**A Reliability Calculation Method of Safety Device in Cars**

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**Abstract.** Aiming at the safety accident of children mislocked in the car incurred the death, a reliability calculation method of vehicle safety device is proposed. In order to avoid the accident as far as possible, a device is used for the monitoring and alerting of living beings in the vehicle. So the device reliability becomes particularly important. In the study, the safety logic relationship of the device unit is clarified through the detailed analysis of the composition function and work flow of the device. Furthermore, this paper introduces the method of building the device reliability models, gives the equivalent models of solving the device reliability, and defines a series of solving functions of reliabilities. This paper also studies the calculation method of the reliability of the network equivalent model, that is, the calculation method of the network model decomposition method. Finally, an example of reliability calculation is given to show the effectiveness of the proposed method. The results show that the proposed method can obtain the reliability value of the device.

**1. Introduction**

At present, product safety has attracted wide attention from various industries, from aircraft, high-speed rail to bread and milk bottles. Therefore, under the existing cognitive conditions, how to guarantee product safety is a hot subject for experts and scholars. In this paper, the safety device for detecting and alarming the existence of life in the car is taken as the object to study the calculation method of its reliability. Now, the household car has entered thousands of families, which brings great convenience to people's work and life. At the same time, it maybe also brings some harm to people, such as the phenomenon of children (or pets) mistakenly locking the car to death. In the hot sun, the temperature in the car can usually rise to more than 60 °C, which leads to the death of children or pets locked in the car by mistake. Many manufacturers have designed monitoring and early warning devices for such problems, but they still fail to fundamentally solve the problem. Comprehensive analysis shows the effective theoretical guidance is lack in product design and leads to functional failure. Therefore, a reliability calculation method of safety device in cares is proposed to solve the essential problem of product functional failure from the view of reliability.

In recent years, there have been some researches on car safety [1], such as brake failure, anti-collision and other aspects of safety research. However, there are few studies on the safety of the children death by accidentally locked in the car. The only research focuses on two kinds: 1. Product engineering design; 2. Product safety methods. The safety device products belonged to the former type have the alarm design for children staying in the car [2], control design for children staying in
the car [3], alarm device design based on the single clip [4], etc. The latter research on safety methods includes an alarm system design for preventing mistaking lock children in the car based on Arduino [5], a protection system design for children in the car based on GSM communication [6], etc. However, the all studies haven’t fundamentally solved the problem of children's accidental locking in the car and improved the devices safety from the theoretical perspective. Therefore, a reliability calculation method of the safety device in the vehicle is proposed in this paper, which can improve the effectiveness and safety of the safety device in the theory. There are many researches on reliability, and the reliability application range is also wide. For example, there are the research of network communication reliability [7] [8], device reliability [9], space reliability [10], intelligent algorithm reliability [11] [12] [13]. Service reliability research occupies a certain proportion, such as cloud resource service reliability research [14], and Web service transaction reliability research [15]. Grid reliability is a very good research topic, such as the research on power supply operation reliability [16], relay protection device reliability [17], energy network reliability [18] [19], etc. In many reliability studies, it can be shown that researches on the reliability of safety devices for children locked accidentally in car by is a lack.

2. Logic analysis of advice safety

2.1. Advice function analysis

In order to prevent children from accidentally locking the car, a safety device to prevent children from being locked in the car is designed. This safety device is composed of three sensors, central processing, power supply equipment and alarm equipment. The composition and connection diagram of the equipment are shown in Figure 1.

![Figure 1. Safety equipment diagram for locked children in the car.](image)

(1) The sensors have three, and they are temperature sensor, thermal sensor and pressure sensor, which are used to collect the data of temperature in the system, the existence of life (children), and the pressure on the vehicle seat.

(2) Central processing. It is used to receive and store the data collected by the sensor, analyze and process the collected data according to certain rules, and make whether to control the alarm device to send out sound and light alarm according to the analysis results.

(3) Power supply equipment. It is an energy module that provides power supply for safety devices and ensures the normal operation of each functional unit. Redundant dual power supply mode can be adopted for power supply.
(4) Alarm unit. The devices are designed with lighting, sounding, wireless app information promoting and other alarm modes. Support the alarm with light and sound power of 1W and duration of more than 15 minutes.

The work flow of safety advice is seen the following as figure 2.

![Flow Diagram](image)

**Figure 2.** The flow diagram for safety devices.

2.2. *Advice safety logic*

Set the whole system as $S$, where the sensor is the input $X$ of the system, and $X$ has multiple state components $X_1, X_2, X_n$. For this reason, assume the state variable of the temperature sensor is one of $X$, which can correspond to the state component $X_1$ of the system input, the state variable of the thermal sensor is another component of $X$, the corresponding input state component is $X_2$, then, the pressure sensor, which corresponds to the input state component is $X_3$. The corresponding relationship between the functional unit of the design device and the variable is listed in Table 1 below.
Table 1. Unit and variable corresponding relationship.

| Unit                     | Variables |
|--------------------------|-----------|
| Temperature sensor       | $X_1$     |
| Thermal sensor           | $X_2$     |
| Pressure sensor          | $X_3$     |
| CPU                      | $X_4$     |
| Power supply module      | $X_5$     |
| Alarm advice             | $X_6$     |

Assume the system’s security logic output is $Y$. Then, under different input conditions, the corresponding output has multiple results, which are set as $Y$ components $Y_1$, $Y_2$ … $Y_n$.

In the safety device, there is a certain safety logic relationship between the state of unit variables $X_1$, $X_2$, …, and the output safety variable $Y$. Combined with the work flow of the device, the logic relationship can be expressed by the contents listed in the safety truth table 2. In the table, it means no high temperature, no children and no pressure respectively when $X_1$, $X_2$ and $X_3$ are "0" are detected. While it means high temperature, having children and existing pressure respectively when they are "1" are detected. In the table, variables $X_4$, $X_5$ and $X_6$ are "0" represents no work, while the "1" for the working.

The output variable $Y_i$ has four states, and they are disable, alarm, safety, and SOS.

Table 2. Safety truth tables.

| $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $Y_i$ | $S_i$   |
|-------|-------|-------|-------|-------|-------|-------|---------|
| 0     | 0     | 0     | 0     | 0     | 0     | $Y_1$ | disable |
| ...   | ...   | ...   | ...   | ...   | ...   | ...   | ...     |
| 0     | 0     | 0     | 1     | 1     | 1     | $Y_{57}$ | disable |
| 0     | 0     | 1     | 1     | 1     | 1     | $Y_{58}$ | safety  |
| 0     | 1     | 0     | 1     | 1     | 1     | $Y_{59}$ | alarm   |
| 0     | 1     | 1     | 1     | 1     | 1     | $Y_{60}$ | alarm   |
| 1     | 0     | 0     | 1     | 1     | 1     | $Y_{61}$ | safety  |
| 1     | 1     | 0     | 1     | 1     | 1     | $Y_{62}$ | alarm   |
| 1     | 0     | 1     | 1     | 1     | 1     | $Y_{63}$ | alarm   |
| 1     | 1     | 1     | 1     | 1     | 1     | $Y_{64}$ | SOS     |

Here, suppose $Y$ is the function of $X$, then the equation (1) can be gotten.

$$ Y = F(X) = F \left( \sum_{i=1}^{n} (w_i x_i - \theta) \right) $$  \hspace{1cm} (1)

Here, $w_i$ is the safety weight of unit $i$,
$x_i$ is the safety value of unit $i$,
$\theta$ is a adjusting parameter of unit $i$ for safety.
$Y$ is corresponding to safety levels under the different states, and $S_i$ represents different alarm modes of control device.

3. Reliability modeling and computing

3.1. Reliability modeling
Analysing the functional of the above-mentioned safety devices and the corresponding safety logic relationship of their units, the reliability model of module level can be established. Only when all
the functional modules of the device are normal, the whole system can work normally to ensure the safe realization of the system. Therefore, the reliability model of the safety device is constructed, and the model is shown in Figure 3.

![Figure 3. Reliability model of children safety advice.](image)

The reliability model of the device is a network model, which can better express the safety logic relations listed in Table 2. The network relationship of this model is mainly expressed a network relationship among the all modules. For example, when \( X_1 = 0, X_2 = 0, X_3 = 1, X_4 = 1, X_5 = 1, X_6 = 1 \), it means that the temperature is not high, there are no children in the car, and there are things in the car. At this time, the system is safe. In this state, only the pressure sensor, CPU, power supply device and alarm device can work correctly, and the temperature sensor, thermal sensor and pressure sensor are in parallel. This reliability model can reflect this relationship.

3.2. **Reliability computing**

According to the traditional idea of calculating reliability, the reliability model of safety device is finally equivalent to a series / parallel model to compute its reliability. The model reliability calculation is generally classified into these categories: Series reliability calculation model, parallel system reliability calculation model, and hybrid reliability calculation model. Independent series or parallel models are relatively easy to understand. For relatively complex models, the hybrid simplification method can be used to simplify system into a series / parallel model, as shown in Figure 4.

![Figure 4. Simplified the serial system model.](image)

3.2.1. **Serial computing**

For a series system with \( n \) units, as shown in Figure 5, if the failure rate, repair rate and average failure repair time of the unit are \( \lambda_i, \mu_i \) and \( \gamma_i \) respectively, the series system can be equivalent to a single component, and its failure rate, repair rate and average failure repair time are \( \lambda_s, \mu_s \) and \( \gamma_s \) respectively.
In a series system, the failure of any component leads to the failure of the whole system. Therefore, formula (2) for calculating failure rate is hold.

$$\lambda_s = \sum_{i=1}^{n} \lambda_i$$  \hspace{1cm} (2)

If the mean time to repair is $\gamma_i$, the mean time to repair of the whole system $\gamma_s$ is as follows (3):

$$\gamma_s = \frac{1}{\lambda_s} \sum_{i=1}^{n} \lambda_i \gamma_i$$  \hspace{1cm} (3)

Here, the relationship between the average repair rate $\mu_s$ and the average repair time $r_s$ is as follows (4):

$$\mu_s = \frac{1}{\gamma_s}$$  \hspace{1cm} (4)

3.2.2. Parallel computing

For a parallel system with $n$ units, as shown in Figure 6, if the failure rate, repair rate and average failure repair time of each unit are $\lambda_i$, $\mu_i$ and $\gamma_i$ respectively, the parallel system can still be equivalent to a single component, and its failure rate, repair rate and average failure repair time are $\lambda_p$, $\mu_p$ and $\gamma_p$ respectively.

In parallel system, when all components fail, the system will fail as a whole. If any component is repaired in good condition, the system is in good condition. Therefore, the repair rate of the system can be obtained, as shown in formula (5).

$$\mu_p = \sum_{i=1}^{n} \mu_i$$  \hspace{1cm} (5)

According to the repair rate of the system, the repair time can be calculated, as shown in formula (6).

$$\gamma_p = \frac{1}{\mu_p} = \frac{1}{\sum_{i=1}^{n} \mu_i}$$  \hspace{1cm} (6)

Further, the failure rate of the system is obtained, as shown in formula (7).
4. Reliability computations for network model

In reality, there is also a structure that cannot be simplified by the hybrid method. It is a complex network model, and the equivalent model diagram of the complex network model has no fixed form, so its reliability solution method is relatively difficult. The safety device studied belongs to this kind of network model. The calculation method and calculation function of the reliability model are introduced below.

4.1. Network model

For a network system with multiple elements, the network equivalent model is relatively complex, as shown in Figure 7. It is difficult to calculate the reliability of this kind of network system.

The reliability calculation of network system is relatively complex, and there are many methods to get it, such as segmentation, path set, event space, truth table and factorization. Next, take the network model in Figure 7 as an example to introduce the reliability calculation process of factorization.

The reliability of network model is calculated by selecting key nodes to decompose the network into simpler models. As shown in Figure 7, the node \( v_3 \) is used as the key node to divide the network into two networks. The normal working equivalent diagram of node \( v_3 \) is shown in Figure 8, and the failure equivalent diagram of node \( v_3 \) is shown in Figure 9.

The equivalent model in Figure 8 is a parallel-series hybrid model. Through simplification, a series model can be obtained. Its reliability can be calculated by formula (3) and formula (6). Assuming that the unit reliability is \( r_i \) and the total reliability of the model is \( r_{g1} \), the following formula (8) is established.

\[
Y_P = \prod_{i=1}^{n} \left( \frac{\lambda_i}{\mu_i} \right) \prod_{i=1}^{n} \mu_i \tag{7}
\]

\[
r_{g1} = r_i \ast (r_s + r_k - r_s \ast r_k) \ast r_v \tag{8}
\]
The equivalent model in Figure 8 is also a series hybrid model. Assuming that the unit reliability is \( r_i \) and the total reliability of the model is \( r_g \), the reliability of the model is calculated as follows (9).

\[
r_g = r_i \times (r_s \times r_i + r_s \times r_k - r_s \times r_k \times r_i) \times r_v.
\]

Then, the total reliability \( r_g \) of the network model can be solved by the reliability of the decomposition model, as shown in equation (10).

\[
r_g = r_v \times (r_s \times r_i + (1 - r_s) \times r_g)
\]

\[
r_g = r_v \times (r_s \times r_i + r_k \times r_i - r_k \times r_i \times r_s) \times r_v
\]

\[
+ (1 - r_s) \times r_v \times (r_s \times r_k \times r_i + r_k \times r_k \times r_i)
\]

\[
- r_v \times r_k \times r_i \times r_v.
\]

If the reliability of all components being in normal work is the same, and they are all \( r \), then formula (11) can be obtained.

\[
r_g = 4r^4 - 3r^5 - 6r^6 + r^7
\]

4.2. Determining parameters

All components of the safety device are basically independent electronic devices, and the device belongs to electronic products according to the characteristics of reliability products. Then, the reliability of electronic products generally follows the exponential distribution law, and the product reliability is closely related to its life time. Therefore, the time \( t \) function of single component with reliability \( r_i \) is as follows (12).

\[
r_i(t) = 1 - e^{-\lambda t} \quad (\lambda > 0, t \geq 0)
\]

Then, the system reliability \( R_g \) can be obtained by equation (13).

\[
R_g(t) = 4e^{-4\lambda t} - 3e^{-5\lambda t} - e^{-6\lambda t} + e^{-7\lambda t}
\]

Therefore, the expression (14) of the failure rate \( \lambda_g \) of the device can also be obtained.

\[
\lambda_g = \int_0^{+\infty} (4e^{-4\lambda t} - 3e^{-5\lambda t} - e^{-6\lambda t} + e^{-7\lambda t}) dt
\]

\[
= \int \left( \frac{1}{7\lambda} - \frac{1}{6\lambda} - \frac{3}{5\lambda} + \frac{4}{4\lambda} \right)
\]

If the mean time to repair is \( r \), the solution of the mean time to repair \( r_g \) of the whole system is as follows (15).
The relationship between the overall average repair rate $\mu_g$ and the overall average repair time $r_g$ is as follows, as shown in formula (16).

$$\mu_g = \frac{1}{r_g} \sum_{i=1}^{d} \sum_{j=1}^{d} \lambda_i \gamma_j$$

(15)

The design of product reliability depends on its application needs, economic conditions and other factors. The reliability of safety devices with the same structure model can be different, and the safety devices with different structures can also be designed with the same high reliability. The specific product safety design shall be determined in combination with the product safety requirements.

5. Case studies

Now, taking the safety device of children accidentally locked in the car as the example, the advice is shown in Figure 1, the calculating processes by using the proposed reliability calculation method for the safety device is introduced, and verify the correctness of the calculation results. The safety device studied consists of six main modules, and each of them is composed of electronic devices. Then, Referring to the reliability literature records of electronic products and the reliability indexes of similar products published by manufacturers, the reliability values of each electronic device listed in Table 3 are given after sorting. Based on this value, the reliability indexes of the whole safety device can be calculated.

At present, the MTBF of a single electronic product is about 100000 hours, and the unit scalar level of device failure rate in Table 3 is set as $10^{-5}$ / h.

| Units                  | Failure rates times/(10^{-5}h per) |
|------------------------|------------------------------------|
| Temperature sensor     | 6.6711                             |
| Thermal sensor         | 6.8167                             |
| Pressure sensor        | 8.0242                             |
| CPU                    | 7.7681                             |
| Power supply module    | 7.1313                             |
| Alarm advice           | 7.0242                             |

Table 3. Unit reliabilities.

According to the above modeling method, the equivalent reliability model of the device can be seen as a network model, the completed reliability network model is shown in Figure 10, and the equipment list corresponding to the model node is listed in Table 4.
Based on the equivalent model figure 10, the factorization method is used to solve its reliability, and the final result can be obtained by decomposing the model with node \( v_4 \) as the key node and iterating continuously. Taking the data in Table 3, calculate the reliability of each unit according to formula (12), and then compute the reliability of the whole system based on the device model and the calculation method of the model. The calculation formula is as formula (17).

\[
R_g(t) = (1 - e^{-\lambda t})(1 - e^{-\lambda t})(1 - e^{-\lambda t})(1 - e^{-\lambda t})
\]

\[
\times(1 - e^{-\lambda t})
\]

\[
= 0.9979
\]

Results analysis. According to the reliability data in Table 3, the safety device unit is designed. The reliability of the whole system is 0.9979, that is to say, there is a failure rate of 21 / 10000, or the system works in about 100000 hours, and there may be 21 failures in 10000 devices.

If we take into account the probability of human factors accidentally locking, one in ten thousand people has a probability of accidentally locking children in the car, the probability of such problem is smaller. So this design index is within the acceptable range, and it is also a design conforming to reality the reality.
6. Conclusions
A reliability calculation method of car safety device is proposed, which provides a theoretical support for the design of car safety device. A method of device safety analysis is given, which provides a new idea for device safety analysis. Through the reliability analysis of the safety device, the construction method of the device reliability model, the construction method of the network equivalent model and the reliability calculation method based on the model are given, which provides guidance for the accurate calculation of the device reliability design. The analysis data used in the proposed method comes from all kinds of literature data, and the extraction and determination of all kinds of data will be the next research topic.

Acknowledgments
Authors would like to thank financial support from the National Natural Science Foundation of China (NNSFC Award No. 51807107) and help from the Energy Internet Research Institute, Tsinghua University, China.

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