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Reliability Analysis of Swarm Self-security Intelligence System Based on Fault Tree and Monte Carlo Simulation

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***Abstract*—Group autonomous security intelligent system is an improvement of the traditional security system. By establishing group autonomous security intelligent system, traditional security system fault tree model, using the Monte Carlo method to simulate the fault tree model, finally through the fault tree simulation calculation, matlab group autonomous security intelligent system and traditional security system reliability curve, inefficiency curve, the average fault-free working time (MTBF) and the importance of the components. The results show that the group autonomous security intelligent system lasts longer and the average fault-free working time is longer than the traditional security systems.**

Keywords-self-security intelligence; swarm self-security intelligence; Fault tree; Monte Carlot

I. INTRODUCTION

It is crucial to ensure that radioactive substances are not lost or stolen during transportation.The traditional security system is composed of infrared, radar, camera, thermal imaging and other security measures, so it is difficult to deal with new technology threats (drones, etc.) [1]; group autonomous security intelligent system adds individual intelligence to add individual sensors, network module, individual communication together with the security [2], form a group network to deal with more complex external environment.By establishing the fault tree model of both, the Monte Carlo method is used to analyze and compare the fault tree for reliability, and to provide improvement measures for the weak links of the system.

II. FAULT TREE ANALYSIS OF THE GROUP AUTONOMOUS SECURITY INTELLIGENT SYSTEM

Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Fault tree analysis is a model of system fault analysis. Determine the fault tree structure of the system by dividing the events in the system into bottom events, intermediate events, and top events.Solve the fault tree minimum cut set and the structure function to analyze the system reliability. It is of practical significance to analyze the importance of each bottom event, find the weak links of the system, and guide the maintenance and improvement of the system. [3].

Security system failure serves as the top event of the fault tree. Traditional security system takes infrared, radar, camera, thermal imagers as an example to form the bottom event. The group autonomous safety intelligent system uses individual intelligent radioactive waste bucket X1, X2, X3, X4, infrared, radar, camera and thermal imager. The traditional security system fault tree is shown in Figure 1, and Figure 2 shows the fault tree of the group autonomous security intelligent system. From Figure 1 and Figure 2, the logic gate of traditional security system failure tree is gate, if any bottom event fails; the logic gate of group autonomous security intelligent system failure tree includes the gate and the gate, where bottom events X1, X2, X3, X4 form a network collaborative alarm. When an individual encounters the threat, other individuals in the network make timely security response, if and only when all individuals in the failure of the network fail.

Table 1 shows the base event number, name, distribution type of failure density function and distribution characteristic parameters of the fault tree.The distribution function and characteristic parameters of each bottom event need to be determined first.Document [4] does not mention the parameter value of distribution function; Document [5] obtained the characteristic value of failure distribution function after calculation and verification based on 51 fault data of Jilin University AK33100D power blade within 4 years.Literature [6] load loss efficiency in the simulation is assumed to be 2.2831x10-6, Actual failure or once every 50 years, so it is difficult to get an accurate failure rate for all components in the real system. Literature [7] consulted the disk shear design manual and fault tree maintenance information to determine the failure rate of each bottom event of the fault tree.Literature [8] introduces several parameter estimation methods for failure probability distributions.Each bottom event in this article has no memory, and its failure time follows the index distribution. According to Article 60 of the Implementation Regulations of the Enterprise Income Tax Law of the People's Republic of China, the average service life of electronic equipment is 3 years [9], and the characteristic parameter of the index distribution is $3.8 \mathrm{x} 10^{-5}$。

TABLE I. TYPES AND COEFFICIENT PARAMETERS OF THE BOTTOM EVENT FAILURE DENSITY FUNCTIONS OF THE FAILURE TREE

Types of the bottom event			
Event serial number	***Event name***	***Event failure density function Fi (t)***	***Parameters for the Fi (t)***
X1	Waste bucket 1	exponential distribution	$3.8 \mathrm{x} 10^{-5}$

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Types of the bottom event			
Event serial number	*Event name*	*Event failure density function Fi (t)*	*Parameters for the Fi (t)*
X2	Waste bucket 2	exponential distribution	$3.8x10^{-5}$
X3	Waste bucket 3	exponential distribution	$3.8x10^{-5}$
X4	Waste bucket 4	exponential distribution	$3.8x10^{-5}$
X5	camera	exponential distribution	$3.8x10^{-5}$
X6	infrared ray	exponential distribution	$3.8x10^{-5}$
X7	radar	exponential distribution	$3.8x10^{-5}$
X8	Thermal imager	exponential distribution	$3.8x10^{-5}$

III. MONTE CARLO SIMULATION AND ANALYSIS METHODS

The Monte Carlo method is a mathematical stochastic simulation method, with probability theory and mathematical statistics as theoretical support for [10].By determining the probability model of the events, the probability model is randomly sampled, taking the distribution of each basic event in the sample as its actual probability [11-14].

A. Establishment of the reliability simulation model

If the system is represented by T. There are n basic events, the system is represented by:as in

T={S1，S2，⋯，Sn}.

Si(i=1,2, ⋯ , n) indicates that there are n basic components in the system T, and each basic component has a corresponding failure distribution function that is represented by Fi (t) (i=1,2, ⋯ , n). The fault tree can represent the logical relationship between the bottom events. The simulated logical relationship can be obtained through the system fault tree. If the failure tree top event fails, the top event failure is caused by the bottom event S i failure. By adding the time parameter t, a structure function that indicates whether the fault tree fails at time t is obtained. The vector composed of the state variable Xi (t) in the function, that is Φ [X (t)] X (t)

$$\bar{X}(t) = [x1(t), x2(t), \ldots, xi(t), \ldots, xn(t)]$$

- X i (t) in the equation:

$$xi(t) = \begin{cases} 1 & \textit{The ith bottom event occurs at time t} \\ 0 & \textit{The ith bottom event did not occur at time t} \end{cases}$$

- The state of the top event at time t can be expressed as: Φ [X (t)]

$$\Phi[\bar{X}(t)] = \begin{cases} 1 & \textit{The top event occurs at time t} \\ 0 & \textit{The top event did not occur at time t} \end{cases}$$

B. Reliability simulation process

a) Sample the failure time of each basic event to obtain the sample of the failure time of each basic event. The i th basic event failure time sampling value is:

$$\text{ti} = F_i^{-1}(\partial)$$

$F_i^{-1}(\partial)$ The inverse function representing the failure density distribution function for the i-th event in Eq.During the j th simulation, the i th basic event failure time sampling value is tijThere are:

$$\text{tij} = F_i^{-1}(\partial_{ij})$$

$\partial_{ij} F_i^{-1}$ It represents the random number generated by sampling the i-th basic event in the j-th simulation, and substituting the random number into the failure distribution function infunction gives the random number conforming to the distribution function. From the above formula, the failure state of the i basic event at time t can be represented as:

$$x_{ij} = \begin{cases} 1 & t \geq t_{ij} \\ 0 & t < t_{ij} \end{cases}$$

The j th sampling is:$\bar{X}_j(t)\bar{X}_j(t) = [x_{1j}(t), x_{2j}(t), \ldots, x_{ij}(t)]$

$\partial(\text{t}) = \partial[\bar{X}(t)]$Let the system simulate N times, then j =1,2, ⋯, N. Enter the formula to, calculate the time tij of the top event fails in the j-th sampling, As follows:

$$\partial_j = \begin{cases} 1 & t_{ij} \geq t_{kj} \\ 0 & t_{ij} < t_{kj} \end{cases}$$

b) Perverse through the failure tree to find out the top event failure time t ij. In the j th simulation run the sampling produces n basic event failure times t 1j, t2j,...,tij,⋯,tnj 。Sort these n basic events from small to large (in TFi), as also the corresponding base events.Place the base event corresponding to the minimum failure time in the sort in the failure state, and none of the remaining base events fail at this time. Then check these basic events in turn, and judge whether the system top event fails through the failure tree structure function, until the system fails.

c) Δt=T_max/m(3) The maximum cumulative failure time is recorded as Tmax, and the T max is divided into m intervals, then the size of each time interval is, and the failure distribution statistics are realized by counting the number of failures within each interval.The number of system failures within an interval (tr-1, tr) is indicated.Δ mrWhen t tr, the number of system failures is:

$$\text{m(tr)} = \sum_{1}^{r} \Delta mr = \sum_{j=1}^{N} \Phi_j(t) \qquad t \leq tr$$

C. Reliability, simulation results statistics

If the system failure time μ is a random variable, the statistical formula for each estimate of the system is as follows:

- System accumulated failure probability Fs (t):

$$Fs(t) = P(\mu \le tr) \approx \frac{1}{N}\sum_{j=1}^{N} \Phi_j(t) = \frac{m(tr)}{N}$$

- System Reliability Rs (tr):

$$R_s(t_r) = 1 - F_s(t_r)$$

- Average fault-free working time MTBF:

$$MTBF = E(\mu) \approx \sum_{tr=0}^{\infty}\left[tr.\frac{1}{N}\sum_{j=1}^{N}\Phi_j(t)\right] \qquad (tr-1<t<tr)$$

- Basic component mode importance WN (S i)

$$WN(Si) = \frac{Nsfsi}{Tnsf}$$

Nsfsi=Number of system failures caused by Si failure of basic components;Tnsf=Total number of system failures

- Probability importance W (Si)

$$W(Si) = \frac{Nsfsi}{Tnfsi}$$

Nsfsi= Number of system failures caused by Si failure of basic components;Tnfsi=Total number of basic component si failures

IV. SIMULATION CALCULATION AND EXAMPLE ANALYSIS

Through the previous analysis of the fault tree of the group autonomous security intelligent system, the minimum cut set of the fault tree should be required, that is, the minimum cut set [15] necessary to cause the top event.{X1, X2, X3, X4}, {X5}, {X6}, {X7}, and {X8}. The system reliability index, average fault-free working time, basic component mode importance and probability importance are obtained by MATLAB simulation.

Let the total number of simulations be NS=10000 times. Literature [16] shows that the result becomes stable when the simulation times reaches 10000 times, and the error between the simulation results and the statistical calculation results is 1.8%, and the simulation results are reliable.The cumulative failure time of the group autonomous safety intelligent system is $Tmax=17.2X10^4$h, The cumulative failure time of traditional security system is $Tmax=5.0x10^4$h.By running the simulation program, and the average fault-free time of the group autonomous security intelligent system is calculated as $MTBF=5.872x10^4$h, average fault-free working time of traditional security system $0.912x10^4$h.Both system reliability curve and efficiency curve (shown in Figure 3 / 4).

As can be seen by the reliability function, over time, the system reliability decreases, the failure phenomenon is more and more obvious, due to the security work reliability requirements are generally 0.8~1, so to make the system reliability is not less than 0.8, can be seen by the traditional security general work about 1200h for system maintenance, and group intelligent security general work is about 7600h for technical maintenance. Figure 4 shows the simulation curve of the system failure function, which shows that the traditional security system failure system rises rapidly and finally fails completely; the group intelligent security system failure trend is slower and decreasing than the former.

Table 2,3 records the mode importance and probability importance of the basic components of the group autonomous security intelligent security system and the traditional security system, respectively.For a basic component with a probability importance of 1, it means that as long as the component fails, the system will fail. To improve the system reliability, the components represented by basic events of high probabilistic importance. Similarly, the mode importance indicates the percentage of the number of system failures caused by the basic component failure in the total system failure. Its value indicates that its failure has a greater probability to make the total system failure, which is determined as the weak link of the system. Therefore, it can be determined from Table 2 that the waste buckets 1,2,3 and 4, the components of the wireless network in the group autonomous security intelligent system, are the weak links of the system, and the improvement and maintenance should be emphasized.Table 3 shows that the probability importance of each component of the traditional security system is 1, indicating that any failure system will fail, and the system is very unstable.

TABLE II. MODE IMPORTANCE AND PROBABILITY IMPORTANCE OF BASIC COMPONENTS OF GROUP AUTONOMOUS SECURITY AND INTELLIGENT SECURITY SYSTEM

Group autonomous security and intelligent security system		
Basic parts	***Basic part mode importance***	***Probability importance***
X1	0.2565	0.2565
X2	0.2415	0.2415
X3	0.2455	0.2455
X4	0.2385	0.2385
X5	0.005	0.006
X6	0.004	0.0048
X7	0.0075	0.009
X8	0.003	0.0036

TABLE III. THE IMPORTANCE OF THE BASIC COMPONENTS AND THE MODE IMPORTANCE OF THE TRADITIONAL SECURITY SYSTEM

Traditional security system		
Basic parts	***Basic part mode importance***	***Probability importance***
X5	0.2535	1.0
X6	0.2395	1.0
X7	0.25	1.0
X8	0.2595	1.0

V. CONCLUSION

Based on the fault tree analysis, establish group autonomous security intelligent system fault tree model using Monte Carlo simulation analysis of model reliability analysis, simulation results and theoretical calculation results error is small, the method can accurately and objectively analyze the reliability of the system, solve the corresponding reliability parameters, provide strong support for the system reliability design.This method is also suitable for the reliability analysis of other complex systems.

It can be seen from the simulation results that the group autonomous security intelligent system and the traditional security system reliability curve and the inefficiency curve, and the average failure-free working time is $5.872\text{x}10^4$ respectivelyAnd the $0.912\text{x}10^4$, The average group autonomous security intelligent system has a longer fault-free working time and a higher reliability.

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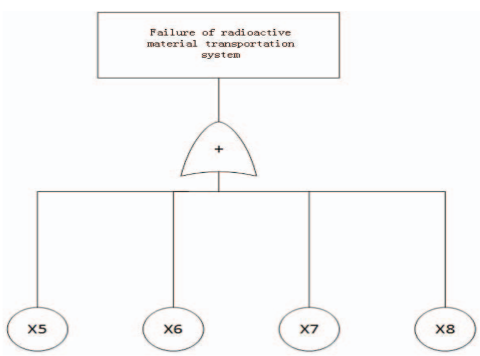

Figure 1. Traditional security system fault tree

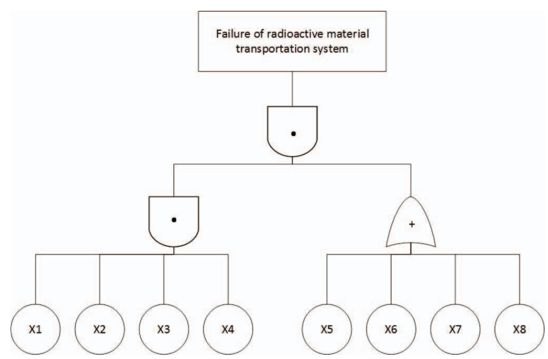

Figure 2. Fault tree of autonomous security intelligent system

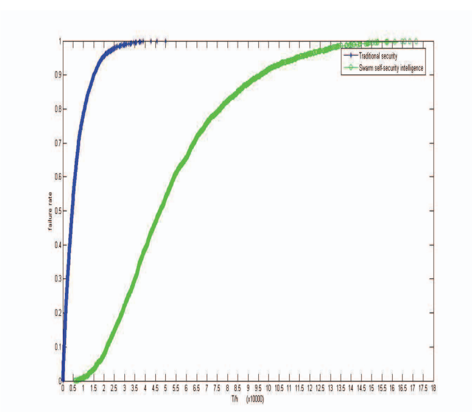

Figure 3. System Reliability

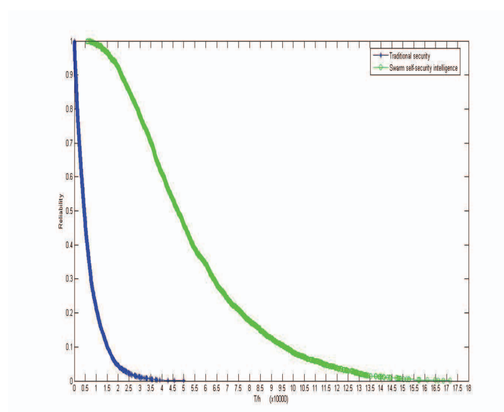

Figure 4 System efficiency