OVERALL CREDIBILITY EVIDENCE INTERVAL WITH CONSIDERING ENVIRONMENTAL DEVIATION

Evidence interval	Overall credibility evidence interval	Environm ental deviation	Overall credibility evidence interval after correction
$EI_d = [0.6,0.9]$	[0.8070,0.9235]	0.5	[0.4035, 0.9618]
$EI_g = [0.5693, 0.9160]$			

The environmental deviation simulation of credibility is carried out, assuming the direct credibility evidence interval between trusting node and trusted node is [0.6, 0.9], the theoretical results are as table 8.

Simulation results are shown in Fig. 4.

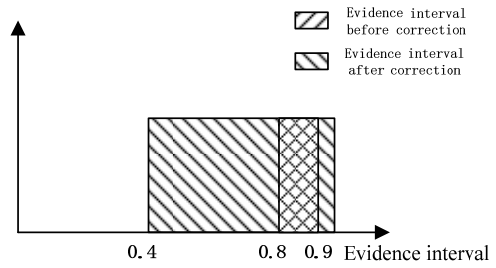

Figure 4. the comparison chart of the evidence interval before- and after-considering the environmental deviation

V. CONCLUSION

This paper has proposed a method to calculate the credibility of CPS based on the improved D-S evidential theory, which is well-adapted to the characteristics of CPS, high credibility, high self adaptability, great feedback control and heterogeneity. Based on D-S evidential theory, historical experience can be taken as an advantage in calculating credibility, which has shown the different attitudes of nodes with different experience towards the same thing. It has comprehensively considered the influence of internal and external environmental factors on the nodes. CPS credibility calculation method based on the improved D-S evidential theory can express the trust relationship among nodes reasonably and effectively.

CPS is an open heterogeneous system, which has many uncertainties, and with the development of 3C technology, converting the assessment methods of CPS credibility to a system that is adapted to the entire CPS will face many challenges. In the future, there would certainly encounter new problems during practical application, therefore the calculation method needs to be further improved and perfected.

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