Security Threat Assessment of an Internet Security System Using Attack Tree and Vague Sets

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Security threat assessment of the Internet security system has become a greater concern in recent years because of the progress and diversification of information technology. Traditionally, the failure probabilities of bottom events of an Internet security system are treated as exact values when the failure probability of the entire system is estimated. However, security threat assessment when the malfunction data of the system's elementary event are incomplete—the traditional approach for calculating reliability—is no longer applicable. Moreover, it does not consider the failure probability of the bottom events suffered in the attack, which may bias conclusions. In order to effectively solve the problem above, this paper proposes a novel technique, integrating attack tree and vague sets for security threat assessment. For verification of the proposed approach, a numerical example of an Internet security system security threat assessment is adopted in this paper. The result of the proposed method is compared with the listing approaches of security threat assessment methods.

1. Introduction

Due to information age's advance, security threat assessment of an Internet security system has become much more important and complicated. To ensure information security, many organizations use firewalls to provide a level of security by controlling access to information systems. A security manager has to make a decision and choose to implement a subset of these policies in order to maximize resource utilization. There has now been extensive research on security threat assessments; for some recent examples, see Tidwell et al. [1], Dhillon and Torkzadeh [2], Satoh et al. [3], Symantec Corporation [4], Opdahl and Sindre [5], Wu and Ye [6], Lee and Chang [7], and Blyth [8]. Helmer et al. [9] proposed the Multi-Agents Intrusion Detection System (MAIDS), which uses mobile agents in a distributed system to obtain audit data, correlate events, and discover intrusions. They used software fault trees to define intrusions and develop the requirement model for intrusion detection systems. Azaiez and Bier [10] used optimal attack strategies by analogy with existing results for the least expected cost failure state diagnosis of reliability systems. In addition, the growing popularity of e-government services on the Internet has also brought with it security threats. Similarly, J. J. Zhao and S. Y. Zhao [11] assessed the security of US state e-government sites to identify opportunities for and threats to the sites and their users. They used a combination of three methods—web content analysis, information security auditing, and computer network security mapping—for data collection and analysis.

The increasing frequency and complexity of Internet attacks have raised the level of sophistication required by systems administrators to effectively cope with script kiddies and more sophisticated hackers, for example, top causes of data breaches of Symantec Corporation in 2012, as shown in Figure 1. Hackers continue to be responsible for the largest number of data breaches, making up 40 percent of all breaches [4]. A secure computer system provides guarantees regarding the confidentiality, integrity, and availability of its data. However, systems generally contain design and implementation flaws that result in security vulnerabilities [9]. In addition, due to uncertainties and imprecision of data, it may be difficult or even impossible to precisely determine the failure probabilities of components. On the other hand, the incomplete failure data of the bottom events suffered in the attack also increase the difficulty of security threat assessment.
assessments are formalized and structured methods for analyzing threats. The possible decomposition of an attack tree to divide the goal into subgoals is an interesting way of describing the security of systems and subsystems. It is a catalog of all possible attacks against a system. The purpose of the attack tree is to define and analyze possible attacks on a system in a structured way. The attack trees provide a formal, methodical way of describing the security of systems, based on varying attacks. An attack tree is initiated by a root node describing a type of attack, and each path is terminated by a leaf node (no children). Nodes can be decomposed by “AND” and “OR” relations.

If we let \( x_j \) be a random variable such that \( x_j = 1 \) corresponds to the accomplishments of subtask \( j \) and \( x_j = 0 \) corresponds to the failure of task \( j \), then \( P(x_1, x_2, \ldots, x_n) \) is the joint probability distribution. In an “AND” node (see Figure 2), it must have \( P(x_1 = 1, x_2 = 1, \ldots, x_n = 1) \). The accomplishment for the parent goal requires the success of all children—that is, \( P_{\text{AND}} = \prod_{j=1}^{n} p_j \) which is the product of the probability of accomplishments of all children. In an “OR” node (see Figure 2), this is essentially the negation of the probability that all subtasks fail: \( 1 - \prod_{j=1}^{n} p_j \). The accomplishment for the parent goal requires the success of any one of the children—that is, \( P_{\text{OR}} = 1 - \prod_{j=1}^{n} (1 - p_j) \) which is the product of the probability of an accomplishment of any one of the children. It assumes that the attacker can try all available subtasks until he finds one that succeeds. This is an unrealistic assumption in attack modeling, because if an attacker needs to try more than one subtask, he has manifested at least one failure. This is a situation that may be untenable in an attack. Therefore, Yager [23] assumed that in an “OR” node, where the attacker needs only to succeed at one subtask, he cannot try all possibilities but must try one. Thus, the probability of success at an “OR” node without any failure is \( P_{\text{OR}} = \max_j \{ p_j \} \). It is also clear that \( P_{\text{OR}} = \max_j \{ p_j \} \geq P_{\text{AND}} = \prod_{j=1}^{n} p_j .

3. Vague Sets and Their Operations

This section introduces the definitions and properties of vague sets and four arithmetic operations of the triangle vague set.

3.1. Definitions and Properties of Vague Sets [24]. Zadeh [25] proposed fuzzy sets to describe fuzzy phenomena under
can explain that the evidence is 0.6 and the declined evidence is 0.1. If function. In 1996, Bustince and Burillo [27] propose that vague sets are intuitionistic fuzzy sets. The membership grade function, \( \mu_{V}(x), x \in X \), assigns a grade membership to each object that ranges between 0 and 1. This single value combines the evidence for \( x \in X \) and the evidence against \( x \in X \), without indicating how much there is of each value.

The notion of an intuitionistic fuzzy set was introduced for the first time by Atanassov [26] in 1983 as a generalization of an ordinary Zadeh fuzzy set. Let a set \( A \) be defined. An intuitionistic fuzzy set \( A \) in \( X \) is an object that has the form \( A = \{(x, \mu_{A}(x), \nu_{A}(x) | x \in X)\} \), where the functions \( \mu_{A}(x) : X \rightarrow [0,1] \) and \( \nu_{A}(x) : X \rightarrow [0,1] \) define the degree of membership and the degree of nonmembership of the element \( x \in X \) to the set \( A \); moreover, \( 0 \leq \mu_{A}(x)+\nu_{A}(x) \leq 1 \) must hold.

The concept of the vague set was proposed by Gau and Buehrer [12]. In a vague set \( V \), for assigning a membership grade to every phenomenon, this membership grade is an interval of \([0,1]\). This interval presents accepted evidence of the element \( x \in X \) and the evidence against it means that the value of \( V \) is a class of objects, along its four arithmetic operations will be easier.

\begin{align*}
A &= \langle \{(a_1', b_1, c_1'; \mu_1), (a_1, b_1, c_1; \mu_2)\} \\
B &= \langle \{(a_2', b_2, c_2'; \mu_3), (a_2, b_2, c_2; \mu_4)\} \\
A(+)B &= \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1, b_1, c_1; \mu_2)\} \\
&= \langle \{(a_1, b_1, c_1; \mu_2)\} \\
A(-)B &= \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1, b_1, c_1; \mu_2)\} \\
&= \langle \{(a_1, b_1, c_1; \mu_2)\} \\
A(\times)B &= \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1, b_1, c_1; \mu_2)\} \\
&= \langle \{(a_1, b_1, c_1; \mu_2)\} \\
A(\div)B &= \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1', b_1, c_1'; \mu_1), (a_2, b_2, c_2; \mu_2)\} \\
&\quad \langle \{(a_1, b_1, c_1; \mu_2)\} \\
&= \langle \{(a_1, b_1, c_1; \mu_2)\} \\
\end{align*}

When \( a_1 = a_1', c_1 = c_1' \) and \( a_2 = a_2', c_2 = c_2' \), the vague sets of its four arithmetic operations will be easier.

4. Proposed Combination of an Attack Tree and Vague Sets Approach

4.1. The Reason for Using Attack Tree and Vague Sets. Security threat assessment of the Internet security system has become a greater concern in recent years, due to progress and diversification of information technology. For an Internet security system, due to uncertainties and imprecision of data, it may be difficult or even impossible to precisely determine the failure probabilities of components. Moreover, we must consider the failure probability of the bottom events suffered in the attack when security threat assessment is executed.
Therefore, it cannot be fully solved by traditional probability reliability. An attack tree provides a way of modeling goals of an attack and alternative ways to achieve that goal. This helps us to study the system from the attackers’ points of view, which may lead us to determine possible ways that the system can be compromised. Therefore, using an attack tree and vague sets approach to solve security threat assessment problems is more suitable. The major advantage of the vague set over the fuzzy set is that the vague set separates the positive (the degree of membership) and negative (the degree of nonmembership) evidence of membership of an element in the set. Fuzzy sets are vague sets, but the converse is not necessarily true. For this reason, it is more suitable to use the vague set, not the fuzzy set, in attack tree diagrams.

4.2. The Procedure of the Proposed Approach. According to the definitions in Section 3, this paper proposes six steps in order to implement vague attack tree analysis in security threat assessment of an Internet security system. The six steps are described as follows.

Step 1 (construct the attack tree diagram). Construct the attack tree diagram by the AND node and OR node, tracing back the whole process from the main goal to the physical tasks.

Step 2 (establish a system of reliability block diagram). A reliability block diagram can explain the units’ relationships in parallel and in series.

Step 3 (define the vague membership degree of leaf nodes). A unit fault can cause the breakdown of the whole system. Define the vague membership degree of leaf nodes according to an expert’s knowledge and experience. Possible failure intervals of bottom events are obtained by aggregating group decision-making opinions of the experts’ opinions.

Step 4 (calculate the possible malfunction probability of the main goal). Use the attack tree diagram and vague set arithmetic operations to calculate the possible malfunction probability of the main goal.

Step 5 (calculate the reliability of the main goal). The reliability of the main goal is equal to one minus the possible malfunction probability of the main goal.

Step 6 (analyze the results and provide suggestions). From Step 5, the results can be further analyzed to provide the decision maker with feasible solutions.

5. An Illustrative Example

In this section, an illustrative example of Internet security system failure during attack is presented in order to demonstrate the procedure that is proposed in this paper. This research also compares the experimental results with the traditional probability reliability and Huang et al.’s [22] methods. First of all, an attack tree is constructed that includes the main goal (the failure of the Internet security system during attack), the sub-goals (IP table, firewall daemon, domain name system (DNS), transport layer security, post office protocol 3 (POP3), secure shell (SSH), the subtasks (DetectionServiceFailure), and the physical tasks (IP Table configuration errors, address translation failure, authentication failure, etc.). An attack tree integrates the main goal, the subgoals, the subtasks, and the physical tasks with "AND" and "OR" nodes (Figure 5). The descriptions of the physical tasks are listed in Table 1. Because of the incomplete failure data of system physical tasks, this paper proposes speculation by experts’ opinions according to the incomplete information condition. The reliability block diagram of the Internet security system failure during attack is shown in Figure 6.

5.1. Traditional Probability Reliability. This research calculated the failure possibility of an “Internet security system” during attack, based on the data of Table 1 (column $b_i$), by the traditional probability reliability method as follows:

\[
q_T = \left\{ (1 - q_A) \left( 1 - q_B \right) \left( 1 - q_C \right) \left( 1 - q_D \right) \right. \\
\times \left( 1 - q_{E1} q_{E2} q_{E3} q_{E4} \right) \times \left( 1 - q_e \right) \left( 1 - q_H \right) \left( 1 - q_I \right) \times \left( 1 - q_{J1} q_{M} q_{N} \right) \times \left( 1 - q_{K1} q_{K2} \right) \left\} \\
= \left\{ 1 - (1 - 0.35)(1 - 0.15)(1 - 0.10)(1 - 0.05) \times (1 - 0.13 \times 0.11 \times 0.05 \times 0.04) \times (1 - 0.10) (1 - 0.05) (1 - 0.40) \times (1 - 0.14 \times 0.20 \times 0.30) \times (1 - 0.18 \times 0.25 \times 0.40) \times (1 - 0.09 \times 0.07 \times 0.04) \right\} \\
= 1 - 0.2359 = 0.7641.
\]

After the calculation above, it is shown that the failure probability of the “Internet security system” during attack is 0.2359 and the reliability of the “Internet security system” is 0.7641.

5.2. Huang et al. Method [22]. When the failure probability of a system is extremely small or when essential statistical data are scarce, the possibst fault-tree analysis proposed by Huang et al. [22] could be applied to predict and diagnose a system’s failures and evaluate its reliability and safety. Calculations of
the failure possibility of the “Internet security system,” based on the crisp failure possibilities, are listed in Table 1 (column $b_i$), as per the following:

$$P_{oss}(SSH) = \min(P_{oss}(O), P_{oss}(P), P_{oss}(Q))$$

$$= \min(0.09, 0.07, 0.04) = 0.04,$$

$$P_{oss}(POP3) = \min(P_{oss}(L), P_{oss}(M), P_{oss}(N))$$

$$= \min(0.18, 0.25, 0.40) = 0.18,$$

$$P_{oss}(Transport Layer Security)$$

$$= \min(P_{oss}(I), P_{oss}(J), P_{oss}(K))$$

$$= \min(0.14, 0.20, 0.30) = 0.14,$$

$$P_{oss}(DNS) = \max(P_{oss}(F), P_{oss}(G), P_{oss}(H))$$

$$= \max(0.10, 0.05, 0.40) = 0.40,$$

$$P_{oss}(Detection Service Failure)$$

$$= \min(P_{oss}(E1), P_{oss}(E2), P_{oss}(E3), P_{oss}(E4))$$

$$= \min(0.13, 0.11, 0.05, 0.04) = 0.04,$$

$$P_{oss}(Firewall Daemon)$$

$$= \max(P_{oss}(D), P_{oss}(Detection Service Failure))$$

$$= \max(0.05, 0.04) = 0.05,$$

$$P_{oss}(IP Table) = \max(P_{oss}(A), P_{oss}(B), P_{oss}(C))$$

$$= \max(0.35, 0.15, 0.10) = 0.35.$$

Then, the top event possibilities of “Internet security system failure” during attacking can be calculated as

$$P_{oss}(Internet Security System Failure)$$

$$= \max(P_{oss}(SSH), P_{oss}(POP3), P_{oss}(Transport Layer Security), P_{oss}(DNS), P_{oss}(Firewall Daemon), P_{oss}(IP Table))$$

$$= \max(0.04, 0.18, 0.14, 0.40, 0.05, 0.35) = 0.40.$$
Table 1: The possible range of leaf node failures.

| Failure possibility                                      | $a_i$ | $a'_i$ | $b_i$ | $c'_i$ | $c_i$ | $\mu_A(U)$ | $1 - \nu_A(U)$ |
|---------------------------------------------------------|-------|--------|-------|--------|-------|------------|----------------|
| A (IP Table configuration errors)                        | 0.30  | 0.33   | 0.35  | 0.37   | 0.40  | 0.8        | 0.9            |
| B (address translation failure)                          | 0.10  | 0.12   | 0.15  | 0.18   | 0.20  | 0.9        | 1.0            |
| C (authentication failure)                               | 0.80  | 0.90   | 0.10  | 0.11   | 0.12  | 0.9        | 0.9            |
| D (Firewall Daemon configuration errors)                 | 0.04  | 0.04   | 0.05  | 0.06   | 0.06  | 0.8        | 0.9            |
| $E_1$ (scan failure)                                     | 0.11  | 0.12   | 0.13  | 0.14   | 0.15  | 0.9        | 1.0            |
| $E_2$ (cleanse failure)                                  | 0.10  | 0.10   | 0.11  | 0.12   | 0.12  | 0.9        | 1.0            |
| $E_3$ (audit failure)                                    | 0.03  | 0.04   | 0.05  | 0.06   | 0.07  | 0.9        | 1.0            |
| $E_4$ (validation failure)                               | 0.03  | 0.03   | 0.04  | 0.05   | 0.05  | 0.9        | 1.0            |
| $F$ (DNS configuration errors)                           | 0.08  | 0.09   | 0.10  | 0.11   | 0.12  | 0.8        | 0.9            |
| $G$ (monitor service failure)                            | 0.04  | 0.04   | 0.05  | 0.06   | 0.06  | 0.9        | 1.0            |
| $H$ (malicious access detected)                          | 0.35  | 0.37   | 0.40  | 0.43   | 0.45  | 0.8        | 1.0            |
| $I$ (Transport Layer Security configuration errors)       | 0.12  | 0.13   | 0.14  | 0.15   | 0.16  | 0.9        | 0.9            |
| $J$ (peer entity authentication)                         | 0.15  | 0.16   | 0.20  | 0.24   | 0.25  | 0.8        | 1.0            |
| $K$ (security parameter negotiation)                     | 0.27  | 0.28   | 0.30  | 0.32   | 0.33  | 0.8        | 0.9            |
| $L$ (POP3 configuration errors)                          | 0.16  | 0.17   | 0.18  | 0.19   | 0.20  | 0.8        | 0.9            |
| $M$ (entry authentication)                               | 0.22  | 0.24   | 0.25  | 0.26   | 0.28  | 0.8        | 1.0            |
| $N$ (entry security parameter)                           | 0.38  | 0.39   | 0.40  | 0.41   | 0.42  | 0.8        | 0.9            |
| $O$ (security parameter authentication)                  | 0.07  | 0.08   | 0.09  | 0.10   | 0.11  | 0.8        | 1.0            |
| $P$ (key generation)                                     | 0.05  | 0.06   | 0.07  | 0.08   | 0.09  | 0.8        | 0.9            |
| $Q$ (data confidentiality)                               | 0.03  | 0.03   | 0.04  | 0.05   | 0.05  | 0.9        | 0.9            |

After the calculation above, it is shown that the failure probability of the "Internet security system" during attack is 0.40 and the reliability of the "Internet security system" is 0.60.

5.3. Proposed Method. According to (1), the failure range of subgoals (SSH, POP3, Transport Layer Security, DNS, Detection Service Failure, Firewall Daemon, and IP Table) can be calculated as

\[
P_{\text{and}}(\text{SSH}) = P_O \times P_P \times P_Q
\]

\[
P_{\text{and}}(\text{POP3}) = P_L \times P_M \times P_N
\]

\[
P_{\text{and}}(\text{IP Table}) = P_I \times P_P \times P_Q
\]
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\( P_{\text{and}} \) (Transport Layer Security)
\[
= P_I \times P_J \times P_K \\
= \langle [\langle 0.13, 0.14, 0.15 \rangle ; 0.8], [\langle 0.12, 0.14, 0.16 \rangle ; 0.9] \rangle \\
\times \langle [\langle 0.16, 0.20, 0.24 \rangle ; 0.8], [\langle 0.15, 0.20, 0.25 \rangle ; 1.0] \rangle \\
\times \langle [\langle 0.28, 0.30, 0.32 \rangle ; 0.8], [\langle 0.27, 0.30, 0.33 \rangle ; 0.9] \rangle \\
= \langle [\langle 0.0208, 0.0280, 0.0360 \rangle ; 0.8], [\langle 0.0180, 0.0280, 0.0400 \rangle ; 0.9] \rangle \\
\times \langle [\langle 0.16, 0.20, 0.24 \rangle ; 0.8], [\langle 0.15, 0.20, 0.25 \rangle ; 1.0] \rangle \\
\times \langle [\langle 0.28, 0.30, 0.32 \rangle ; 0.8], [\langle 0.27, 0.30, 0.33 \rangle ; 0.9] \rangle \\
= \langle [\langle 0.005824, 0.008400, 0.011520 \rangle ; 0.8], [\langle 0.004860, 0.008400, 0.013200 \rangle ; 0.9] \rangle \\
\]

\( P_{\text{or}} \) (DNS)
\[
= \max (P_F, P_G, P_H) \\
= \max \{ \langle [\langle 0.09, 0.10, 0.11 \rangle ; 0.8], [\langle 0.08, 0.10, 0.12 \rangle ; 0.9] \rangle, \\
\langle [\langle 0.04, 0.05, 0.06 \rangle ; 0.9], [\langle 0.04, 0.05, 0.06 \rangle ; 1.0] \rangle, \\
\langle [\langle 0.37, 0.40, 0.43 \rangle ; 0.8], [\langle 0.35, 0.40, 0.45 \rangle ; 1.0] \rangle \} \\
= \langle [\langle 0.37, 0.40, 0.43 \rangle ; 0.8], [\langle 0.35, 0.40, 0.45 \rangle ; 0.9] \rangle \\
\]

\( P_{\text{and}} \) (Detection Service Failure)
\[
= P_{E1} \times P_{E2} \times P_{E3} \times P_{E4} \\
= \langle \langle [\langle 0.12, 0.13, 0.14 \rangle ; 0.9], [\langle 0.11, 0.13, 0.15 \rangle ; 1.0] \rangle, \\
\langle [\langle 0.10, 0.11, 0.12 \rangle ; 0.9], [\langle 0.10, 0.11, 0.12 \rangle ; 1.0] \rangle, \\
\langle [\langle 0.04, 0.05, 0.06 \rangle ; 0.9], [\langle 0.03, 0.05, 0.07 \rangle ; 1.0] \rangle, \\
\langle [\langle 0.03, 0.04, 0.05 \rangle ; 0.9], [\langle 0.03, 0.04, 0.05 \rangle ; 1.0] \rangle \} \\
= \langle \langle [\langle 0.0000144, 0.0000286, 0.0000504 \rangle ; 0.9], [\langle 0.0000099, 0.0000286, 0.0000630 \rangle ; 1.0] \rangle \}, \\
\]

\( P_{\text{or}} \) (Firewall Daemon)
\[
= \max (P_D, P_{\text{Detection Service Failure}}) \\
= \max \{ \langle [\langle 0.04, 0.05, 0.06 \rangle ; 0.8], [\langle 0.04, 0.05, 0.06 \rangle ; 0.9] \rangle, \\
\langle [\langle 0.0000144, 0.0000286, 0.0000504 \rangle ; 0.9], [\langle 0.0000099, 0.0000286, 0.0000630 \rangle ; 1.0] \rangle \} \\
= \langle [\langle 0.04, 0.05, 0.06 \rangle ; 0.8], [\langle 0.04, 0.05, 0.06 \rangle ; 0.9] \rangle, \\
\]

\( P_{\text{or}} \) (IP Table)
\[
= \max (P_A, P_B, P_C) \\
= \max \{ \langle [\langle 0.33, 0.35, 0.37 \rangle ; 0.8], [\langle 0.30, 0.35, 0.40 \rangle ; 0.9] \rangle, \\
\langle [\langle 0.12, 0.15, 0.18 \rangle ; 0.9], [\langle 0.10, 0.15, 0.20 \rangle ; 1.0] \rangle \}, \\
\]

\[
= \langle [\langle 0.09, 0.10, 0.11 \rangle ; 0.9], [\langle 0.08, 0.10, 0.12 \rangle ; 0.9] \rangle \\
= \langle [\langle 0.33, 0.35, 0.37 \rangle ; 0.8], [\langle 0.30, 0.35, 0.40 \rangle ; 0.9] \rangle. \\
\]

\[
= \max (P_{\text{SSH}}, P_{\text{POP3}}, P_{\text{Transport Layer Security}}) \\
\]

5.4. Comparisons and Discussion. In order to evaluate the proposed method, a numerical verification is performed in Section 5. This study also compares the experimental results with the traditional probability reliability and Huang et al.’s [22] methods. The input data of these methods are shown in Figure 5 and Table 1. In the comparison of the results of the three methods, the differences between the proposed method and the listing methods can be shown clearly in Figure 7. From Figure 7, there are some findings.

(1) The traditional probability reliability and Huang et al.’s [22] methods do not consider the confidence level of domain experts. Therefore, the proposed method can be more flexible to present the confidence level of experts (highest confidence = 0.9).

(2) In both the traditional probability reliability method and Huang et al.’s [22] methods, the failure possibilities of the top event are all equal to 0.2359 and 0.40. Because these methods are fit, the outcome of the top event is certain and precise as long as the assignment of basic events is decent from reliable information.

(3) In the traditional probability reliability method, the failure possibilities of the top event are all equal at 0.2359. This is because the traditional probability reliability method does not consider the failure probability of the bottom events suffered in an attack and may obtain biased conclusions.
The advantages of the proposed approach are summarized as follows.

(1) The proposed method considers the malfunction data of the system elementary event as incomplete.

(2) The proposed method provides more accurate and effective information to assist the decision-making process.

(3) The failure information in a system's elementary event is described as vague variables; this result is more realistic and is a flexible reflection of the real situation.

(4) From a hacker's point of view, finding the weak links in the system for design is to find out a better design of an Internet security system.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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