# System Health Monitoring
# and
# Proactive Response Activation

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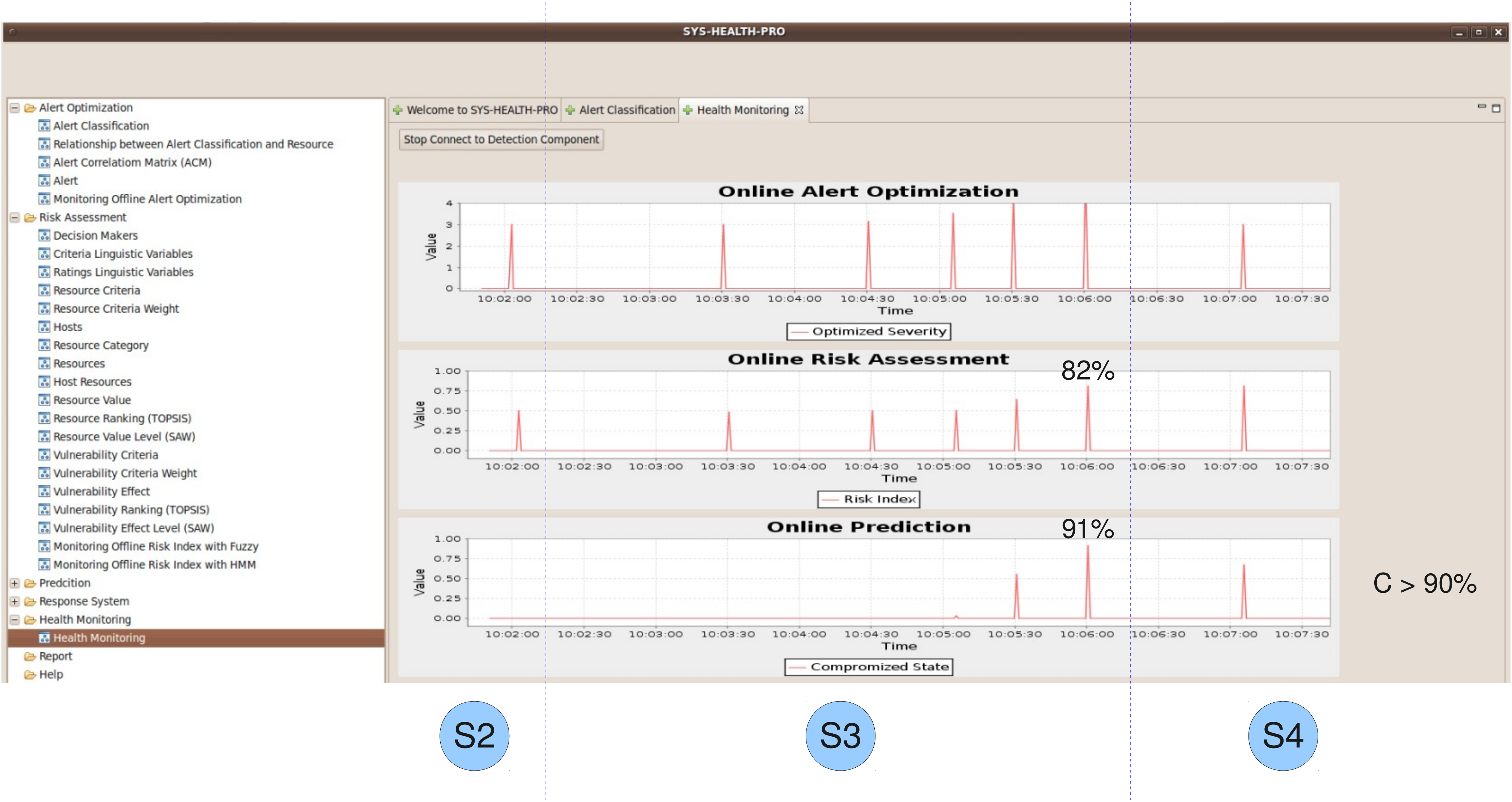
# Scenario of Multi-step attack

| Phase | Name | Time |
|---|---|---|
| 1 | Probing | 10:00 to 10:01 |
| 2 | Bruteforce username and password | 10:01 to 10:03 |
| 3 | Find vulnerabilities | 10:03 to 10:06 |
| 4 | Establish a reverse shell | 10:06 to 10:08 |

- Eventually, the attacker finds 192.168.10.2/test.php?cmd=id
- Attack type:
  - HTTP_Bruteforce_Password
  - HTTP_Vulnerability_Exploit
  - Reverse_Shell

# Result of Risk Assessment and Prediction

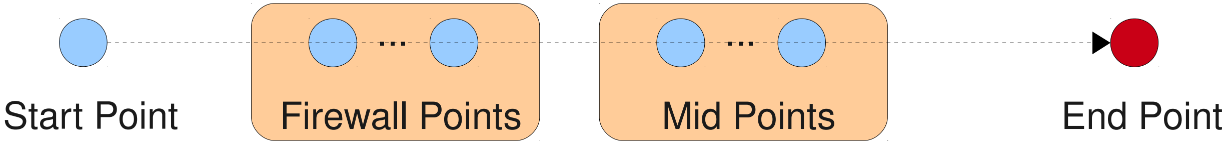


SYS-HEALTH-PRO

- Alert Optimization
  - Alert Classification
  - Relationship between Alert Classification and Resource
  - Alert Correlatiom Matrix (ACM)
  - Alert
  - Monitoring Offline Alert Optimization
- Risk Assessment
  - Decision Makers
  - Criteria Linguistic Variables
  - Ratings Linguistic Variables
  - Resource Criteria
  - Resource Criteria Weight
  - Hosts
  - Resource Category
  - Resources
  - Host Resources
  - Resource Value
  - Resource Ranking (TOPSIS)
  - Resource Value Level (SAW)
  - Vulnerability Criteria
  - Vulnerability Criteria Weight
  - Vulnerability Effect
  - Vulnerability Ranking (TOPSIS)
  - Vulnerability Effect Level (SAW)
  - Monitoring Offline Risk Index with Fuzzy
  - Monitoring Offline Risk Index with HMM
- Predcition
- Response System
- Health Monitoring
  - Health Monitoring
- Report
- Help

# New Architecture of IRS

- Supports dynamic evaluation of "***Response Cost***"
  - Account for the user's need in terms of quality of services (QoS)
  - Account the dependencies of critical processes
- Supports "***Attack Path***" technique
  - Find the best locations where to apply responses, with the lowest penalty cost

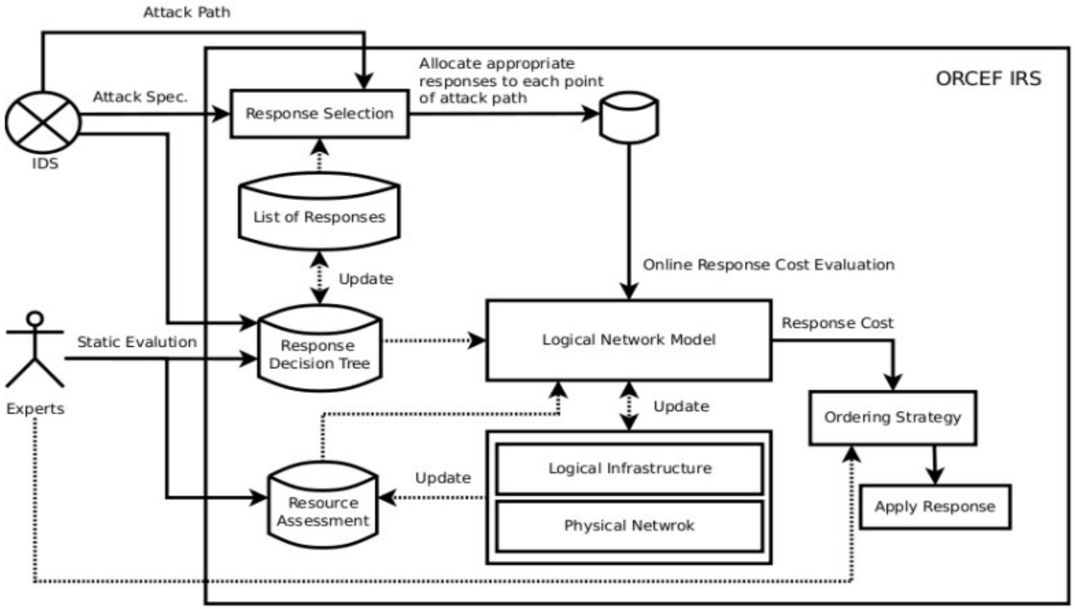


Start Point

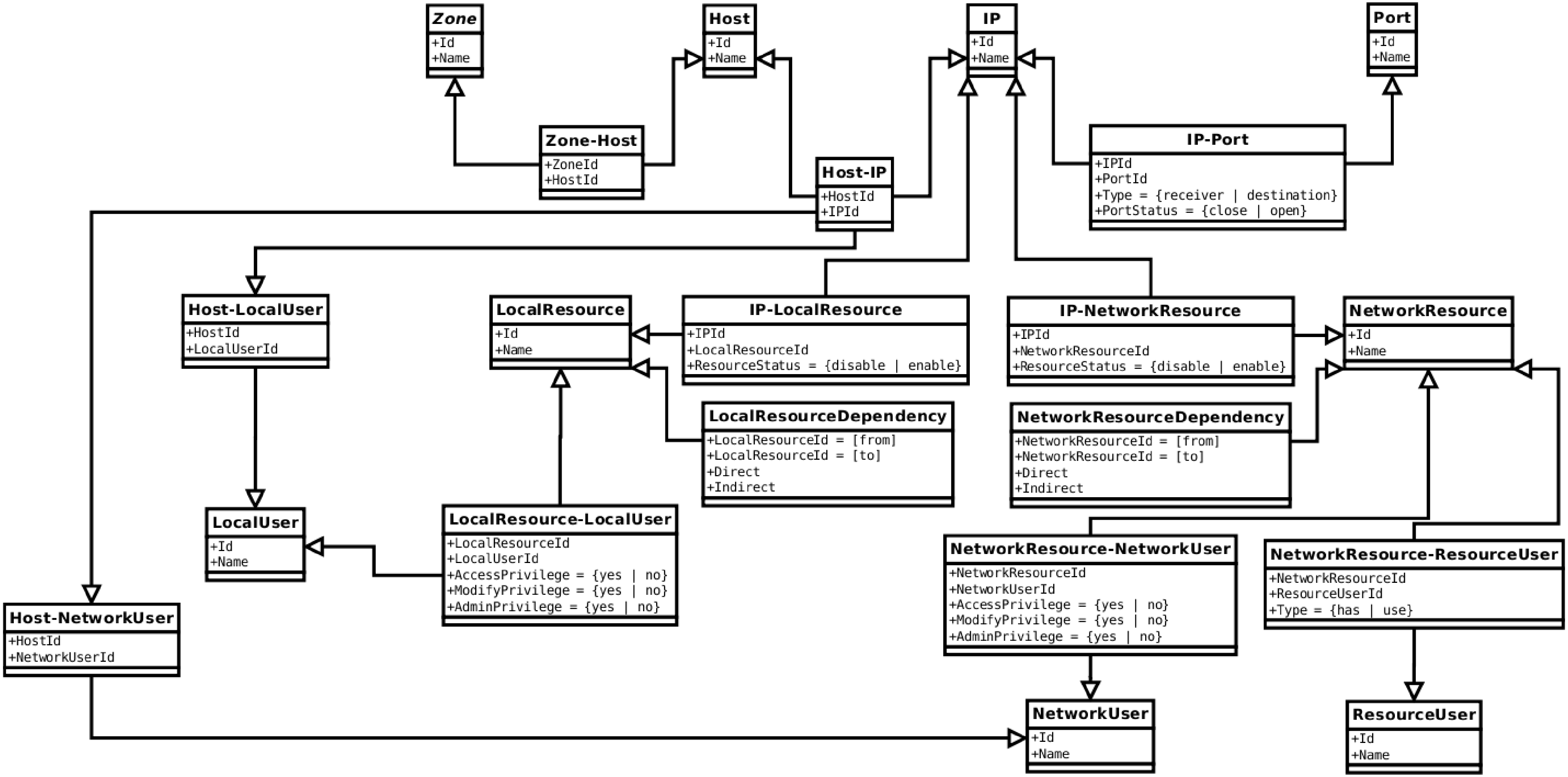
Firewall Points

Mid Points

End Point



# Logical Network Model of IRS



**Zone**
+Id
+Name

**Host**
+Id
+Name

**IP**
+Id
+Name

**Port**
+Id
+Name

**Zone-Host**
+ZoneId
+HostId

**Host-IP**
+HostId
+IPId

**IP-Port**
+IPId
+PortId
+Type = {receiver | destination}
+PortStatus = {close | open}

**Host-LocalUser**
+HostId
+LocalUserId

**LocalResource**
+Id
+Name

**IP-LocalResource**
+IPId
+LocalResourceId
+ResourceStatus = {disable | enable}

**IP-NetworkResource**
+IPId
+NetworkResourceId
+ResourceStatus = {disable | enable}

**NetworkResource**
+Id
+Name

**LocalResourceDependency**
+LocalResourceId = [from]
+LocalResourceId = [to]
+Direct
+Indirect

**NetworkResourceDependency**
+NetworkResourceId = [from]
+NetworkResourceId = [to]
+Direct
+Indirect

**LocalUser**
+Id
+Name

**LocalResource-LocalUser**
+LocalResourceId
+LocalUserId
+AccessPrivilege = {yes | no}
+ModifyPrivilege = {yes | no}
+AdminPrivilege = {yes | no}

**NetworkResource-NetworkUser**
+NetworkResourceId
+NetworkUserId
+AccessPrivilege = {yes | no}
+ModifyPrivilege = {yes | no}
+AdminPrivilege = {yes | no}

**NetworkResource-ResourceUser**
+NetworkResourceId
+ResourceUserId
+Type = {has | use}

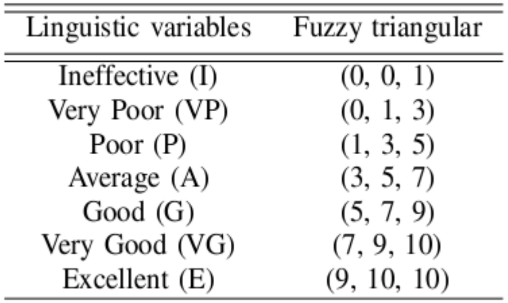
**Host-NetworkUser**
+HostId
+NetworkUserId

**NetworkUser**
+Id
+Name

**ResourceUser**
+Id
+Name

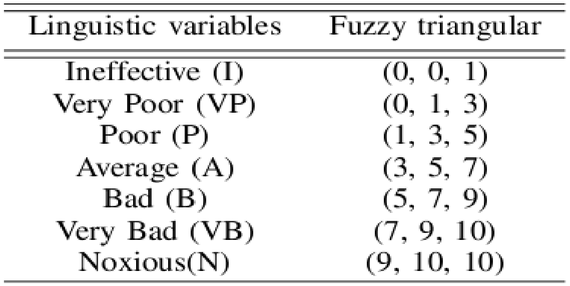
# Evaluation Criteria

- Positive effects
  - Positive Confidentiality (P_C)
  - Positive Integrity (P_I)
  - Positive Availability (P_A)
  - Positive Speed (P_S)



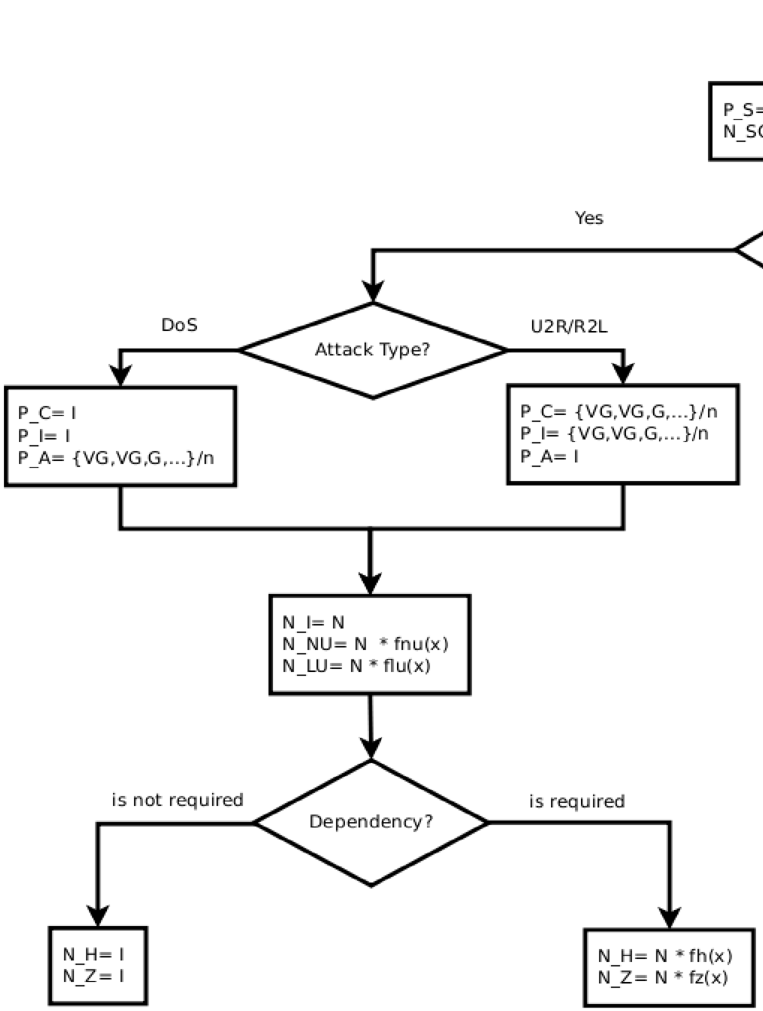
| Linguistic variables | Fuzzy triangular |
|---|---|
| Ineffective (I) | (0, 0, 1) |
| Very Poor (VP) | (0, 1, 3) |
| Poor (P) | (1, 3, 5) |
| Average (A) | (3, 5, 7) |
| Good (G) | (5, 7, 9) |
| Very Good (VG) | (7, 9, 10) |
| Excellent (E) | (9, 10, 10) |

- Negative Impact
  - Negative Itself (N_I)
  - Negative Host (N_H)
  - Negative Zone (N_Z)
  - Negative Network User (N_NU)
  - Negative Local User (N_LU)
  - Negative Setup Cost(N_SC)



| Linguistic variables | Fuzzy triangular |
|---|---|
| Ineffective (I) | (0, 0, 1) |
| Very Poor (VP) | (0, 1, 3) |
| Poor (P) | (1, 3, 5) |
| Average (A) | (3, 5, 7) |
| Bad (B) | (5, 7, 9) |
| Very Bad (VB) | (7, 9, 10) |
| Noxious(N) | (9, 10, 10) |

# Response Decision Tree



x= Resource

P_S= {E,E,E, ...}/n
N_SC= {P,VP,P,...}/n

Known?

Yes

No

P_C= {VG,VG,G,..}/n
P_I= {G,VG,G,...}/n
P_A= {VG,VG,G,...}/n
N_I= I
N_H= I
N_Z= I
N_NU= I
N_LU= I
N_SC= I

Attack Type?

DoS

U2R/R2L

P_C= I
P_I= I
P_A= {VG,VG,G,...}/n

P_C= {VG,VG,G,...}/n
P_I= {VG,VG,G,...}/n
P_A= I

N_I= N
N_NU= N  * fnu(x)
N_LU= N * flu(x)

Dependency?

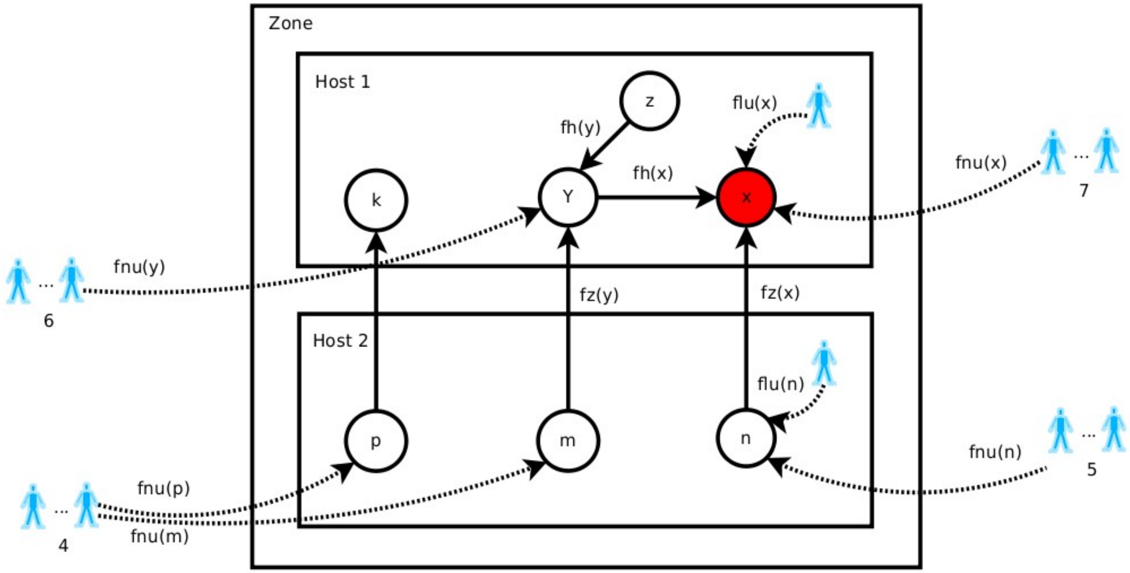
is not required

is required

N_H= I
N_Z= I

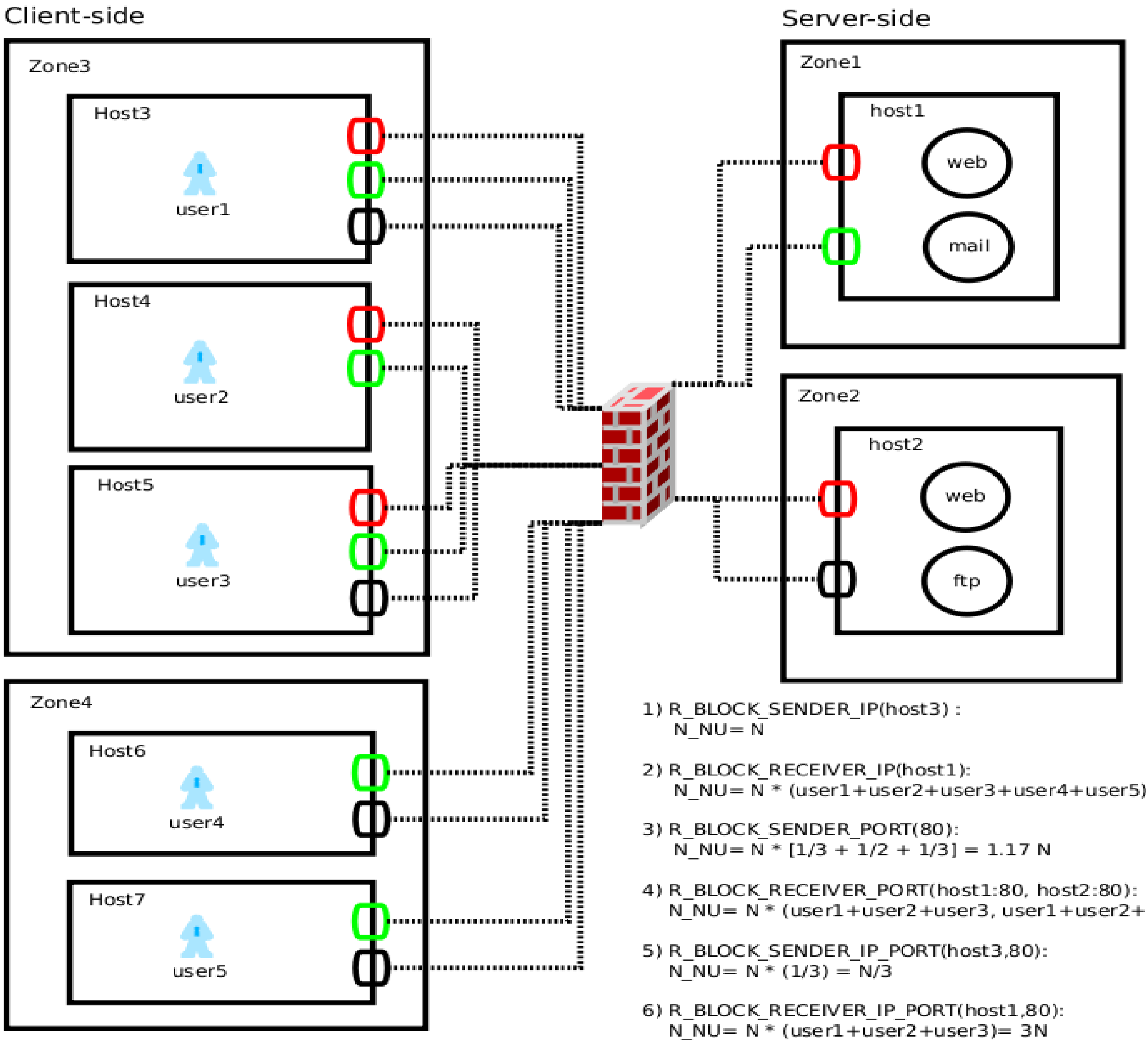
N_H= N * fh(x)
N_Z= N * fz(x)

Kill process decision tree



1) fh(x) = Direct + Indirect = {y} + {z} = 2
2) fz(x) = Direct + Indirect = {n} + {m} = 2
3) fnu(x) = Direct + Indirect = {x:7} + {n:5, m:4, y:6} = 22
4) flu(x) = Direct + Indirect= {x:1} + {n:1} = 2

# Blocking on Firewall



1) R_BLOCK_SENDER_IP(host3) :
N_NU= N

2) R_BLOCK_RECEIVER_IP(host1):
N_NU= N * (user1+user2+user3+user4+user5) = 5N

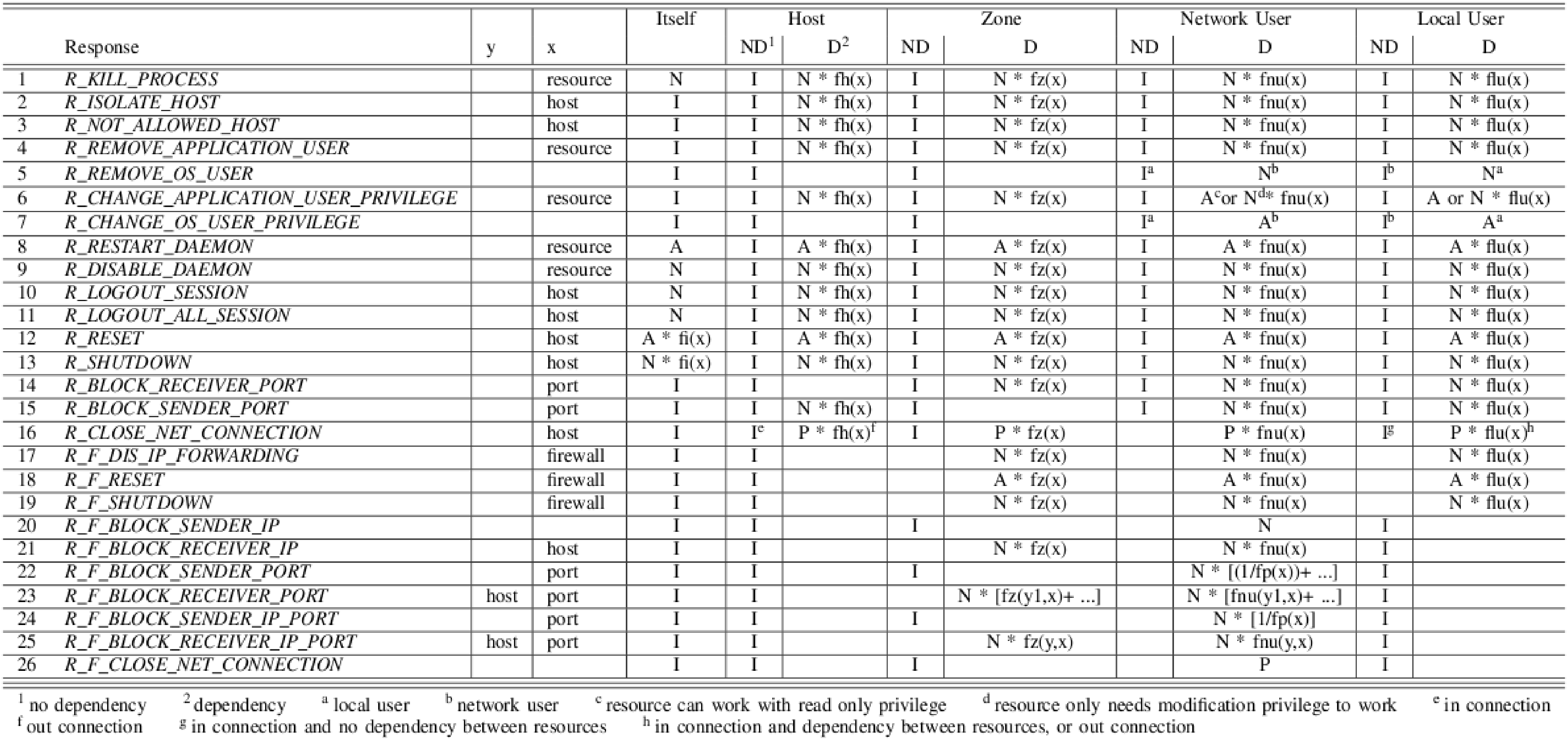
3) R_BLOCK_SENDER_PORT(80):
N_NU= N * [1/3 + 1/2 + 1/3] = 1.17 N

4) R_BLOCK_RECEIVER_PORT(host1:80, host2:80):
N_NU= N * (user1+user2+user3, user1+user2+user3) = 6N

5) R_BLOCK_SENDER_IP_PORT(host3,80):
N_NU= N * (1/3) = N/3

6) R_BLOCK_RECEIVER_IP_PORT(host1,80):
N_NU= N * (user1+user2+user3)= 3N

# Decision making table to calculate negative criteria



| | | | | Itself | Host | | Zone | | Network User | | Local User | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Response | y | x | | ND[1] | D[2] | ND | D | ND | D | ND | D |
| 1 | *R_KILL_PROCESS* | | resource | N | I | N * fh(x) | I | N * fz(x) | I | N * fnu(x) | I | N * flu(x) |
| 2 | *R_ISOLATE_HOST* | | host | I | I | N * fh(x) | I | N * fz(x) | I | N * fnu(x) | I | N * flu(x) |
| 3 | *R_NOT_ALLOWED_HOST* | | host | I | I | N * fh(x) | I | N * fz(x) | I | N * fnu(x) | I | N * flu(x) |
| 4 | *R_REMOVE_APPLICATION_USER* | | resource | I | I | N * fh(x) | I | N * fz(x) | I | N * fnu(x) | I | N * flu(x) |
| 5 | *R_REMOVE_OS_USER* | | | I | I | | I | | I[a] | N[b] | I[b] | N[a] |
| 6 | *R_CHANGE_APPLICATION_USER_PRIVILEGE* | | resource | I | I | N * fh(x) | I | N * fz(x) | I | A[c]or N[d]* fnu(x) | I | A or N * flu(x) |
| 7 | *R_CHANGE_OS_USER_PRIVILEGE* | | | I | I | | I | | I[a] | A[b] | I[b] | A[a] |
| 8 | *R_RESTART_DAEMON* | | resource | A | I | A * fh(x) | I | A * fz(x) | I | A * fnu(x) | I | A * flu(x) |
| 9 | *R_DISABLE_DAEMON* | | resource | N | I | N * fh(x) | I | N * fz(x) | I | N * fnu(x) | I | N * flu(x) |
| 10 | *R_LOGOUT_SESSION* | | host | N | I | N * fh(x) | I | N * fz(x) | I | N * fnu(x) | I | N * flu(x) |
| 11 | *R_LOGOUT_ALL_SESSION* | | host | N | I | N * fh(x) | I | N * fz(x) | I | N * fnu(x) | I | N * flu(x) |
| 12 | *R_RESET* | | host | A * fi(x) | I | A * fh(x) | I | A * fz(x) | I | A * fnu(x) | I | A * flu(x) |
| 13 | *R_SHUTDOWN* | | host | N * fi(x) | I | N * fh(x) | I | N * fz(x) | I | N * fnu(x) | I | N * flu(x) |
| 14 | *R_BLOCK_RECEIVER_PORT* | | port | I | I | | I | N * fz(x) | I | N * fnu(x) | I | N * flu(x) |
| 15 | *R_BLOCK_SENDER_PORT* | | port | I | I | N * fh(x) | I | | I | N * fnu(x) | I | N * flu(x) |
| 16 | *R_CLOSE_NET_CONNECTION* | | host | I | I[e] | P * fh(x)[f] | I | P * fz(x) | | P * fnu(x) | I[g] | P * flu(x)[h] |
| 17 | *R_F_DIS_IP_FORWARDING* | | firewall | I | I | | | N * fz(x) | | N * fnu(x) | | N * flu(x) |
| 18 | *R_F_RESET* | | firewall | I | I | | | A * fz(x) | | A * fnu(x) | | A * flu(x) |
| 19 | *R_F_SHUTDOWN* | | firewall | I | I | | | N * fz(x) | | N * fnu(x) | | N * flu(x) |
| 20 | *R_F_BLOCK_SENDER_IP* | | | I | I | | I | | | N | I | |
| 21 | *R_F_BLOCK_RECEIVER_IP* | | host | I | I | | | N * fz(x) | | N * fnu(x) | I | |
| 22 | *R_F_BLOCK_SENDER_PORT* | | port | I | I | | I | | | N * [(1/fp(x))+ ...] | I | |
| 23 | *R_F_BLOCK_RECEIVER_PORT* | host | port | I | I | | | N * [fz(y1,x)+ ...] | | N * [fnu(y1,x)+ ...] | I | |
| 24 | *R_F_BLOCK_SENDER_IP_PORT* | | port | I | I | | I | | | N * [1/fp(x)] | I | |
| 25 | *R_F_BLOCK_RECEIVER_IP_PORT* | host | port | I | I | | | N * fz(y,x) | | N * fnu(y,x) | I | |
| 26 | *R_F_CLOSE_NET_CONNECTION* | | | I | I | | I | | | P | I | |

[1] no dependency [2] dependency [a] local user [b] network user [c] resource can work with read only privilege [d] resource only needs modification privilege to work [e] in connection
[f] out connection [g] in connection and no dependency between resources [h] in connection and dependency between resources, or out connection

# System Scenario

## The number of online user

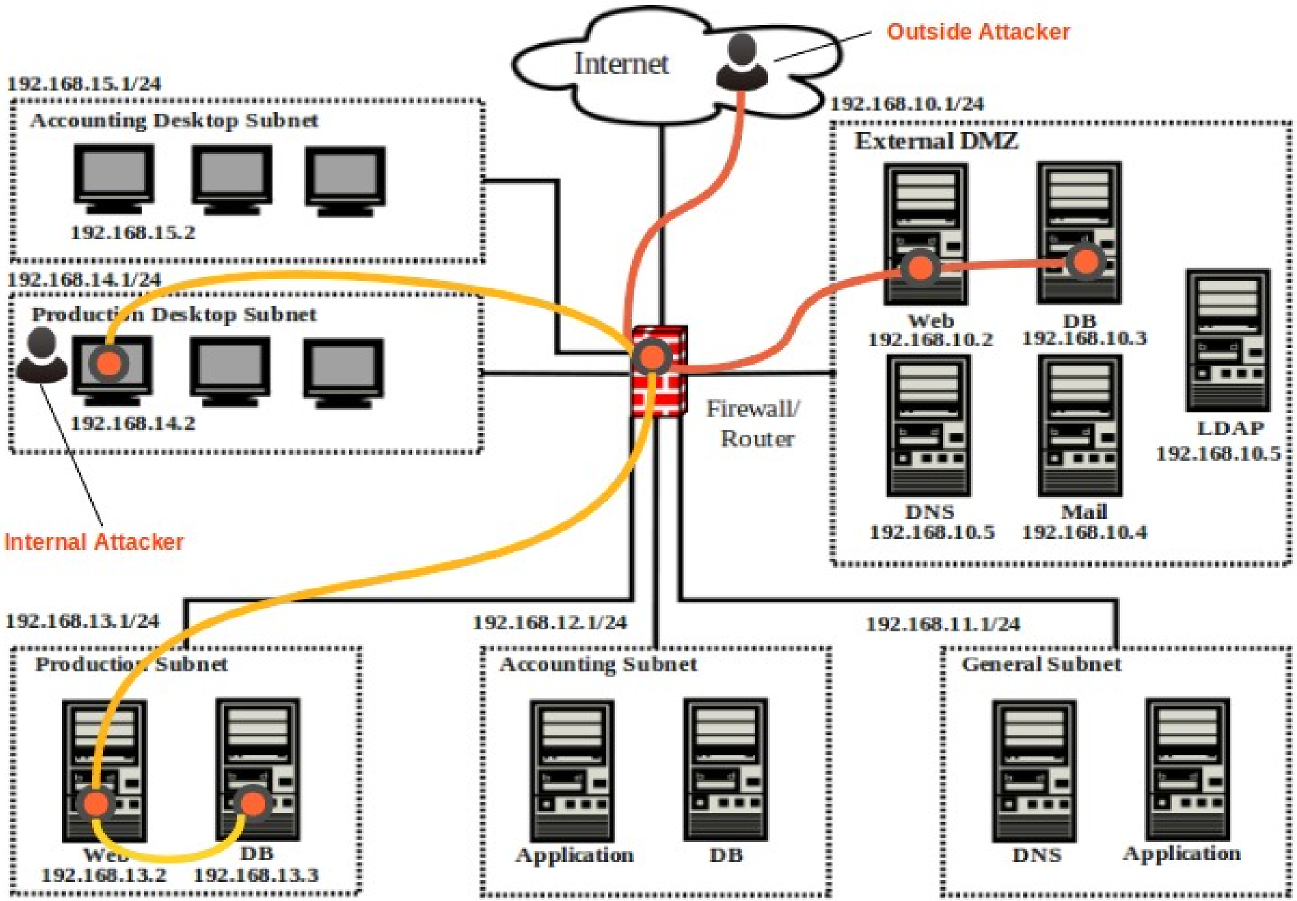
| Type | No. |
|---|---|
| Internal email user | 46 |
| Outside email user | 4 |
| Internal web user | 46 |
| Outside web user | 54 |
| Production software user | 23 |
| Local user | 11 |
| Remote admin user | 1 |
| MySQL user | 2 |

## Attack damage cost

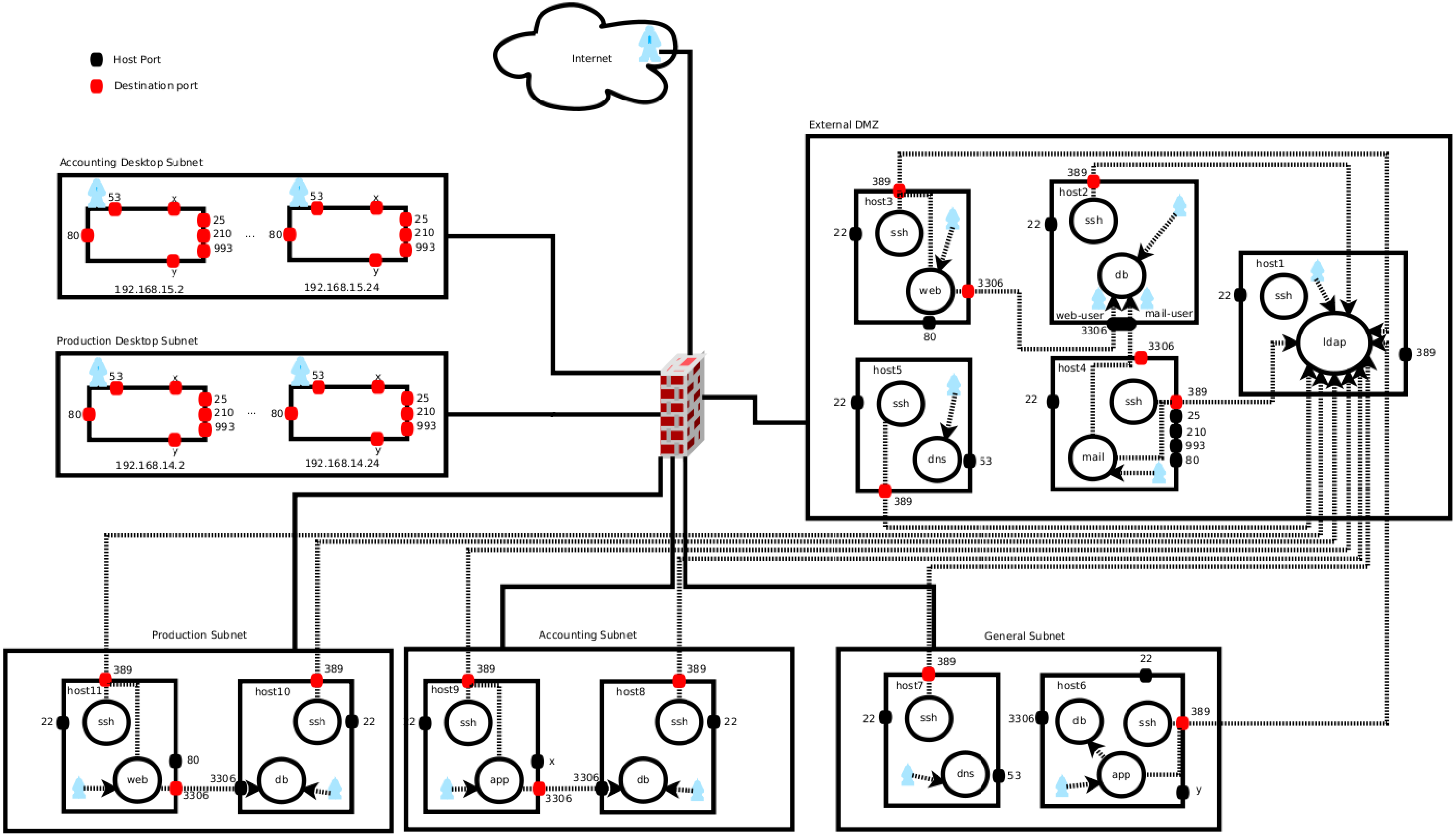
| Type | Cost |
|---|---|
| U2R | 100 |
| R2L | 60 |
| DoS | 35 |
| PROBE | 5 |

## Resource value

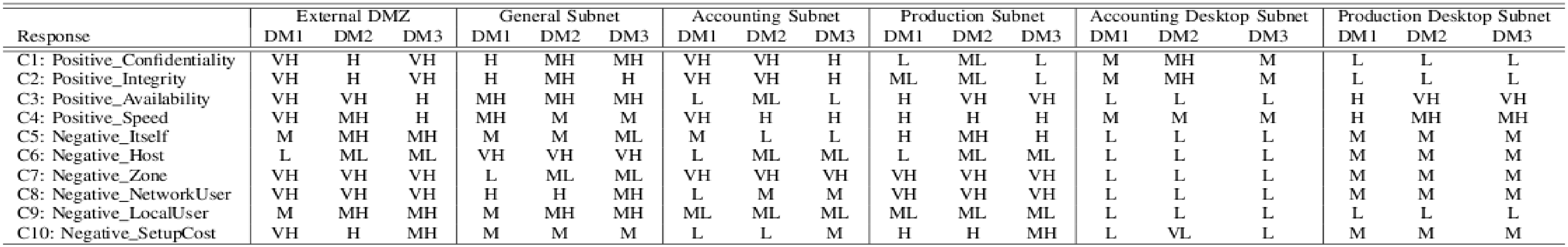
| Name | Fuzzification | Defuzzification | Scale %100 |
|---|---|---|---|
| DMZ.Web | (1.64,2.08,2.43) | 2.06 | 81 |
| DMZ.DB | (1.97,2.31,2.47) | 2.26 | 90 |
| Production.Web | (1.54,1.90,2.25) | 1.88 | 74 |
| Production.DB | (1.76,2.14,2.37) | 2.10 | 83 |



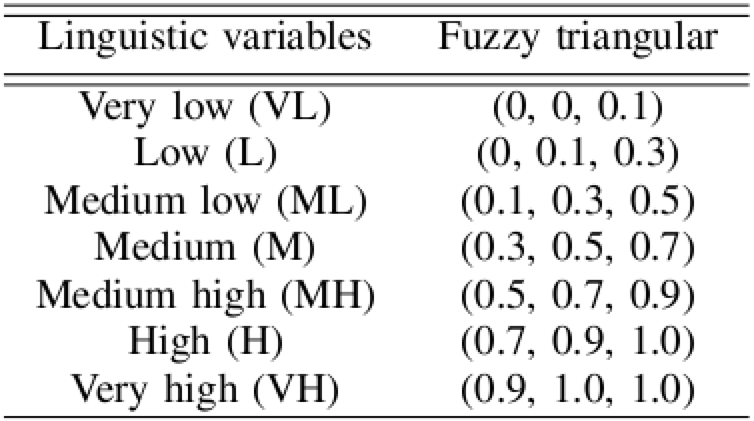
# Services Dependency



# Step1 ) Importance weight of criteria

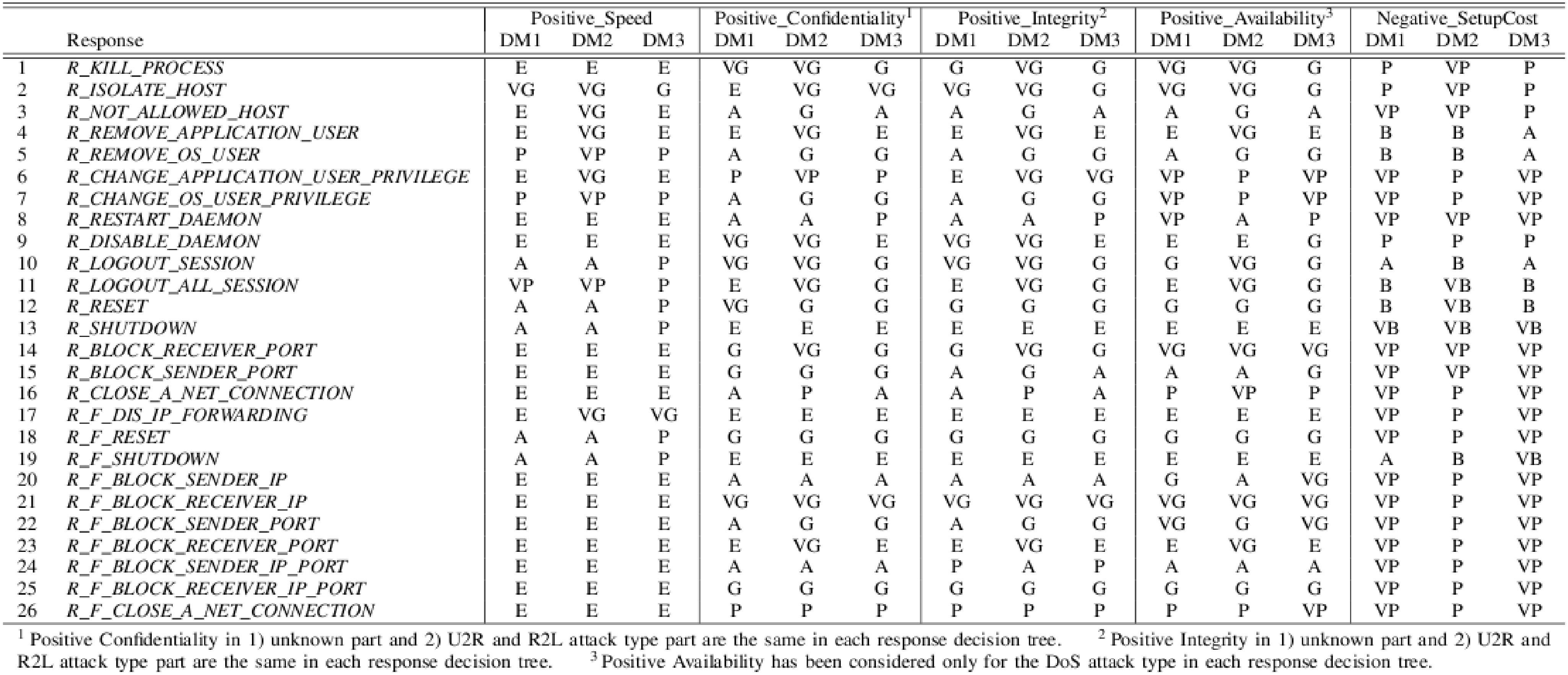


| | External DMZ | | | General Subnet | | | Accounting Subnet | | | Production Subnet | | | Accounting Desktop Subnet | | | Production Desktop Subnet | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Response | DM1 | DM2 | DM3 | DM1 | DM2 | DM3 | DM1 | DM2 | DM3 | DM1 | DM2 | DM3 | DM1 | DM2 | DM3 | DM1 | DM2 | DM3 |
| C1: Positive_Confidentiality | VH | H | VH | H | MH | MH | VH | VH | H | L | ML | L | M | MH | M | L | L | L |
| C2: Positive_Integrity | VH | H | VH | H | MH | H | VH | VH | H | ML | ML | L | M | MH | M | L | L | L |
| C3: Positive_Availability | VH | VH | H | MH | MH | MH | L | ML | L | H | VH | VH | L | L | L | H | VH | VH |
| C4: Positive_Speed | VH | MH | H | MH | M | M | VH | H | H | H | H | H | M | M | M | H | MH | MH |
| C5: Negative_Itself | M | MH | MH | M | M | ML | M | L | L | H | MH | H | L | L | L | M | M | M |
| C6: Negative_Host | L | ML | ML | VH | VH | VH | L | ML | ML | L | ML | ML | L | L | L | M | M | M |
| C7: Negative_Zone | VH | VH | VH | L | ML | ML | VH | VH | VH | VH | VH | VH | L | L | L | M | M | M |
| C8: Negative_NetworkUser | VH | VH | VH | H | H | MH | L | M | M | VH | VH | VH | L | L | L | M | M | M |
| C9: Negative_LocalUser | M | MH | MH | M | MH | MH | ML | ML | ML | ML | ML | ML | L | L | L | L | L | L |
| C10: Negative_SetupCost | VH | H | MH | M | M | M | L | L | M | H | H | MH | L | VL | L | M | M | M |



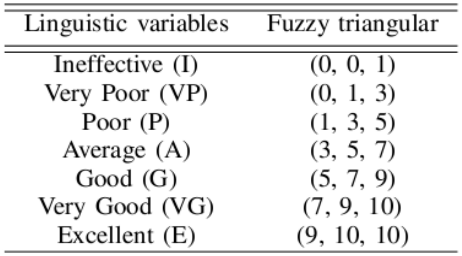
| Linguistic variables | Fuzzy triangular |
|---|---|
| Very low (VL) | (0, 0, 0.1) |
| Low (L) | (0, 0.1, 0.3) |
| Medium low (ML) | (0.1, 0.3, 0.5) |
| Medium (M) | (0.3, 0.5, 0.7) |
| Medium high (MH) | (0.5, 0.7, 0.9) |
| High (H) | (0.7, 0.9, 1.0) |
| Very high (VH) | (0.9, 1.0, 1.0) |

# Step2 ) Assess static criteria

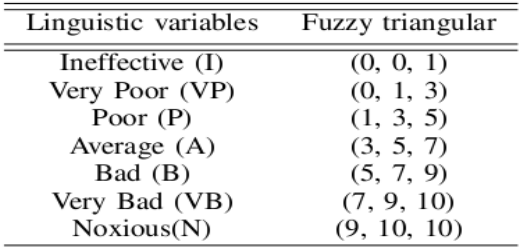


| | | Positive_Speed | | | Positive_Confidentiality[1] | | | Positive_Integrity[2] | | | Positive_Availability[3] | | | Negative_SetupCost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Response | DM1 | DM2 | DM3 | DM1 | DM2 | DM3 | DM1 | DM2 | DM3 | DM1 | DM2 | DM3 | DM1 | DM2 | DM3 |
| 1 | R_KILL_PROCESS | E | E | E | VG | VG | G | G | VG | G | VG | VG | G | P | VP | P |
| 2 | R_ISOLATE_HOST | VG | VG | G | E | VG | VG | VG | VG | G | VG | VG | G | P | VP | P |
| 3 | R_NOT_ALLOWED_HOST | E | VG | E | A | G | A | A | G | A | A | G | A | VP | VP | P |
| 4 | R_REMOVE_APPLICATION_USER | E | VG | E | E | VG | E | E | VG | E | E | VG | E | B | B | A |
| 5 | R_REMOVE_OS_USER | P | VP | P | A | G | G | A | G | G | A | G | G | B | B | A |
| 6 | R_CHANGE_APPLICATION_USER_PRIVILEGE | E | VG | E | P | VP | P | E | VG | VG | VP | P | VP | VP | P | VP |
| 7 | R_CHANGE_OS_USER_PRIVILEGE | P | VP | P | A | G | G | A | G | G | VP | P | VP | VP | P | VP |
| 8 | R_RESTART_DAEMON | E | E | E | A | A | P | A | A | P | VP | A | P | VP | VP | VP |
| 9 | R_DISABLE_DAEMON | E | E | E | VG | VG | E | VG | VG | E | E | E | G | P | P | P |
| 10 | R_LOGOUT_SESSION | A | A | P | VG | VG | G | VG | VG | G | G | VG | G | A | B | A |
| 11 | R_LOGOUT_ALL_SESSION | VP | VP | P | E | VG | G | E | VG | G | E | VG | G | B | VB | B |
| 12 | R_RESET | A | A | P | VG | G | G | G | G | G | G | G | G | B | VB | B |
| 13 | R_SHUTDOWN | A | A | P | E | E | E | E | E | E | E | E | E | VB | VB | VB |
| 14 | R_BLOCK_RECEIVER_PORT | E | E | E | G | VG | G | G | VG | G | VG | VG | VG | VP | VP | VP |
| 15 | R_BLOCK_SENDER_PORT | E | E | E | G | G | G | A | G | A | A | A | G | VP | VP | VP |
| 16 | R_CLOSE_A_NET_CONNECTION | E | E | E | A | P | A | A | P | A | P | VP | P | VP | P | VP |
| 17 | R_F_DIS_IP_FORWARDING | E | VG | VG | E | E | E | E | E | E | E | E | E | VP | P | VP |
| 18 | R_F_RESET | A | A | P | G | G | G | G | G | G | G | G | G | VP | P | VP |
| 19 | R_F_SHUTDOWN | A | A | P | E | E | E | E | E | E | E | E | E | A | B | VB |
| 20 | R_F_BLOCK_SENDER_IP | E | E | E | A | A | A | A | A | A | G | A | VG | VP | P | VP |
| 21 | R_F_BLOCK_RECEIVER_IP | E | E | E | VG | VG | VG | VG | VG | VG | VG | VG | VG | VP | P | VP |
| 22 | R_F_BLOCK_SENDER_PORT | E | E | E | A | G | G | A | G | G | VG | G | VG | VP | P | VP |
| 23 | R_F_BLOCK_RECEIVER_PORT | E | E | E | E | VG | E | E | VG | E | E | VG | E | VP | P | VP |
| 24 | R_F_BLOCK_SENDER_IP_PORT | E | E | E | A | A | A | P | A | P | A | A | A | VP | P | VP |
| 25 | R_F_BLOCK_RECEIVER_IP_PORT | E | E | E | G | G | G | G | G | G | G | G | G | VP | P | VP |
| 26 | R_F_CLOSE_A_NET_CONNECTION | E | E | E | P | P | P | P | P | P | P | P | VP | VP | P | VP |

[1] Positive Confidentiality in 1) unknown part and 2) U2R and R2L attack type part are the same in each response decision tree. [2] Positive Integrity in 1) unknown part and 2) U2R and R2L attack type part are the same in each response decision tree. [3] Positive Availability has been considered only for the DoS attack type in each response decision tree.

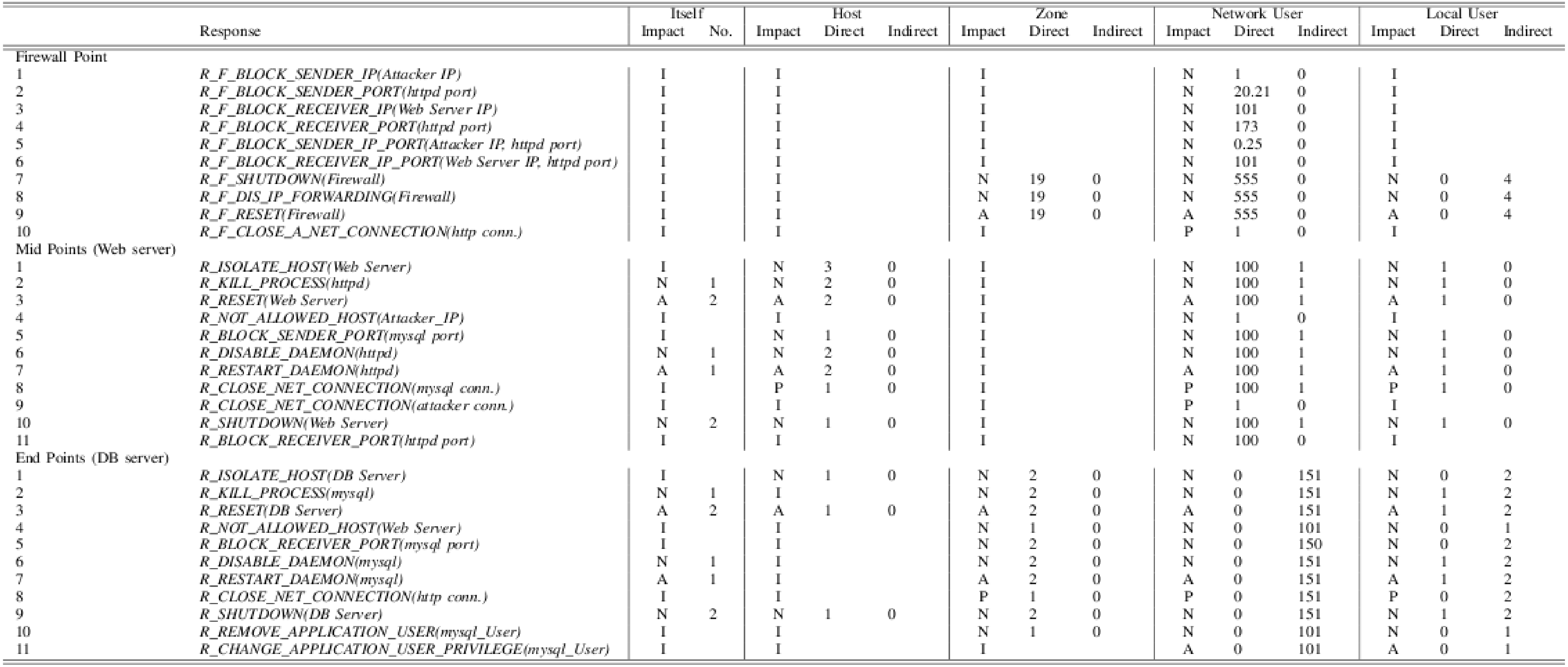


| Linguistic variables | Fuzzy triangular |
|---|---|
| Ineffective (I) | (0, 0, 1) |
| Very Poor (VP) | (0, 1, 3) |
| Poor (P) | (1, 3, 5) |
| Average (A) | (3, 5, 7) |
| Good (G) | (5, 7, 9) |
| Very Good (VG) | (7, 9, 10) |
| Excellent (E) | (9, 10, 10) |



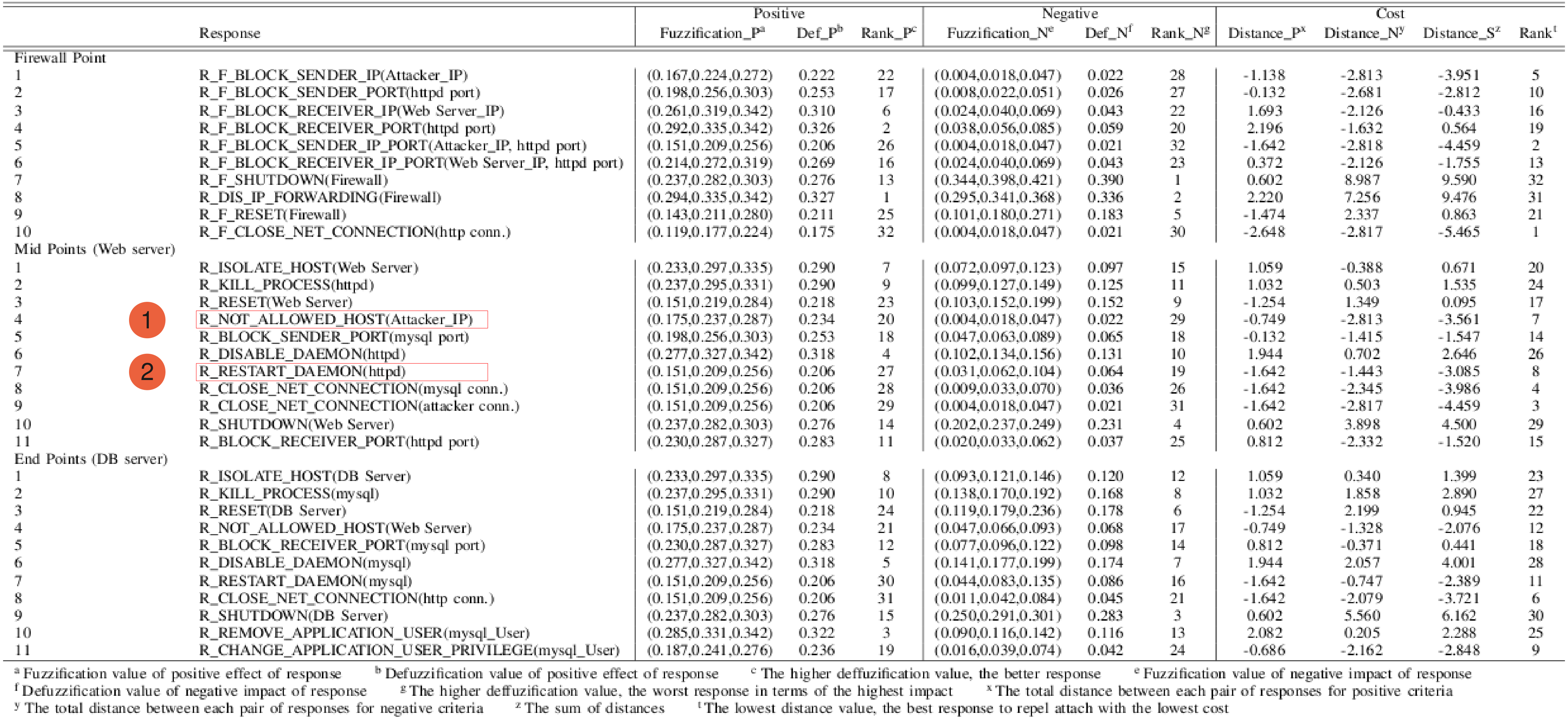
| Linguistic variables | Fuzzy triangular |
|---|---|
| Ineffective (I) | (0, 0, 1) |
| Very Poor (VP) | (0, 1, 3) |
| Poor (P) | (1, 3, 5) |
| Average (A) | (3, 5, 7) |
| Bad (B) | (5, 7, 9) |
| Very Bad (VB) | (7, 9, 10) |
| Noxious(N) | (9, 10, 10) |

# Step 3) The value of negative criteria for outside attacker



| | | Itself | | Host | | | Zone | | | Network User | | | Local User | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Response | Impact | No. | Impact | Direct | Indirect | Impact | Direct | Indirect | Impact | Direct | Indirect | Impact | Direct | Indirect |
| Firewall Point | | | | | | | | | | | | | | | |
| 1 | *R_F_BLOCK_SENDER_IP(Attacker IP)* | I | | I | | | I | | | N | 1 | 0 | I | | |
| 2 | *R_F_BLOCK_SENDER_PORT(httpd port)* | I | | I | | | I | | | N | 20.21 | 0 | I | | |
| 3 | *R_F_BLOCK_RECEIVER_IP(Web Server IP)* | I | | I | | | I | | | N | 101 | 0 | I | | |
| 4 | *R_F_BLOCK_RECEIVER_PORT(httpd port)* | I | | I | | | I | | | N | 173 | 0 | I | | |
| 5 | *R_F_BLOCK_SENDER_IP_PORT(Attacker IP, httpd port)* | I | | I | | | I | | | N | 0.25 | 0 | I | | |
| 6 | *R_F_BLOCK_RECEIVER_IP_PORT(Web Server IP, httpd port)* | I | | I | | | I | | | N | 101 | 0 | I | | |
| 7 | *R_F_SHUTDOWN(Firewall)* | I | | I | | | N | 19 | 0 | N | 555 | 0 | N | 0 | 4 |
| 8 | *R_F_DIS_IP_FORWARDING(Firewall)* | I | | I | | | N | 19 | 0 | N | 555 | 0 | N | 0 | 4 |
| 9 | *R_F_RESET(Firewall)* | I | | I | | | A | 19 | 0 | A | 555 | 0 | A | 0 | 4 |
| 10 | *R_F_CLOSE_A_NET_CONNECTION(http conn.)* | I | | I | | | I | | | P | 1 | 0 | I | | |
| Mid Points (Web server) | | | | | | | | | | | | | | | |
| 1 | *R_ISOLATE_HOST(Web Server)* | I | | N | 3 | 0 | I | | | N | 100 | 1 | N | 1 | 0 |
| 2 | *R_KILL_PROCESS(httpd)* | N | 1 | N | 2 | 0 | I | | | N | 100 | 1 | N | 1 | 0 |
| 3 | *R_RESET(Web Server)* | A | 2 | A | 2 | 0 | I | | | A | 100 | 1 | A | 1 | 0 |
| 4 | *R_NOT_ALLOWED_HOST(Attacker_IP)* | I | | I | | | I | | | N | 1 | 0 | I | | |
| 5 | *R_BLOCK_SENDER_PORT(mysql port)* | I | | N | 1 | 0 | I | | | N | 100 | 1 | N | 1 | 0 |
| 6 | *R_DISABLE_DAEMON(httpd)* | N | 1 | N | 2 | 0 | I | | | N | 100 | 1 | N | 1 | 0 |
| 7 | *R_RESTART_DAEMON(httpd)* | A | 1 | A | 2 | 0 | I | | | A | 100 | 1 | A | 1 | 0 |
| 8 | *R_CLOSE_NET_CONNECTION(mysql conn.)* | I | | P | 1 | 0 | I | | | P | 100 | 1 | P | 1 | 0 |
| 9 | *R_CLOSE_NET_CONNECTION(attacker conn.)* | I | | I | | | I | | | P | 1 | 0 | I | | |
| 10 | *R_SHUTDOWN(Web Server)* | N | 2 | N | 1 | 0 | I | | | N | 100 | 1 | N | 1 | 0 |
| 11 | *R_BLOCK_RECEIVER_PORT(httpd port)* | I | | I | | | I | | | N | 100 | 0 | I | | |
| End Points (DB server) | | | | | | | | | | | | | | | |
| 1 | *R_ISOLATE_HOST(DB Server)* | I | | N | 1 | 0 | N | 2 | 0 | N | 0 | 151 | N | 0 | 2 |
| 2 | *R_KILL_PROCESS(mysql)* | N | 1 | I | | | N | 2 | 0 | N | 0 | 151 | N | 1 | 2 |
| 3 | *R_RESET(DB Server)* | A | 2 | A | 1 | 0 | A | 2 | 0 | A | 0 | 151 | A | 1 | 2 |
| 4 | *R_NOT_ALLOWED_HOST(Web Server)* | I | | I | | | N | 1 | 0 | N | 0 | 101 | N | 0 | 1 |
| 5 | *R_BLOCK_RECEIVER_PORT(mysql port)* | I | | I | | | N | 2 | 0 | N | 0 | 150 | N | 0 | 2 |
| 6 | *R_DISABLE_DAEMON(mysql)* | N | 1 | I | | | N | 2 | 0 | N | 0 | 151 | N | 1 | 2 |
| 7 | *R_RESTART_DAEMON(mysql)* | A | 1 | I | | | A | 2 | 0 | A | 0 | 151 | A | 1 | 2 |
| 8 | *R_CLOSE_NET_CONNECTION(http conn.)* | I | | I | | | P | 1 | 0 | P | 0 | 151 | P | 0 | 2 |
| 9 | *R_SHUTDOWN(DB Server)* | N | 2 | N | 1 | 0 | N | 2 | 0 | N | 0 | 151 | N | 1 | 2 |
| 10 | *R_REMOVE_APPLICATION_USER(mysql_User)* | I | | I | | | N | 1 | 0 | N | 0 | 101 | N | 0 | 1 |
| 11 | *R_CHANGE_APPLICATION_USER_PRIVILEGE(mysql_User)* | I | | I | | | I | | | A | 0 | 101 | A | 0 | 1 |

# Step 4) The results for outside attacker



| | | Positive | | | Negative | | | Cost | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Response | Fuzzification_P[a] | Def_P[b] | Rank_P[c] | Fuzzification_N[e] | Def_N[f] | Rank_N[g] | Distance_P[x] | Distance_N[y] | Distance_S[z] | Rank[t] |
| Firewall Point | | | | | | | | | | | |
| 1 | R_F_BLOCK_SENDER_IP(Attacker_IP) | (0.167,0.224,0.272) | 0.222 | 22 | (0.004,0.018,0.047) | 0.022 | 28 | -1.138 | -2.813 | -3.951 | 5 |
| 2 | R_F_BLOCK_SENDER_PORT(httpd port) | (0.198,0.256,0.303) | 0.253 | 17 | (0.008,0.022,0.051) | 0.026 | 27 | -0.132 | -2.681 | -2.812 | 10 |
| 3 | R_F_BLOCK_RECEIVER_IP(Web Server_IP) | (0.261,0.319,0.342) | 0.310 | 6 | (0.024,0.040,0.069) | 0.043 | 22 | 1.693 | -2.126 | -0.433 | 16 |
| 4 | R_F_BLOCK_RECEIVER_PORT(httpd port) | (0.292,0.335,0.342) | 0.326 | 2 | (0.038,0.056,0.085) | 0.059 | 20 | 2.196 | -1.632 | 0.564 | 19 |
| 5 | R_F_BLOCK_SENDER_IP_PORT(Attacker_IP, httpd port) | (0.151,0.209,0.256) | 0.206 | 26 | (0.004,0.018,0.047) | 0.021 | 32 | -1.642 | -2.818 | -4.459 | 2 |
| 6 | R_F_BLOCK_RECEIVER_IP_PORT(Web Server_IP, httpd port) | (0.214,0.272,0.319) | 0.269 | 16 | (0.024,0.040,0.069) | 0.043 | 23 | 0.372 | -2.126 | -1.755 | 13 |
| 7 | R_F_SHUTDOWN(Firewall) | (0.237,0.282,0.303) | 0.276 | 13 | (0.344,0.398,0.421) | 0.390 | 1 | 0.602 | 8.987 | 9.590 | 32 |
| 8 | R_DIS_IP_FORWARDING(Firewall) | (0.294,0.335,0.342) | 0.327 | 1 | (0.295,0.341,0.368) | 0.336 | 2 | 2.220 | 7.256 | 9.476 | 31 |
| 9 | R_F_RESET(Firewall) | (0.143,0.211,0.280) | 0.211 | 25 | (0.101,0.180,0.271) | 0.183 | 5 | -1.474 | 2.337 | 0.863 | 21 |
| 10 | R_F_CLOSE_NET_CONNECTION(http conn.) | (0.119,0.177,0.224) | 0.175 | 32 | (0.004,0.018,0.047) | 0.021 | 30 | -2.648 | -2.817 | -5.465 | 1 |
| Mid Points (Web server) | | | | | | | | | | | |
| 1 | R_ISOLATE_HOST(Web Server) | (0.233,0.297,0.335) | 0.290 | 7 | (0.072,0.097,0.123) | 0.097 | 15 | 1.059 | -0.388 | 0.671 | 20 |
| 2 | R_KILL_PROCESS(httpd) | (0.237,0.295,0.331) | 0.290 | 9 | (0.099,0.127,0.149) | 0.125 | 11 | 1.032 | 0.503 | 1.535 | 24 |
| 3 | R_RESET(Web Server) | (0.151,0.219,0.284) | 0.218 | 23 | (0.103,0.152,0.199) | 0.152 | 9 | -1.254 | 1.349 | 0.095 | 17 |
| 4 | R_NOT_ALLOWED_HOST(Attacker_IP) | (0.175,0.237,0.287) | 0.234 | 20 | (0.004,0.018,0.047) | 0.022 | 29 | -0.749 | -2.813 | -3.561 | 7 |
| 5 | R_BLOCK_SENDER_PORT(mysql port) | (0.198,0.256,0.303) | 0.253 | 18 | (0.047,0.063,0.089) | 0.065 | 18 | -0.132 | -1.415 | -1.547 | 14 |
| 6 | R_DISABLE_DAEMON(httpd) | (0.277,0.327,0.342) | 0.318 | 4 | (0.102,0.134,0.156) | 0.131 | 10 | 1.944 | 0.702 | 2.646 | 26 |
| 7 | R_RESTART_DAEMON(httpd) | (0.151,0.209,0.256) | 0.206 | 27 | (0.031,0.062,0.104) | 0.064 | 19 | -1.642 | -1.443 | -3.085 | 8 |
| 8 | R_CLOSE_NET_CONNECTION(mysql conn.) | (0.151,0.209,0.256) | 0.206 | 28 | (0.009,0.033,0.070) | 0.036 | 26 | -1.642 | -2.345 | -3.986 | 4 |
| 9 | R_CLOSE_NET_CONNECTION(attacker conn.) | (0.151,0.209,0.256) | 0.206 | 29 | (0.004,0.018,0.047) | 0.021 | 31 | -1.642 | -2.817 | -4.459 | 3 |
| 10 | R_SHUTDOWN(Web Server) | (0.237,0.282,0.303) | 0.276 | 14 | (0.202,0.237,0.249) | 0.231 | 4 | 0.602 | 3.898 | 4.500 | 29 |
| 11 | R_BLOCK_RECEIVER_PORT(httpd port) | (0.230,0.287,0.327) | 0.283 | 11 | (0.020,0.033,0.062) | 0.037 | 25 | 0.812 | -2.332 | -1.520 | 15 |
| End Points (DB server) | | | | | | | | | | | |
| 1 | R_ISOLATE_HOST(DB Server) | (0.233,0.297,0.335) | 0.290 | 8 | (0.093,0.121,0.146) | 0.120 | 12 | 1.059 | 0.340 | 1.399 | 23 |
| 2 | R_KILL_PROCESS(mysql) | (0.237,0.295,0.331) | 0.290 | 10 | (0.138,0.170,0.192) | 0.168 | 8 | 1.032 | 1.858 | 2.890 | 27 |
| 3 | R_RESET(DB Server) | (0.151,0.219,0.284) | 0.218 | 24 | (0.119,0.179,0.236) | 0.178 | 6 | -1.254 | 2.199 | 0.945 | 22 |
| 4 | R_NOT_ALLOWED_HOST(Web Server) | (0.175,0.237,0.287) | 0.234 | 21 | (0.047,0.066,0.093) | 0.068 | 17 | -0.749 | -1.328 | -2.076 | 12 |
| 5 | R_BLOCK_RECEIVER_PORT(mysql port) | (0.230,0.287,0.327) | 0.283 | 12 | (0.077,0.096,0.122) | 0.098 | 14 | 0.812 | -0.371 | 0.441 | 18 |
| 6 | R_DISABLE_DAEMON(mysql) | (0.277,0.327,0.342) | 0.318 | 5 | (0.141,0.177,0.199) | 0.174 | 7 | 1.944 | 2.057 | 4.001 | 28 |
| 7 | R_RESTART_DAEMON(mysql) | (0.151,0.209,0.256) | 0.206 | 30 | (0.044,0.083,0.135) | 0.086 | 16 | -1.642 | -0.747 | -2.389 | 11 |
| 8 | R_CLOSE_NET_CONNECTION(http conn.) | (0.151,0.209,0.256) | 0.206 | 31 | (0.011,0.042,0.084) | 0.045 | 21 | -1.642 | -2.079 | -3.721 | 6 |
| 9 | R_SHUTDOWN(DB Server) | (0.237,0.282,0.303) | 0.276 | 15 | (0.250,0.291,0.301) | 0.283 | 3 | 0.602 | 5.560 | 6.162 | 30 |
| 10 | R_REMOVE_APPLICATION_USER(mysql_User) | (0.285,0.331,0.342) | 0.322 | 3 | (0.090,0.116,0.142) | 0.116 | 13 | 2.082 | 0.205 | 2.288 | 25 |
| 11 | R_CHANGE_APPLICATION_USER_PRIVILEGE(mysql_User) | (0.187,0.241,0.276) | 0.236 | 19 | (0.016,0.039,0.074) | 0.042 | 24 | -0.686 | -2.162 | -2.848 | 9 |

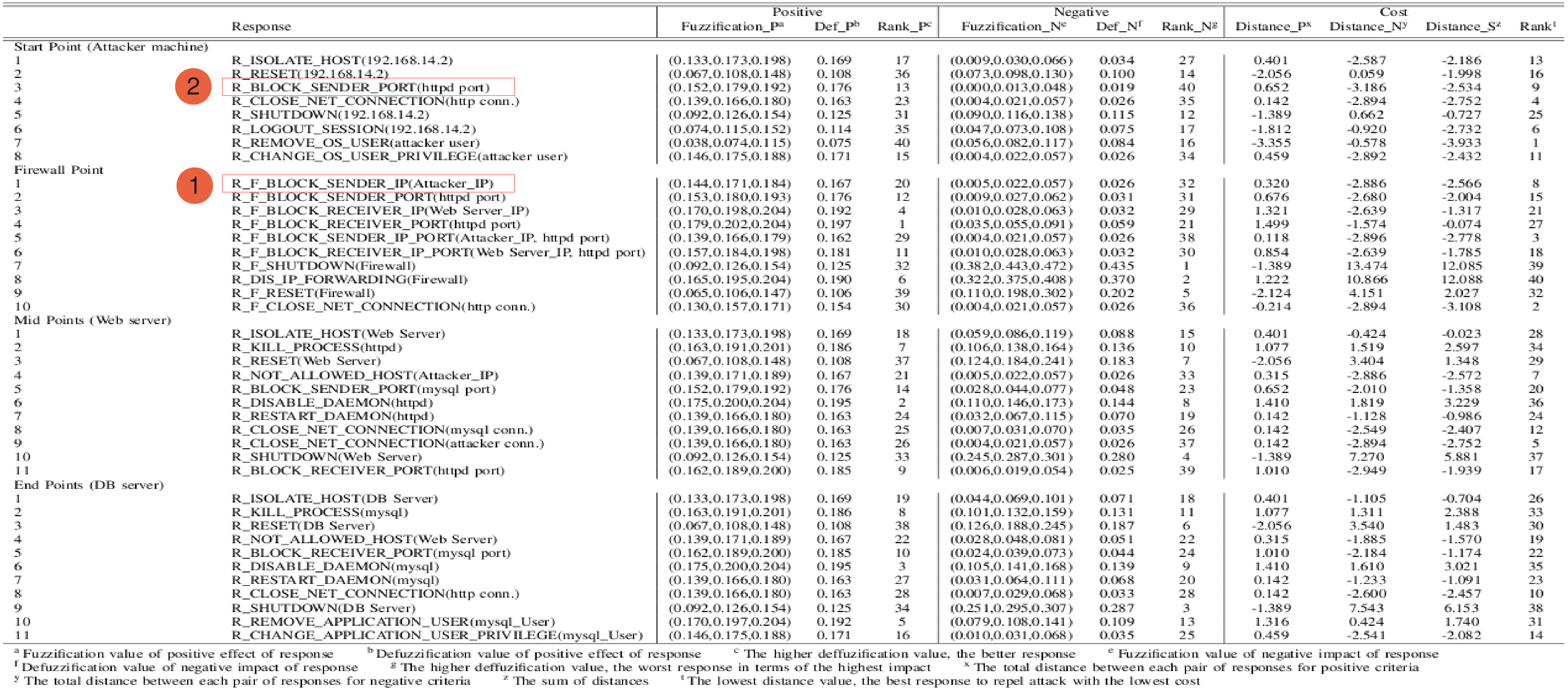
[a] Fuzzification value of positive effect of response [b] Defuzzification value of positive effect of response [c] The higher deffuzification value, the better response [e] Fuzzification value of negative impact of response [f] Defuzzification value of negative impact of response [g] The higher deffuzification value, the worst response in terms of the highest impact [x] The total distance between each pair of responses for positive criteria [y] The total distance between each pair of responses for negative criteria [z] The sum of distances [t] The lowest distance value, the best response to repel attach with the lowest cost

- Ordered List = (R2 , R5 , Rn , · · · , R4 )
- N = k * m
- CR(1) = [(DC * CL * K)/SC] * m + (m * RV)/SC
- CR(i+1) = CR(i)

→

- DC= 60, CL= 0.25, RV= 90, N= 32 (m= 8, k=4), SC=100
- CR(1) = 7
- CR(2) = 8

# Step 4) The results for Internal attacker



| | Response | Positive | | | Negative | | | Cost | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Fuzzification_P[a] | Def_P[b] | Rank_P[c] | Fuzzification_N[e] | Def_N[f] | Rank_N[g] | Distance_P[x] | Distance_N[y] | Distance_S[z] | Rank[t] |
| Start Point (Attacker machine) | | | | | | | | | | | |
| 1 | R_ISOLATE_HOST(192.168.14.2) | (0.133,0.173,0.198) | 0.169 | 17 | (0.009,0.030,0.066) | 0.034 | 27 | 0.401 | -2.587 | -2.186 | 13 |
| 2 | R_RESET(192.168.14.2) | (0.067,0.108,0.148) | 0.108 | 36 | (0.073,0.098,0.130) | 0.100 | 14 | -2.056 | 0.059 | -1.998 | 16 |
| 3 | R_BLOCK_SENDER_PORT(httpd port) | (0.152,0.179,0.192) | 0.176 | 13 | (0.000,0.013,0.048) | 0.019 | 40 | 0.652 | -3.186 | -2.534 | 9 |
| 4 | R_CLOSE_NET_CONNECTION(http conn.) | (0.139,0.166,0.180) | 0.163 | 23 | (0.004,0.021,0.057) | 0.026 | 35 | 0.142 | -2.894 | -2.752 | 4 |
| 5 | R_SHUTDOWN(192.168.14.2) | (0.092,0.126,0.154) | 0.125 | 31 | (0.090,0.116,0.138) | 0.115 | 12 | -1.389 | 0.662 | -0.727 | 25 |
| 6 | R_LOGOUT_SESSION(192.168.14.2) | (0.074,0.115,0.152) | 0.114 | 35 | (0.047,0.073,0.108) | 0.075 | 17 | -1.812 | -0.920 | -2.732 | 6 |
| 7 | R_REMOVE_OS_USER(attacker user) | (0.038,0.074,0.115) | 0.075 | 40 | (0.056,0.082,0.117) | 0.084 | 16 | -3.355 | -0.578 | -3.933 | 1 |
| 8 | R_CHANGE_OS_USER_PRIVILEGE(attacker user) | (0.146,0.175,0.188) | 0.171 | 15 | (0.004,0.022,0.057) | 0.026 | 34 | 0.459 | -2.892 | -2.432 | 11 |
| Firewall Point | | | | | | | | | | | |
| 1 | R_F_BLOCK_SENDER_IP(Attacker_IP) | (0.144,0.171,0.184) | 0.167 | 20 | (0.005,0.022,0.057) | 0.026 | 32 | 0.320 | -2.886 | -2.566 | 8 |
| 2 | R_F_BLOCK_SENDER_PORT(httpd port) | (0.153,0.180,0.193) | 0.176 | 12 | (0.009,0.027,0.062) | 0.031 | 31 | 0.676 | -2.680 | -2.004 | 15 |
| 3 | R_F_BLOCK_RECEIVER_IP(Web Server_IP) | (0.170,0.198,0.204) | 0.192 | 4 | (0.010,0.028,0.063) | 0.032 | 29 | 1.321 | -2.639 | -1.317 | 21 |
| 4 | R_F_BLOCK_RECEIVER_PORT(httpd port) | (0.179,0.202,0.204) | 0.197 | 1 | (0.035,0.055,0.091) | 0.059 | 21 | 1.499 | -1.574 | -0.074 | 27 |
| 5 | R_F_BLOCK_SENDER_IP_PORT(Attacker_IP, httpd port) | (0.139,0.166,0.179) | 0.162 | 29 | (0.004,0.021,0.057) | 0.026 | 38 | 0.118 | -2.896 | -2.778 | 3 |
| 6 | R_F_BLOCK_RECEIVER_IP_PORT(Web Server_IP, httpd port) | (0.157,0.184,0.198) | 0.181 | 11 | (0.010,0.028,0.063) | 0.032 | 30 | 0.854 | -2.639 | -1.785 | 18 |
| 7 | R_F_SHUTDOWN(Firewall) | (0.092,0.126,0.154) | 0.125 | 32 | (0.382,0.443,0.472) | 0.435 | 1 | -1.389 | 13.474 | 12.085 | 39 |
| 8 | R_DIS_IP_FORWARDING(Firewall) | (0.165,0.195,0.204) | 0.190 | 6 | (0.322,0.375,0.408) | 0.370 | 2 | 1.222 | 10.866 | 12.088 | 40 |
| 9 | R_F_RESET(Firewall) | (0.065,0.106,0.147) | 0.106 | 39 | (0.110,0.198,0.302) | 0.202 | 5 | -2.124 | 4.151 | 2.027 | 32 |
| 10 | R_F_CLOSE_NET_CONNECTION(http conn.) | (0.130,0.157,0.171) | 0.154 | 30 | (0.004,0.021,0.057) | 0.026 | 36 | -0.214 | -2.894 | -3.108 | 2 |
| Mid Points (Web server) | | | | | | | | | | | |
| 1 | R_ISOLATE_HOST(Web Server) | (0.133,0.173,0.198) | 0.169 | 18 | (0.059,0.086,0.119) | 0.088 | 15 | 0.401 | -0.424 | -0.023 | 28 |
| 2 | R_KILL_PROCESS(httpd) | (0.163,0.191,0.201) | 0.186 | 7 | (0.106,0.138,0.164) | 0.136 | 10 | 1.077 | 1.519 | 2.597 | 34 |
| 3 | R_RESET(Web Server) | (0.067,0.108,0.148) | 0.108 | 37 | (0.124,0.184,0.241) | 0.183 | 7 | -2.056 | 3.404 | 1.348 | 29 |
| 4 | R_NOT_ALLOWED_HOST(Attacker_IP) | (0.139,0.171,0.189) | 0.167 | 21 | (0.005,0.022,0.057) | 0.026 | 33 | 0.315 | -2.886 | -2.572 | 7 |
| 5 | R_BLOCK_SENDER_PORT(mysql port) | (0.152,0.179,0.192) | 0.176 | 14 | (0.028,0.044,0.077) | 0.048 | 23 | 0.652 | -2.010 | -1.358 | 20 |
| 6 | R_DISABLE_DAEMON(httpd) | (0.175,0.200,0.204) | 0.195 | 2 | (0.110,0.146,0.173) | 0.144 | 8 | 1.410 | 1.819 | 3.229 | 36 |
| 7 | R_RESTART_DAEMON(httpd) | (0.139,0.166,0.180) | 0.163 | 24 | (0.032,0.067,0.115) | 0.070 | 19 | 0.142 | -1.128 | -0.986 | 24 |
| 8 | R_CLOSE_NET_CONNECTION(mysql conn.) | (0.139,0.166,0.180) | 0.163 | 25 | (0.007,0.031,0.070) | 0.035 | 26 | 0.142 | -2.549 | -2.407 | 12 |
| 9 | R_CLOSE_NET_CONNECTION(attacker conn.) | (0.139,0.166,0.180) | 0.163 | 26 | (0.004,0.021,0.057) | 0.026 | 37 | 0.142 | -2.894 | -2.752 | 5 |
| 10 | R_SHUTDOWN(Web Server) | (0.092,0.126,0.154) | 0.125 | 33 | (0.245,0.287,0.301) | 0.280 | 4 | -1.389 | 7.270 | 5.881 | 37 |
| 11 | R_BLOCK_RECEIVER_PORT(httpd port) | (0.162,0.189,0.200) | 0.185 | 9 | (0.006,0.019,0.054) | 0.025 | 39 | 1.010 | -2.949 | -1.939 | 17 |
| End Points (DB server) | | | | | | | | | | | |
| 1 | R_ISOLATE_HOST(DB Server) | (0.133,0.173,0.198) | 0.169 | 19 | (0.044,0.069,0.101) | 0.071 | 18 | 0.401 | -1.105 | -0.704 | 26 |
| 2 | R_KILL_PROCESS(mysql) | (0.163,0.191,0.201) | 0.186 | 8 | (0.101,0.132,0.159) | 0.131 | 11 | 1.077 | 1.311 | 2.388 | 33 |
| 3 | R_RESET(DB Server) | (0.067,0.108,0.148) | 0.108 | 38 | (0.126,0.188,0.245) | 0.187 | 6 | -2.056 | 3.540 | 1.483 | 30 |
| 4 | R_NOT_ALLOWED_HOST(Web Server) | (0.139,0.171,0.189) | 0.167 | 22 | (0.028,0.048,0.081) | 0.051 | 22 | 0.315 | -1.885 | -1.570 | 19 |
| 5 | R_BLOCK_RECEIVER_PORT(mysql port) | (0.162,0.189,0.200) | 0.185 | 10 | (0.024,0.039,0.073) | 0.044 | 24 | 1.010 | -2.184 | -1.174 | 22 |
| 6 | R_DISABLE_DAEMON(mysql) | (0.175,0.200,0.204) | 0.195 | 3 | (0.105,0.141,0.168) | 0.139 | 9 | 1.410 | 1.610 | 3.021 | 35 |
| 7 | R_RESTART_DAEMON(mysql) | (0.139,0.166,0.180) | 0.163 | 27 | (0.031,0.064,0.111) | 0.068 | 20 | 0.142 | -1.233 | -1.091 | 23 |
| 8 | R_CLOSE_NET_CONNECTION(http conn.) | (0.139,0.166,0.180) | 0.163 | 28 | (0.007,0.029,0.068) | 0.033 | 28 | 0.142 | -2.600 | -2.457 | 10 |
| 9 | R_SHUTDOWN(DB Server) | (0.092,0.126,0.154) | 0.125 | 34 | (0.251,0.295,0.307) | 0.287 | 3 | -1.389 | 7.543 | 6.153 | 38 |
| 10 | R_REMOVE_APPLICATION_USER(mysql_User) | (0.170,0.197,0.204) | 0.192 | 5 | (0.079,0.108,0.141) | 0.109 | 13 | 1.316 | 0.424 | 1.740 | 31 |
| 11 | R_CHANGE_APPLICATION_USER_PRIVILEGE(mysql_User) | (0.146,0.175,0.188) | 0.171 | 16 | (0.010,0.031,0.068) | 0.035 | 25 | 0.459 | -2.541 | -2.082 | 14 |

[a] Fuzzification value of positive effect of response
[b] Defuzzification value of positive effect of response
[c] The higher deffuzification value, the better response
[e] Fuzzification value of negative impact of response
[f] Defuzzification value of negative impact of response
[g] The higher deffuzification value, the worst response in terms of the highest impact
[x] The total distance between each pair of responses for positive criteria
[y] The total distance between each pair of responses for negative criteria
[z] The sum of distances
[t] The lowest distance value, the best response to repel attack with the lowest cost

- Ordered List = (R2 , R5 , Rn , · · · , R4 )
- N = k * m
- CR(1) = [(DC * CL * K)/SC] * m + (m * RV)/SC
- CR(i+1) = CR(i)

→

- DC= 60, CL= 0.25, RV= 83, N= 40 (m= 10, k=4), SC=100
- CR(1) = 8
- CR(2) = 9

# Future Work

- Complete the implementation of new architecture of IRS
- Connect *Response component* to the *Risk assessment* and *Prediction component*
- Evaluate all components with more scenarios of multi-step attack

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