RESEARCH ON RISK ANALYSIS METHOD OF TCC BASED ON MULTI-AGENT AND HAZOP

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Abstract: *Risk analysis of TCC can make the risk source management more effective in avoiding major accidents. In this paper, the multi-agent model is established for TCC and two kinds of agent in the multi-agent model is defined. In order to describe the information interaction among agents in multi-agent model, interval track circuit code being the main function of TCC is chosen as an example. Then using the HAZOP analyzes the multi-agent model of TCC to get the security risk log of different angle. According to the security risk log obtained, the risk analysis method that combines multi-agent model with HAZOP is proved to be effective and feasible.*

Keywords: *TCC, Risk analysis, Multi-agent, HAZOP.*

I. INTRODUCTION

The train operation control system is a real-time control system, which controls the high-speed train operation in conditions of high speed and high density. TCC (train control center) is the key system of the ground signal control of the train operation control system. According to the track section occupation, the line speed limit, the interlocking route, the communication between station and so on information, it produces the train traveling license command, and transmits to the vehicle equipment through the track circuit and the active balise. Cui[1] et al.

In order to manage TCC securely and effectively, it is a necessary and effective method to identify the risk in TCC as far as possible. Effective management and analysis of the identified risks can avoid major accidents caused by risk source.

Therefore, the research on risk analysis method of TCC is of great significance to ensure the safe and efficient operation of high-speed railway.

II. MULTI-AGENT AND HAZOP

Multi-agent theory

Agents are generally considered to be hardware system or computer systems based software, which has autonomy, reactivity, pro-activeness and social ability. Multi agent modeling theory and technology is an important branch of distributed artificial intelligence,

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which can construct complex systems into a system that is small, mutual communication, coordination and easy to manage.It is one of the important modeling techniques to describe complex systems.

Multi agent modeling has the ability of natural description of complex systems and the ability to capture the emergence of complex systems. Therefore it is able to carry out a very good description for TCC. TCC is composed of a number of modules. each module needs interaction and cooperation to complete the function of TCC. Every unit module of TCC uses agent to describe and the interaction between agent and agent, between agent and environment is Modeled. Thus it is able to combine the microscopic behavior of the individual with the whole attribute of TCC.

The agent model is the basis of multi agent modeling technology, which is divided into RA(reactive agent), DA(deliberative agent) and HA(hybrid agent) . RA is characterized by the rapid response to external information, but the intelligence and flexibility is low. Huang[2] et al. DA has a high intelligence, but the environmental response is relatively slow. Huang[2] et al. HA has the advantages of RA and DA, But the internal structure is complex. Huang[2] et al. Because TCC is a real-time information processing control system and needs to make a quick response to the external information. so this paper all use RA. The multi-agent model of TCC all adopts RA.

Agent-agent and agent-environment need the interaction of various information in order to complete the function of TCC. So their communication is defined and adopts KQML(knowledge query and manipulation language). KQML is divided into three layers: the content layer, the message layer and the communication layer. Liao[3] et al. The content layer mainly contains the information to be transmitted by KQML, whose presentation language is the language used by the message content. Liao[3] et al. The message layer contains information about the attitude of the sender to the information in the content layer and the description of the content layer properties. And it usually includes the language used by the content , provenance of the term in the content and so on. The communication layer contains the parameters of the underlying communication, usually including the message sender, message receiver and so on. The form of KQML used by the multi-agent model of TCC as follows:

```
(tell
:sender      agent/environment
:receiver    agent/environment
:language    word
:ontology    TCC
:content     (expression))
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The agent model structure used in this paper is showed in fig 1. In fig 1, perceiver is responsible for the perception of external information, receiving KQML communication information. Controller is responsible for the operation of the Rule, and combined with the internal state generates control commands. According to the control command, effector uses perceptual information to generate result information, sends result information to the agent external, and updates the internal state according to the result information and the transmission situation. Rule is a mapping of the received information to the corresponding function action. State is the internal working state of agent. Time is a discrete time series which is changed according to a certain interval.

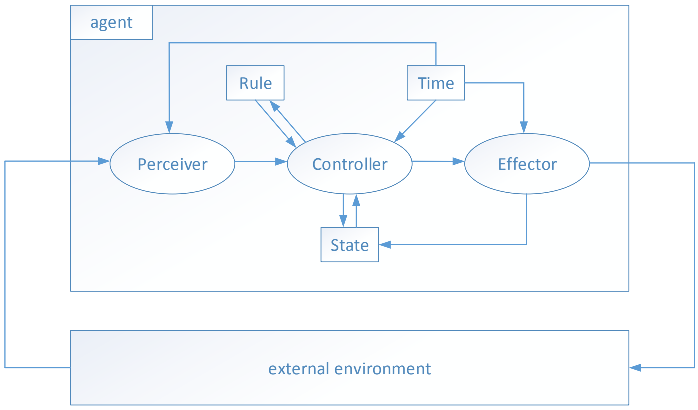

Fig 1. *The agent model structure*

HAZOP analysis method

HAZOP (Hazard and Operability Study) was first developed by the Imperial Chemical Industries Ltd in 1974. Because it is simple, easy to operate, and has characteristics of comprehensive analysis and strong adaptability. At present, it is widely used in the field of railway industry risk identification. HAZOP methods need to convene professionals of security aspects to analyze the object. These professionals will combine guide words with elements to determine the deviation through the form of a meeting. Then according to the deviation, the reasons for the deviation, the possible consequences and the measures taken are determined. Finally, the hazard log is formed. European railway transport management system in its security research report, adopts 9 guide words, which can be a very good description of deviation in the railway transport. Cui[4] et al. These 9 guide words are No, More, Less, In error, As well as, Part of, Reverse, Earlier, Later. The same guide word combines with different elements, which has different meaning. Some combination between guide word and element has no meaning. And these combination need to be discarded. Cui[4] et al.

III. MULTI-AGENT MODELING OF TCC

According to the structure of TCC in the 《TCC technical specification》, the reference model of TCC is obtained by simplifying its structure. The reference model of TCC is showed in fig 2.

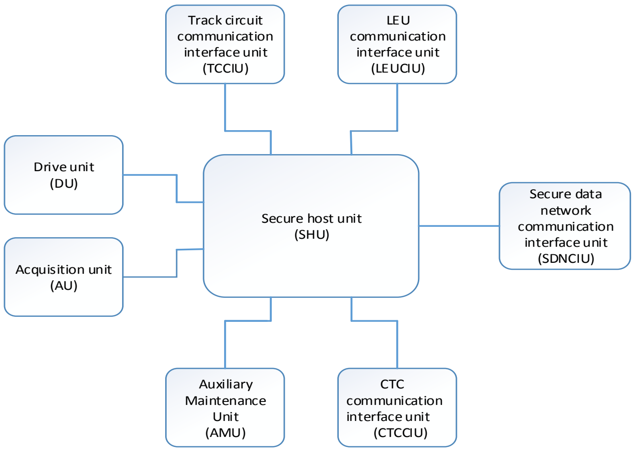

Fig 2. *The reference model of TCC*

In the reference model, SHU is mainly used for the logic operation and software and hardware management. DU is used to drive the suction and the fall of the corresponding relay. AU is used to collect the status of the relay. TCCIU is used for the information transmission between TCC and the track circuit. LEUCIU is used for the information transmission between TCC and LEU(Lineside Electronic Unit). AMU is used for the information transmission between TCC and centralized monitoring. CTCCIU is used for the information transmission between TCC and CTC(Centralized Traffic Control). SDNCIU is used for communication between the TCC and the adjacent TCC, interlock devices, and temporary speed limiting servers.

According to the reference model and the function of each unit, the multi-agent model of TCC can be obtained. The multi-agent model of TCC is showed in fig 3.

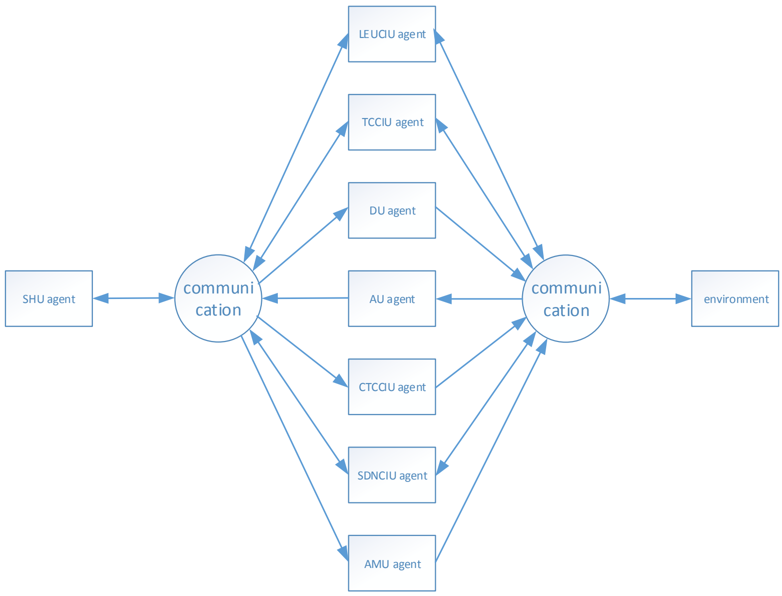

Fig 3. *The multi-agent model of TCC*

According to the structure and characteristics of TCC, the multi-agent model of TCC is abstracted into 8 agents, whose types and main functions are shown in table 1.

Table 1. *The types and main functions of agent*

Name	abbreviation	type	main function	classification
SHU agent	SHUA	RA	Data transceiver and logic operation	first kind
TCCIU agent	TCCIUA	RA	Data transceiver and time injection for information	Second kind
LEUCIU agent	LEUCIUA			
AU agent	AUA			
DU agent	DUA			
SDNCIU agent	SDNCIUA			
CTCCIU agent	CTCCIUA			
AMU agent	AMUA			

The agents of multi-agent of TCC can be divided into two classes according to their main functions. The first class includes SHUA, which has complex logic operations and data transceiver functions. The second class is the other 7 agents, whose main function is to transfer the data between the environment and SHUA, and inject time to the transmitted information.

Design and description of SHUA

The SHUA is defined as the 6 tuple model. SHUA::=<Name, Time, Input, State, Rule, Action, Output>. In addition, SHUA also includes 5 actions, which are SHUA_GetEnv, SHUA_Control, SHUA_Act, SHUA_Send, SHUA_Updata. SHUA's tuple and actions are defined as follows.

SHUA_Name={SHUA};

SHUA_Time={t0, t1, t2…};

ISHUA_nput={<balise status information and LEU device status information from LEUCIUA>, <Track segment status information and Track circuit device status information from TCCIUA>, <Computer interlocking information、Temporary speed limit command information and Safety information between adjacent TCC stations from SDNCIUA>, <Relay status information from AUA >};

SHUA_Rule={Rule-R1: if{[Route information, Temporary speed limit information, open state of inbound signal machine,Adjacent station line boundary information,Interval direction information, Directional relay status information, Interval track relay status information, The status information of Interval foreign invasion relay, Interval track segment status information]} Then (Interval track circuit code)

Rule-R2: if{[Route information, Temporary speed limit information, The status information of station foreign invasion relay, Station track relay status information, Station track segment status information]} Then (Station track circuit code)

Rule-R3: if{[Adjacent station line boundary information, The status of interval signal filament, The status of station entrance light filament]} Then (Interval signal lighting)

Rule-R4: if{[Route information, Temporary speed limit information]} Then (balise code)

…

};

SHUA_State={<stop>, <Start self checking>, <Set up communication>, <Communication failure>, <Initialization>, <Initialization exception>, <normal operation>, <Abnormal operation>, <off-line> } ;

SHUA_Action={<Interval track circuit code>, <Station track circuit code>, <Interval signal lighting>, <balise code>,…} ;

SHUA_Output={<balise message data to LEUCIUA>, <The track circuit frequency and low frequency encoding information to TCCIUA>, <the information of allowing departure in interval, Interval state information,Disaster protection information, Status acquisition information of no wiring station signal machine, Temporary speed limiting state, Track section state, Interval direction information, Initial state information, Safety information between stations to SDNCIUA>, <Interval block section status information, Interval signal machine status information and Equipment status information to CTCCIUA >, <Driving relay command information to DUA>, <agent Status information and alarm information of TCC to AMUA>}

SHUA_Rec==[env?: Environment

SHUA_Perceiver: Environment→TCC-KA_input

out!: SHUA_input|

∀ per: SHUA_Perceiver · ran(per)=dom(per)

result!=ran(per)]

The main content of SHUA_Rec is to perceive the information contained in SHUA_Input from the external environment.

SHUA_Control==[in?: SHUA_input

out!: SHUAZ_Command

S:SHUA_State

R:SHUA_Rule

T:SHUA_Time

SHUA_Controller:(in?×R×T×S)→(out!×S)|

∀ctr:Controller · ran(ran ctr)=ran(dom ctr)]

The main content of SHUA_Control is to manipulate SHUA_Rule to generate action control commands, according to the content of rule. At the same time manipulating SHUA_Rule also need to check SHUA_State and SHUA_Time.

SHUA__Act==[in?: SHUA_input

Com?: SHUA_Command

out!: SHUA_Output

act: SHUA_Action

SHUA_Effector: SHUA_Command→SHUA_Action

SHUA_Action:in? →out!|

∀act: SHUA_Action · out!=ran(act(in?)]

The main content of the SHUA_Act is to perform the function in SHUA_Action according to the action control command.

SHUA_Send==[Out?: SHUA_Output

Env!: Environment

SHUA_Effector: SHUA_Output→Environment|

∀ eff: SHUA_Effector · ran(eff)=dom(eff)

Out?=dom(eff)]

The main content of SHUA_Send is to send the results information that is contained in the SHUA_Output to the external agent.

SHUA_Updata==[S:SHUA_State

SHUA_Effector: SHUA_Send→S|

∀ eff: SHUA_Effector · S=ran(eff)]

The main content of SHUA_Update is to switch the state contained in SHUA_State, according to his feedback that includes the state of sending success and the sending content.

Execution flow of SHUA

1. Input=SHUA_Rec(Environment) SHUA_Time=t(i)

//SHUA perceives external information.

2. Command=SHUA_Control(input, rule, time, state)   SHUA_Time=t(i+1)

//According to the perception of information, rules, state, time, control command is generated.

3. Output=SHUA_Act(Command, Input)   SHUA_Time=t(i+2)

//Control commands activate the corresponding action and produce result information according to input information.

4. feedback=SHUA_Send(Output)   SHUA_Time=t(i+3)

//The result information is sent to the agent external

5. SHUA_Updata(feedback) SHUA_Time=t(i+4)

//Update state of agent

Design and description of TCCIUA

TCCIUA is defined as the 6 tuple model. TCCIUA::=<Name, Time, Input, State, Rule, Action, Output>. In addition, TCCIUA also includes 5 actions, which are TCCIUA_GetEnv, TCCIUA_Control, TCCIUA_Act, TCCIUA_Send, TCCIUA_Updata. TCCIUA's tuple and actions are defined as follows.

Name={TC-TA};

Time={t0，t1，t2⋯};

Input={Track segment status information and Track circuit device status information from environment, Track circuit carrier frequency and low frequency coding information from TCC-KA}

Rule={Rule-R1: if{[Track segment status information and Track circuit device status information from environment] then (data transfer)}

Rule-R2: if{[Track circuit carrier frequency and low frequency coding information] then (data transfer)}

Rule-R3: if{[Don't receive information over a certain time] then(Communication exception handling)}}

State={<Normal communication>,<Communication exception>}

Action={data transfer, exception handling}；

Output={Track segment status information and Track circuit device status information from environment to TCC-KA, Track circuit carrier frequency and low frequency coding information to environment}

The formal description of actions and execution flow of TCCIUA is similar to SHUA, here no longer to repeat.

Design and description of similar agent

Since the internal structure, state and function of the second kind of agent are similar and only the content of the transitional information is different, Internal description and execution flow of LEUCIUA, AUA, DUA, SDNCIUA, CTCCIUA and AMUA is similar to TCCIUA, here no longer to repeat.

Data exchange in multi-agent model of TCC

Since the function of TCC is numerous, the data exchange of the model is illustrated by the example of the interval track circuit code.

Input1=TCCIUA_Rec; Input2=AUA_Rec; Input3=SDNCIUA_Rec   Time=t(i)

//At the same time each agent parallel work. TCCIUA perceives track segment status information and track circuit device status information from environment as input1. AUA perceives directional relay status information, interval track relay status information, interval foreign matter intrusion relay status information from environment as input2. SDNCIUA perceives route information, temporary speed limit information, the signal state of inbound signal, the boundary information of the adjacent station, the interval direction information from environment as input3.

TCCIUA_Command1=TCCIUA_Control(input1，TCCIUA_rule，TCCIUA_time，TCCIUA_state)

AUA_Command1=AUA_Control(input2，AUA_rule，AUA_time，AUA_state)

SDNCIUA_Command1=SDNCIUA_Control(input3，SDNCIUA_rule，SDNCIUA_timeSDNCIUA_state)   T=t(i+1)

//According to the perception of information, rules, time and status of each agent, Action control commands are generated.

input1_t=TCCIUA_Act(TCCIUA_Command1，input1)

input2_t=AUA_Act(AUA_Command1，input2)

input3_t=SDNCIUA_Act(SDNCIUA_Command1，input3)   T=t(i+2)

//Control command activates the corresponding function, which is the information transfer function and injects the time stamp into the information.

feedback1=TCCIUA_Send(input1_t);   feedback2=AUA_Send(input2_t); feedback3=SDNCIUA_Send(input3_t); T=t(i+3)

//The information that is injected to the time stamp is sent to the agent external.

TCCIUA_Updata(feedback1);AUA_Updata(feedback2);   SDNCIUA_Updata(feedback3); T=t(i+4)

//Update state of agent according to the feedback of the transmission.

Input=SHUA_Rec;   T=t(i+5)

//SHUA perceives of input1_t, input2_t and input1_t.

SHUA_command=SHUA_Control(input，SHUA_rule，SHUA_time，SHUA_state);

T=t(i+6)

//According to the perception of information, rules, time and status of each agent, control command of interval track circuit code is generated.

output=SHUA__Act(SHUA_command, input);   T=t(i+7)

//Control command activates the function of interval track circuit code, which generates coding information.

feedback=SHUA_Send(output); T=t(i+8)

//Send interval coding information to SHUA external.

SHUA_Updata(feedback);   T=t(i+9)

//Update state of SHUA

output=TCCIUA_rec; output=CTCCIUA_rec; output=SDNCIUA_rec;   T=t(i+10)

TCCIUA_command2=TCCIUA_Control（output，TCCIUA_rule，TCCIUA_time，TCCIUA_state;

CTCCIUA_command2=CTCCIUA_Control（output，CTCCIUA_rule，CTCCIUA_time CTCCIUA_state;

SDNCIUA_command2=SDNCIUA_Control（input3，SDNCIUA_rule，SDNCIUA_time，SDNCIUA_tate） T=t(i+11)

output_t=TCCIUA_Act(TCCIUA_Command2, output)

output_t=CTCCIUA_Act(CTCCIUA_Command2, output)

output_t=SDNCIUA_Act(SDNCIUA_Command2, output)   T=t(i+12)

Feedback4=TCCIUA_Send(output_t)

Feedback5=CTCCIUA_Send(output_t)

Feedback6=SDNCIUA_Send(output_t)   T=t(i+13)

TCCIUA_Updata(feedback4); CTCCIUA_Updata(feedback5); SDNCIUA_Updata(feedback6);   T=t(i+14)

//Interval coding information through TC-TA, CTC-PA, SDN-QA transmits to the external environment, whose process is similar to t(i) to t(i+4).

IV. HAZOP ANALYSIS OF MULTI-AGENT MODE OF TCC

The elements are given priority in the process of combining the elements with the guide words. Using HAZOP to analyze the multi-agent model of TCC can be divided into two layers. The first layer is that the agent layer is as the element to analyze risk. The second layer is that the content in a action of the agent is as the element to analyze risk.

The first layer

SHUA is as an example to carry out HAZOP. The HAZOP of other agent is similar to it. The example of the first layer hazard log is in table 2.

Table 2. *The example of the first layer hazard log table*

node	element	Guide Words	deviation	Cause of occurrence	Possible consequences	recommended measure
SHUA	Host board	In error	Host board failure	Host board reliability is bad	TCC is out of service, endangering the safety of train operation	Using host board with high reliability; ；Regular maintenance ；Output alarm when failure

The second layer

There are 4 typical contents selected from SHUA_Rec, SHUA_Control, SHUA_Act and SHUA_Update being carried out HAZOP. In each agent, HAZOP of SHUA_Rec is similar to that of SHUA_Send. The analysis of other agent actions is similar to that of SHUA. The example of the second layer hazard log is in table 2.

Table 3. *The example of the second layer hazard log table*

node	element	Guide Words	deviation	Cause of occurrence	Possible consequences	recommended measure
SHUA_Rec	perceiving track segment status information and track circuit device status information from TCCIUA	No	Did not receive this information	TCCIU not working; SHU not working; Communication interrupt	Unable to track track circuit code;endangering the safety of train operation	Improving the reliability of TCCIU and SHU; Regular monitoring of communication lines; Real time monitoring equipment and transmission channel; When coding is abnormal, maintain the original coding sequence and give the alarm.
		In error	Receive this information in error	TCCIU processing error; SHU receiving error; communication transmission error	Track circuit coding update in error, threat to the safety of train operation	Improving the reliability of TCCIU and SHU; Regular monitoring of communication lines; Real time monitoring equipment and transmission channel; When an error is found, the coding is not updated.
		Part of	Receiving part of this information	TCCIU’s processing is not complete; SHUA’s receiving is not complete;the content of communication transmission is not complete	Unable to track track circuit code;endangering the safety of train operation	Improving the reliability of TCCIU and SHU; Regular monitoring of communication lines; Real time monitoring equipment and transmission channel; When an error is found, the coding is not updated. The missing information regard as a dangerous state.
		Later	The delay of receiving this information	processing delay of TCCIU; receiving delay of SHU; Communication transmission delay	Unable to track track circuit code;endangering the safety of train operation	Improving the reliability of TCCIU and SHU; Regular monitoring of communication lines; Real time monitoring equipment and transmission channel; add a time stamp to the message；throwing away expired information and giving alarm
SHUA_Action	Interval track circuit code	No	Don’t perform Interval track circuit code	SHU not working;program having bug	Interval track circuit coding is not updated; endangering the safety of train operation	Improving the reliability of SHUA; standard program design;Improving program test；When the track circuit does not receive the code, the default code is JC
		In error	Interval track circuit code is false	program having bug	Interval code sequence is false, endangering the safety of train operation	standard program design;Improving program test
		Part of	Interval track circuit code is not complete	program having bug	Part of interval track circuit code is missing	standard program design;Improving program test; The missing code defaults to JC
SHUA_Control	The condition of Interval track circuit code in SHUA_Rule	No	Don’t perform this condition	SHU not working;program having bug	Interval track circuit code is missing or error, endangering the safety of train operation	Improving the reliability of SHUA; standard program design;Improving program test；When the code condition is not performed, the code function can not be performed and the alarm is sent out.
		In error	This condition is performed in error	program having bug	Interval track circuit code is error, endangering the safety of train operation	standard program design;Improving program test；
SHUA_Update	Update to normal operation state	No	Don’t update to normal operation state	program having bug; having disturb	Unable to complete the function of the normal operation state, endangering the safety of train operation	standard program design;Improving program test; excluding disturb; forced system restart
		Earlier	Update to normal operation state in advance	program having bug; initialization is not complete	endangering the safety of train operation	standard program design;Improving program test; forced system restart
		Later	Delya of updating to normal operation state in advance	Abnormal operation environment	endangering the safety of train operation	keep a good operation environment

V. CONCLUSION

TCC is the key system of the ground equipment in the train operation control system, which plays a key role in ensuring the safety and efficiency of train operation. In this paper, multi-agent model theory and technology are introduced into TCC, exploring the method that is using multi-agent to model and describe TCC. According to the characteristics of the structure and function of TCC, the multi-agent model of TCC is established.

In this paper, the definition of each agent is in terms of function, state, information input, information output, functional constraints and system clock. Through the collaboration between the various agents, the description of TCC is implemented.

By taking the function of the interval track circuit code as an example, the whole data exchange and work flow of the model are discussed in detail.Because the multi-agent model of TCC can describe TCC from several angles. In this paper, the combination of HAZOP method and multi-agent model is used to carry out risk analysis from several angles, getting the security risk log of TCC.

In this paper, by using the HAZOP method, the risk analysis of the multi-agent model of TCC is carried out. Therefore, a risk analysis method that is the combination of HAZOP and multi-agent model is proposed. This method is highly adaptable and can carry out the risk analysis of the system from several angles. At the same time, by using the multi-agent model to describe TCC, laying the foundation for further simulation.

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