Monthly Report

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Outlines

Multiple Models for Risk Assessment

Simulation

Task Planning

Multiple Models for Risk Assessment

Seven Factors about the Risk

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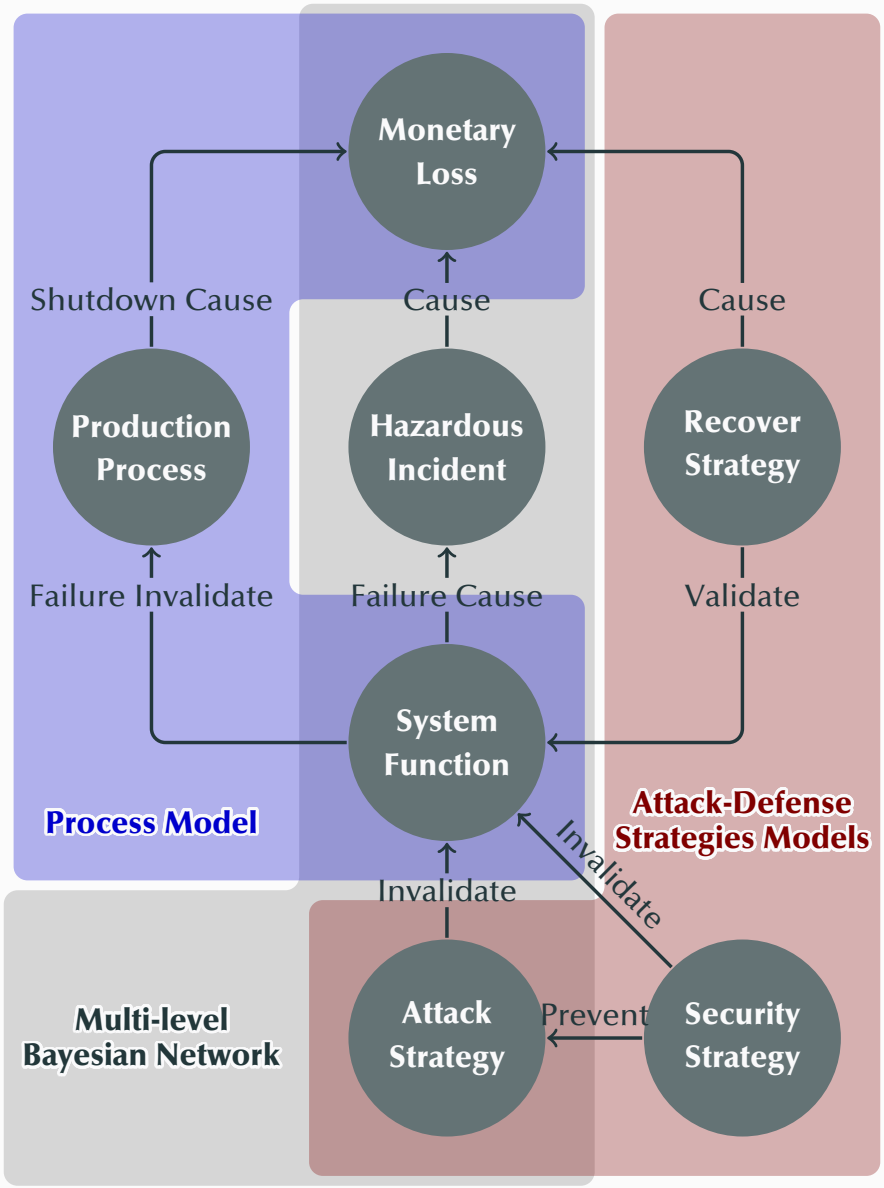
- **Hazardous Incident** refers to the unexpected incident which will cause monetary loss of ICSs.
- **Production Process** refers a manufacturing step which is a part of in a production chain.
- **Monetary Loss** is the sum of the loss caused by malicious attacks, the loss of production process shutdown, and the enforcement cost of defense strategy.

The relationships amongst these seven factors

- The attack strategy can invalidate the system function.



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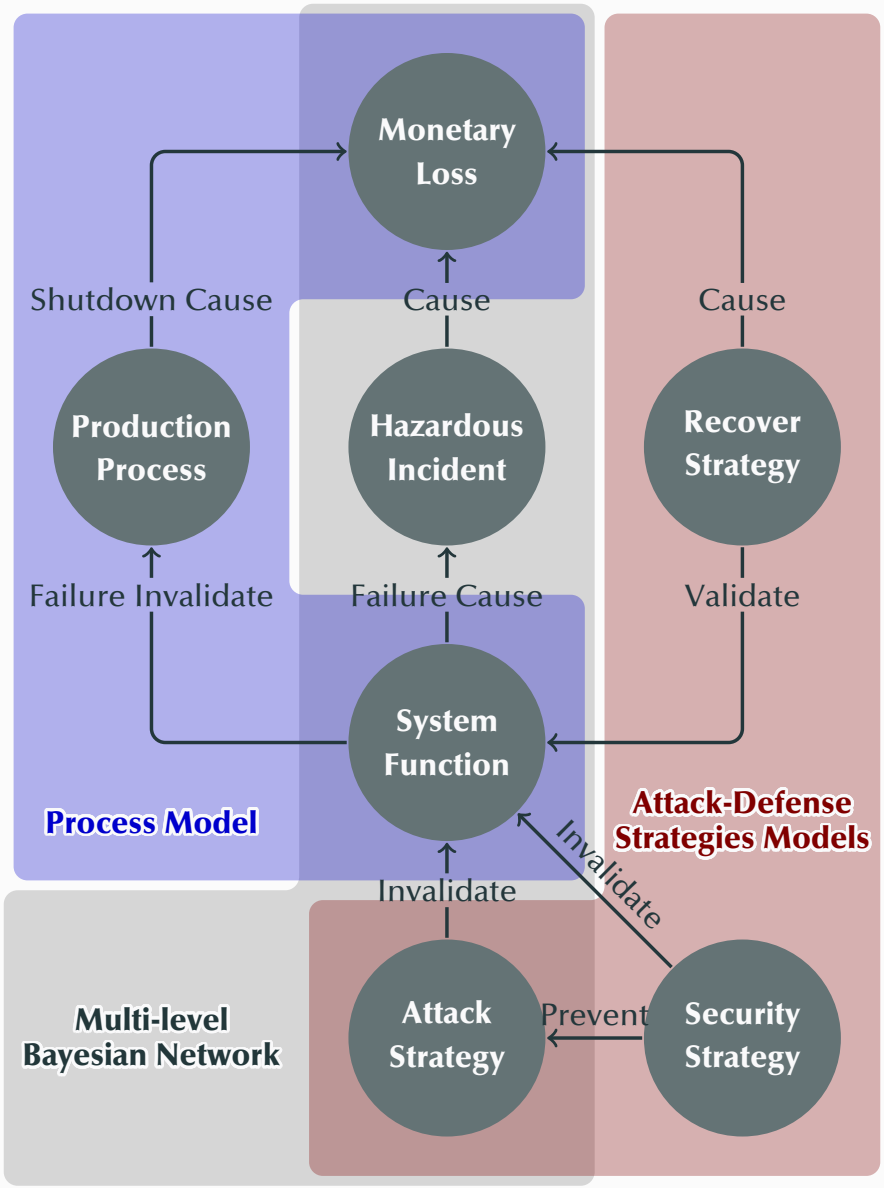

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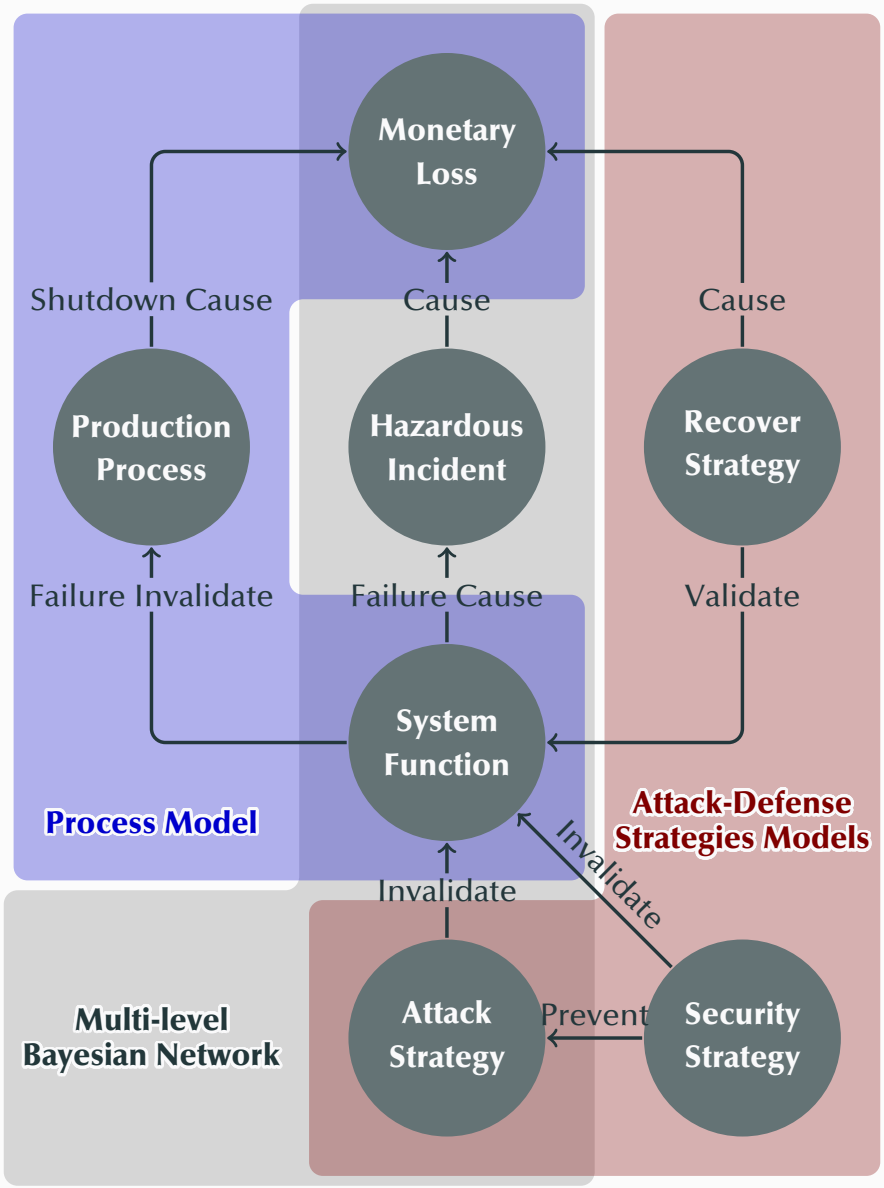

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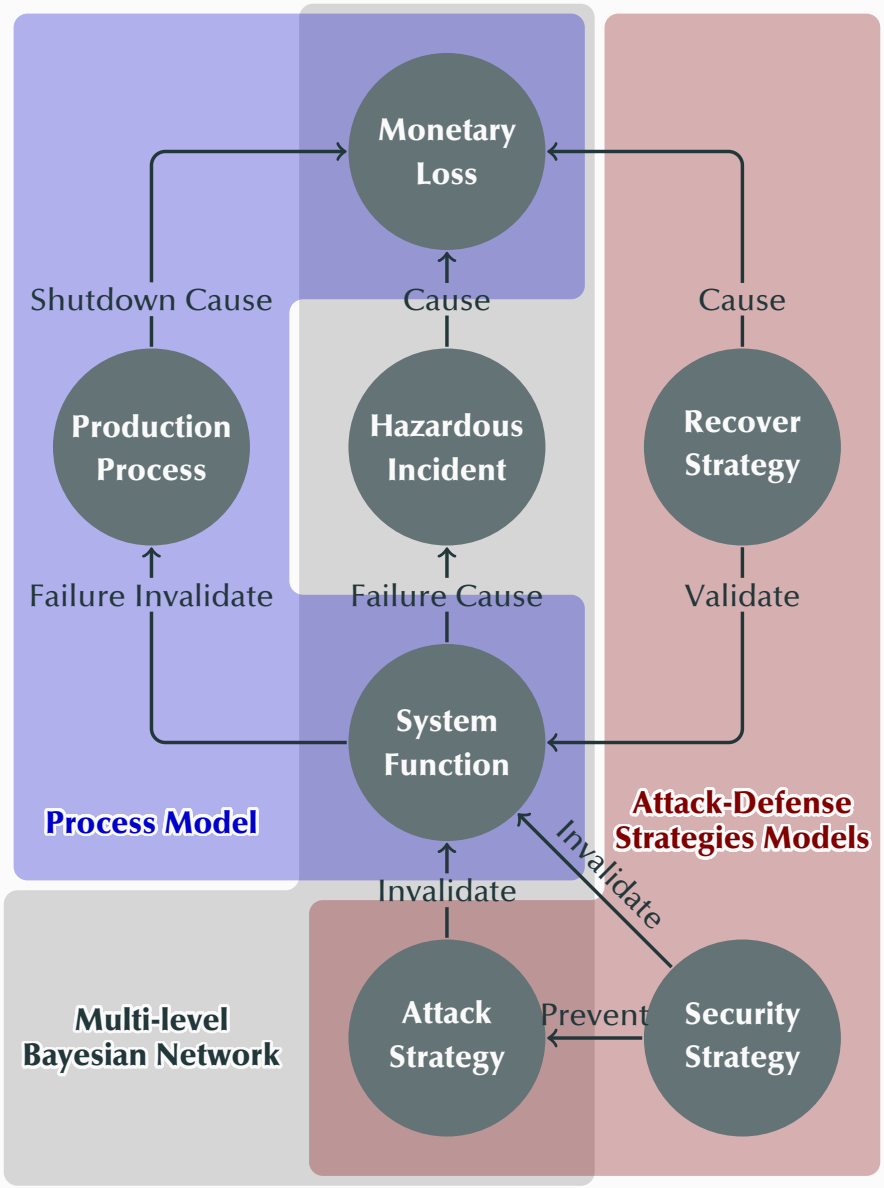

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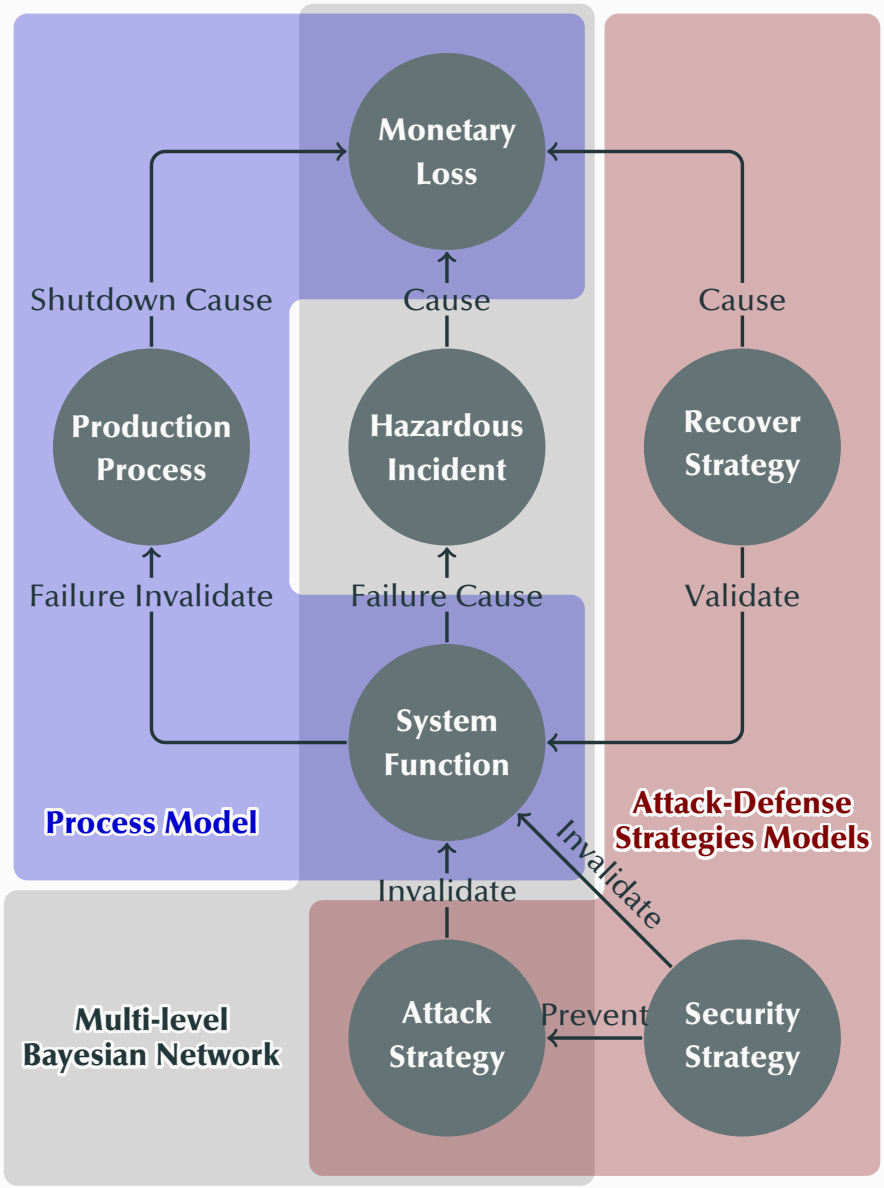
- The security strategy will prevent the enforcement of attack strategy, but its side effect is that it may invalidate the system function.
- The recover strategy has ability of recovering the failed system function, and it has the enforcement cost.



Multiple Models of Risk Assessment for ICSs

The following three models are used to described the relationships amongst these seven factors.

- The **multi-level Bayesian network**, involves attack strategy, system function, hazardous incident, and monetary loss. This model uses Bayesian network to describe the causal relationship of these four factors and it can be used to assess the risk caused by the malicious attacks.

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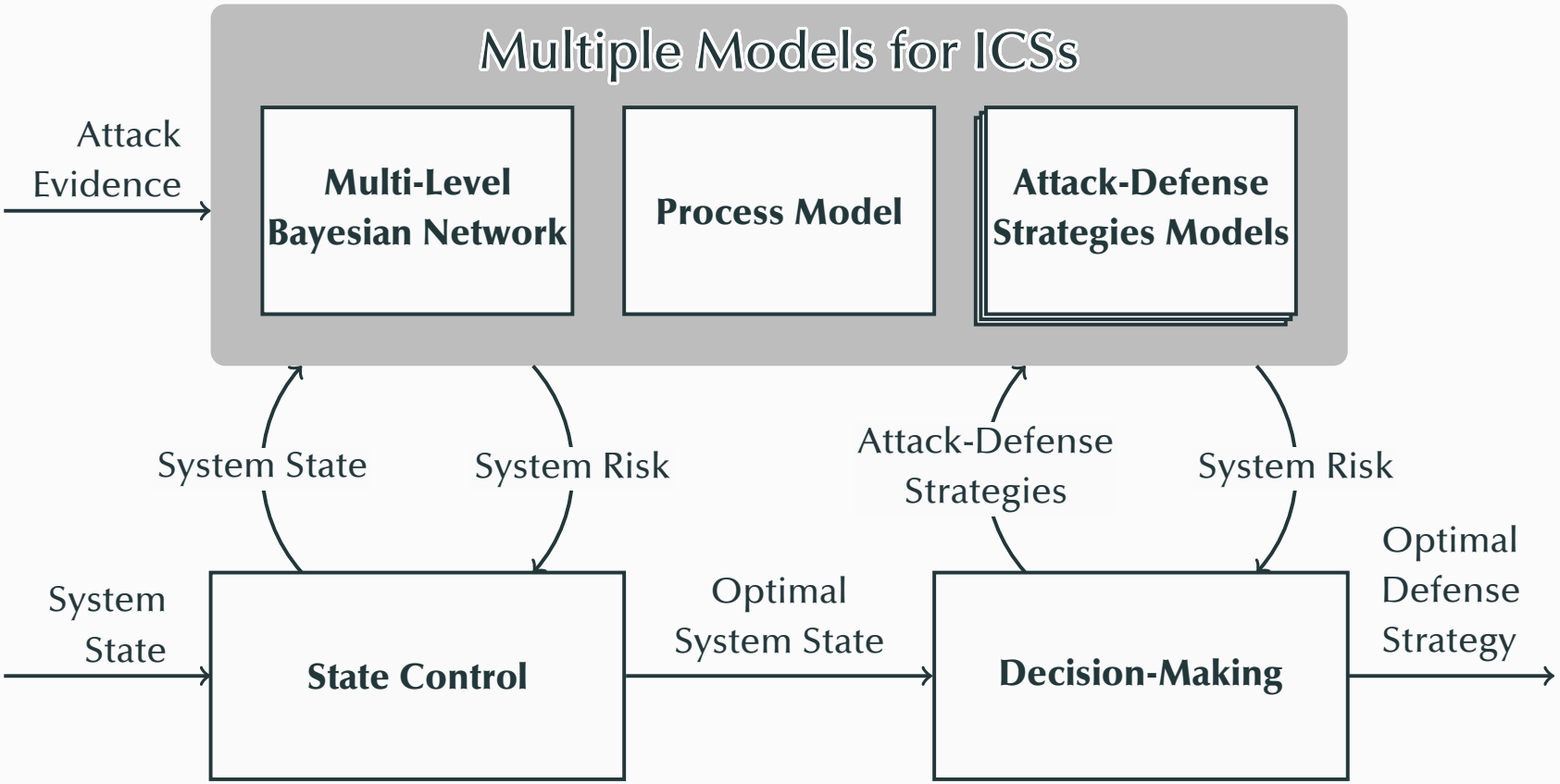
- The **process model** involves system functions, production process, and monetary loss. It can be used to calculate the risk cause by the degradation of control system.
- The **attack-defense strategies models**, include attack strategy model, security strategy model, and recover strategy model. These three models contain the relationships amongst these three kinds of strategies and system functions, and they can be used to quantify the cost and benefit of attack-defense strategies.

Chemical Reactor Control System



Simulation

A Failed Attempt — C++ Version

I had implemented the class `Node` and the class `BayesianNetwork` with C++ language.

The inference of Bayesian network is provided by `dlib`, which is a C++ library. But the computation time of the Bayesian network inference is 30 times slower than that of the implementation by Matlab.

Runtime Environment	Computation Time(ms)
C++ in Debug Mode	40,000
C++ in Release Mode	3,600
Matlab	90

The Matlab has optimized the algorithm for a large amount of computation.

Common Classes

For the simulation, the following common classes are designed:

class `Node` ,

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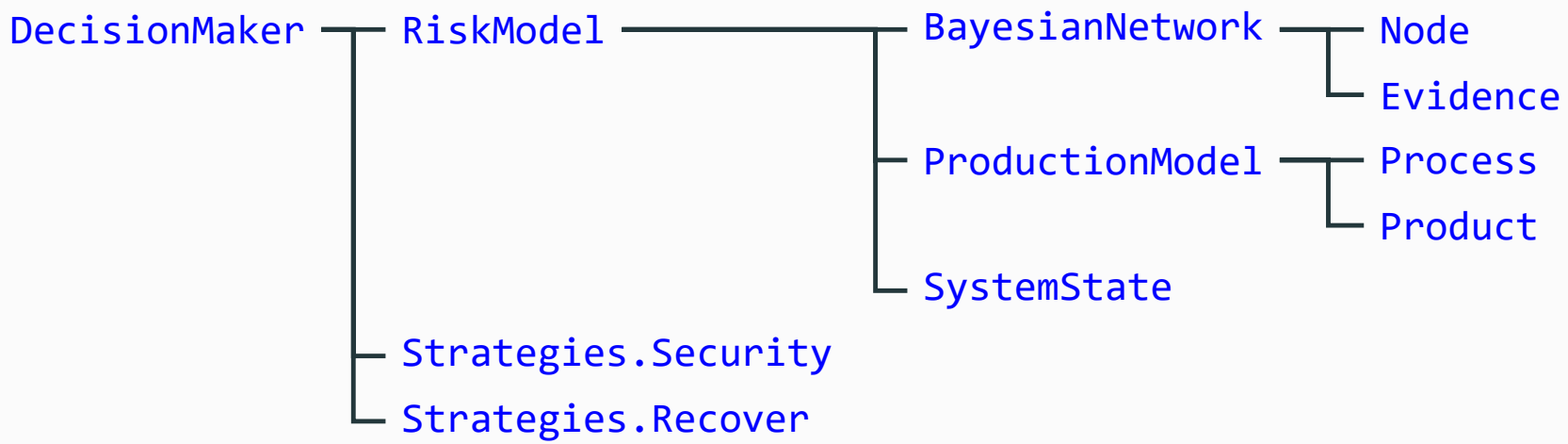
class `Node`, class `Evidence`, class `BayesianNetwork`, class `Product`, class `Process`, class `ProductionModel`, class `SystemState`, class `RiskModel`, class `Strategies.Security`, class `Strategies.Recover`, and class `DecisionMaker`.

The relationship amongst these classes are shown as follows.



How to Use?

The following example is used to introduce how to use the class `Node` and class `BayesianNetwork` to model and inference the Bayesian network.

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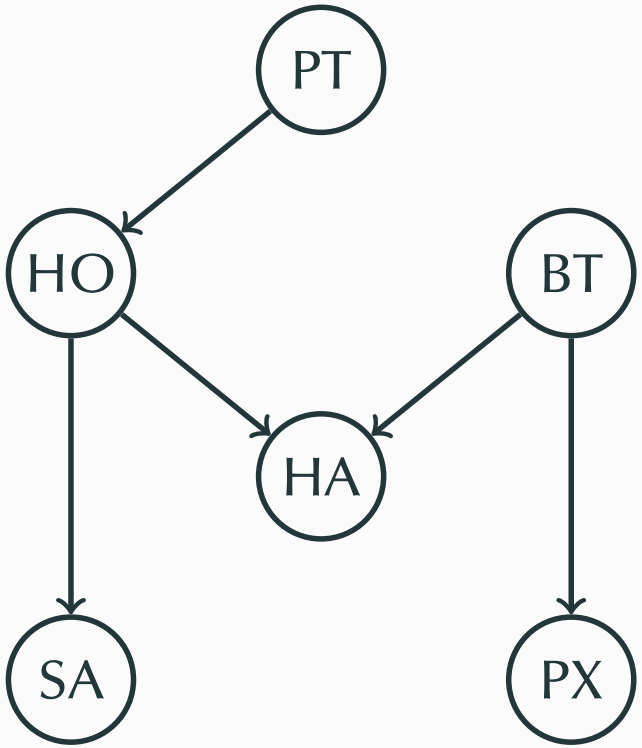

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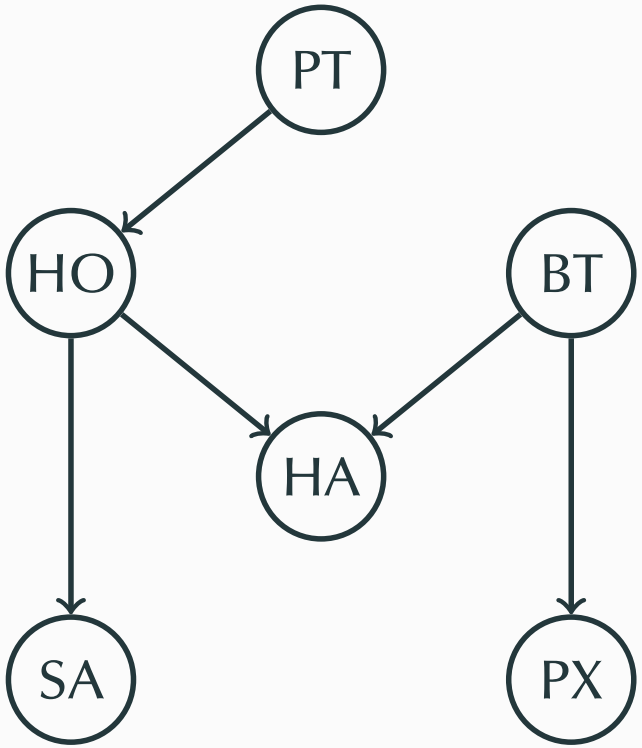


The meanings of nodes are shown as follows.

Symbol	Meaning
PT	Qiqi goes to the Party.
HO	Qiqi has a Hangover.
BT	Qiqi has a Brain Tumor.
HA	Qiqi has a Headache.
SA	Qiqi has an Alcohol Smell.
PX	Qiqi has a Pos Xray.

How to Use?

Step 1, create the nodes of Bayesian network.

```
PT = Classes.Node('Party');
HO = Classes.Node('Hangover');
BT = Classes.Node('Brain Tumor');
HA = Classes.Node('Headache');
SA = Classes.Node('Smell Alcohol');
PX = Classes.Node('Pos Xray');
```

Step 2, set the conditional probabilities of nodes.

```
PT.AddAllParents(... Has no parent node
    0.200);

BT.AddAllParents(... Has no parent node
    0.001);
```

How to Use?

```
12  HO.AddAllParents(PT, ...
13      0.000, ...    F
14      0.700);  %    T
15
16  SA.AddAllParents(HO, ...
17      0.100, ...    F
18      0.800);  %    T
19
20  PX.AddAllParents(BT, ...
21      0.010, ...    F
22      0.980);  %    T
23
24  HA.AddAllParents(HO, BT, ...
25      0.020, ...    F   F
26      0.900, ...    F   T
27      0.700, ...    T   F
28      0.990);  %    T   T
```

How to Use?

Step 3, create the Bayesian network.

```
29 BayesianNetwork = Classes.BayesianNetwork();
```

Step 4, add the nodes into the Bayesian network.

```
30 BayesianNetwork.AddNodes(PT, BT, HO, SA, PX, HA);
```

Step 5, initialize the Bayesian network.

```
31 BayesianNetwork.Initialize();
```

Step 6, infer the Bayesian network.

```
32 BayesianNetwork.Inference();
33 BayesianNetwork.Display(HA);
```

How to Use?

Question: if Qiqi has a Pos Xray (PX), what's the probability that Qiqi has a Brain Tumor (BT)?

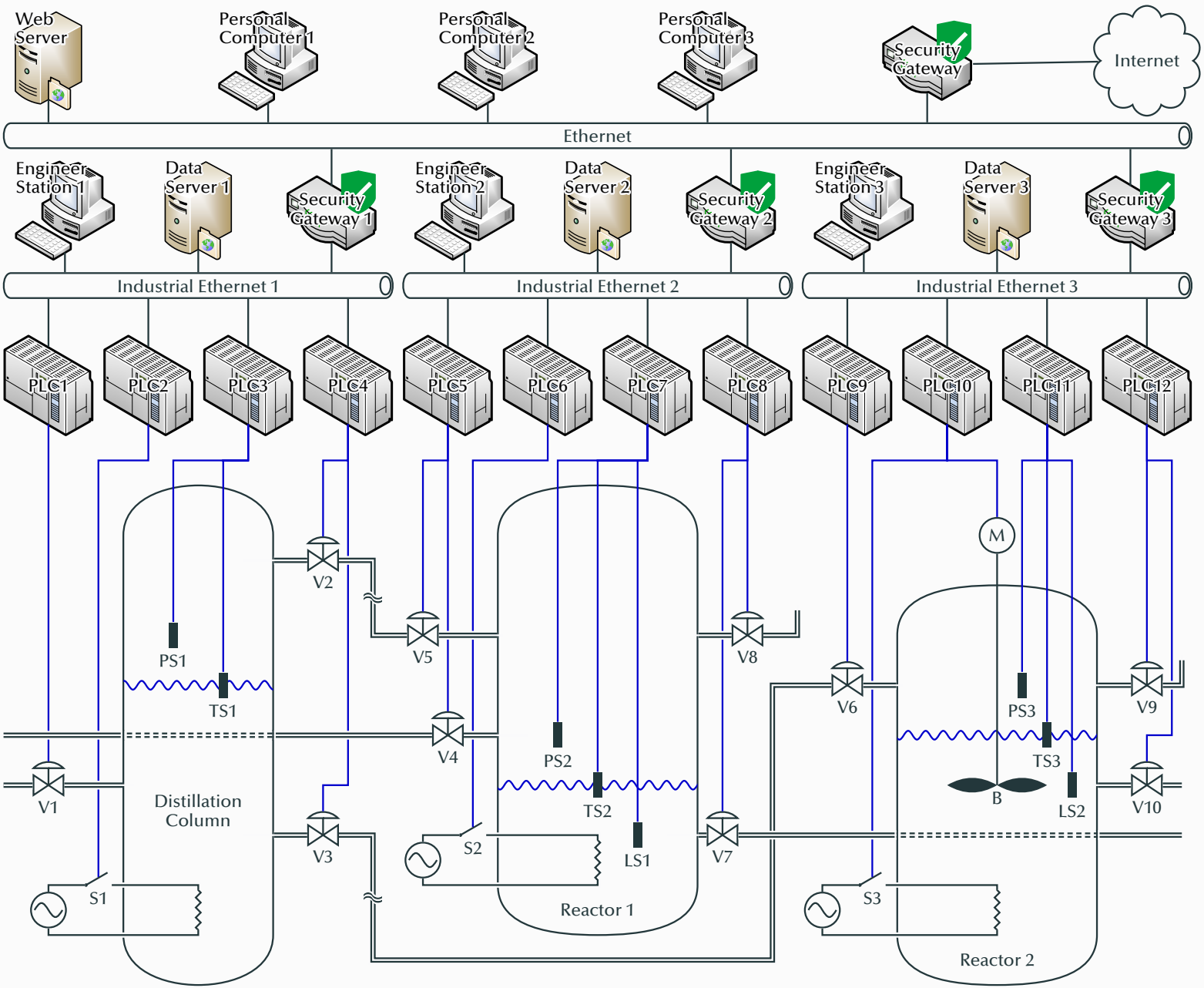
The Matlab codes are shown as follows.

```
34 % Remove all the evidences in the Bayesian network.
35 BayesianNetwork.RemoveEvidences();
36
37 % Add the evidence PX into the evidence list.
38 BayesianNetwork.AddEvidences(PX);
39
40 % Infer the Bayesian network with the evidences.
41 BayesianNetwork.Inference();
42
43 % Show the probability of the node BT.
44 BayesianNetwork.Display(BT);
```

The output of the program is shown as follows.

```
1 P(+Brain Tumor|+Pos Xray) = 0.089335
```

Chemical Reactor Control System



The Analysis of the Chemical Reactor Control System

In this chemical reactor control system, there are 2 semi-product and 2 product which is shown as follows.

Symbol	Type	Description
`s01`	semi-product	the semi-product which is the output from the top of the distillation column
`s02`	semi-product	the semi-product which is the other outputs from the bottom of the distillation column
`s03`	product	the product which is the output from the reactor 1
`s04`	product	the product which is the output from the reactor 2

The Analysis of the Chemical Reactor Control System

The potential attacks are shown as follows.

Symbol	Description	Launch Condition
a01	network scanning of the Ethernet in the management layer	—
a02	vulnerability scanning of the devices in the management layer	launch of a01
a03	buffer overflow attack on the web server	launch of a02
a04	brute force attack on the web server	launch of a02
a05	brute force attack on the personal computer 1	launch of a02
a06	brute force attack on the personal computer 2	launch of a02
a07	brute force attack on the personal computer 3	launch of a02
a08	network scanning of the industrial Ethernet 1 in the control layer	launch of a03, a04, a05, a06, a07

The Analysis of the Chemical Reactor Control System

The potential attacks are shown as follows.

Symbol	Description	Launch Condition
a09	vulnerability scanning of the devices in the industrial Ethernet 1	launch of a08
a10	buffer overflow attack on the data server 1	launch of a09
a11	brute force attack on the data server 1	launch of a09
a12	brute force attack on the engineer station 1	launch of a09
a13	network scanning of the industrial Ethernet 2 in the control layer	launch of a03, a04, a05, a06, a07
a14	vulnerability scanning of the devices in the industrial Ethernet 2	launch of a13
a15	buffer overflow attack on the data server 2	launch of a14
a16	brute force attack on the data server 2	launch of a14

The Analysis of the Chemical Reactor Control System

The potential attacks are shown as follows.

Symbol	Description	Launch Condition
a17	brute force attack on the engineer station 2	launch of a14
a18	network scanning of the industrial Ethernet 3 in the control layer	launch of a03, a04, a05, a06, a07
a19	vulnerability scanning of the devices in the industrial Ethernet 3	launch of a18
a20	buffer overflow attack on the data server 3	launch of a19
a21	brute force attack on the data server 3	launch of a19
a22	brute force attack on the engineer station 3	launch of a19
a23	DoS attack on PLC1	launch of a10, a11, a12
a24	DoS attack on PLC2	launch of a10, a11, a12

The Analysis of the Chemical Reactor Control System

The potential attacks are shown as follows.

Symbol	Description	Launch Condition
a25	DoS attack on PLC3	launch of a10, a11, a12
a26	DoS attack on PLC4	launch of a10, a11, a12
a27	DoS attack on PLC5	launch of a15, a16, a17
a28	DoS attack on PLC6	launch of a15, a16, a17
a29	DoS attack on PLC7	launch of a15, a16, a17
a30	DoS attack on PLC8	launch of a15, a16, a17
a31	DoS attack on PLC9	launch of a20, a21, a22
a32	DoS attack on PLC10	launch of a20, a21, a22

The Analysis of the Chemical Reactor Control System

The potential attacks are shown as follows.

Symbol	Description	Launch Condition
a33	DoS attack on PLC11	launch of a20, a21, a22
a34	DoS attack on PLC12	launch of a20, a21, a22
a35	man-in-the-middle attack on PLC1	launch of a12
a36	man-in-the-middle attack on PLC2	launch of a12
a37	man-in-the-middle attack on PLC3	launch of a12
a38	man-in-the-middle attack on PLC4	launch of a12
a39	man-in-the-middle attack on PLC5	launch of a17
a40	man-in-the-middle attack on PLC6	launch of a17

The Analysis of the Chemical Reactor Control System

The potential attacks are shown as follows.

Symbol	Description	Launch Condition
a41	man-in-the-middle attack on PLC7	launch of a17
a42	man-in-the-middle attack on PLC8	launch of a17
a43	man-in-the-middle attack on PLC9	launch of a22
a44	man-in-the-middle attack on PLC10	launch of a22
a45	man-in-the-middle attack on PLC11	launch of a22
a46	man-in-the-middle attack on PLC12	launch of a22

The Analysis of the Chemical Reactor Control System

The functions of the system are shown as follows.

Symbol	Description	Failure Condition
f01	the temperature control function of distillation column	failure of f03, f05, f06, f07
f02	the pressure control function of distillation column	failure of f04, f06, f08
f03	the traffic control function of V1	launch of a23, a35
f04	the traffic control function of V2	launch of a26, a38
f05	the traffic control function of V3	launch of a26, a38
f06	the switch control function of S1	launch of a24, a36
f07	the temperature sensation function of distillation column	launch of a25, a37
f08	the pressure sensation function of distillation column	launch of a25, a37

The Analysis of the Chemical Reactor Control System

The functions of the system are shown as follows.

Symbol	Description	Failure Condition
f09	the temperature control function of reactor 1	failure of f12, f13, f14, f16, f17
f10	the pressure control function of reactor 1	failure of f15, f16, f18
f11	the level control function of reactor 1	failure of f12, f13, f14, f19
f12	the traffic control function of V4	launch of a27, a39
f13	the traffic control function of V5	launch of a27, a39
f14	the traffic control function of V7	launch of a30, a42
f15	the pressure reducing function of reactor 1	launch of a30, a42
f16	the switch control function of S2	launch of a28, a40

The Analysis of the Chemical Reactor Control System

The functions of the system are shown as follows.

Symbol	Description	Failure Condition
f17	the temperature sensation function of reactor 1	launch of a29, a41
f18	the pressure sensation function of reactor 1	launch of a29, a41
f19	the level sensation function of reactor 1	launch of a29, a41
f20	the temperature control function of reactor 2	failure of f23, f24, f26, f27
f21	the pressure control function of reactor 2	failure of f25, f26, f28
f22	the level control function of reactor 2	failure of f23, f24, f29
f23	the traffic control function of V6	launch of a31, a43
f24	the traffic control function of V10	launch of a34, a46

The Analysis of the Chemical Reactor Control System

The functions of the system are shown as follows.

Symbol	Description	Failure Condition
f25	the pressure reducing function of reactor 2	launch of a34 , a46
f26	the switch control function of S3	launch of a32 , a44
f27	the temperature sensation function of reactor 2	launch of a33 , a45
f28	the pressure sensation function of reactor 2	launch of a33 , a45
f29	the level sensation function of reactor 2	launch of a33 , a45
f30	the mixing function of reactor 2	launch of a32 , a44
f31	the data service of industrial Ethernet 1	some security strategies
f32	the data service of industrial Ethernet 2	some security strategies

The Analysis of the Chemical Reactor Control System

The functions of the system are shown as follows.

Symbol	Description	Failure Condition
f33	the data service of industrial Ethernet 3	some security strategies
f34	the configuration of PLCs of distillation column	some security strategies
f35	the configuration of PLCs of reactor 1	some security strategies
f36	the configuration of PLCs of reactor 2	some security strategies
f37	the data service of the Ethernet	some security strategies
f38	the production scheduling function provided by personal computer 1	some security strategies
f39	the production scheduling function provided by personal computer 2	some security strategies
f40	the production scheduling function provided by personal computer 3	some security strategies

The Analysis of the Chemical Reactor Control System

The functions of the system are shown as follows.

Symbol	Description	Failure Condition
f41	the production scheduling function	failure of f31, f32, f33, f38, f39, f40

The Analysis of the Chemical Reactor Control System

The potential hazardous incident are shown as follows.

Symbol	Description	Location	Inducement
e01	pressure anomaly	distillation column	failure of f02
e02	temperature anomaly	distillation column	failure of f01
e03	traffic of anomaly	distillation column	failure of f03, f04, f05
e04	excessive pressure	reactor 1	failure of f10
e05	low pressure	reactor 1	failure of f10
e06	temperature anomaly	reactor 1	failure of f09
e07	excessive liquid level	reactor 1	failure of f11
e08	low liquid level	reactor 1	failure of f11

The Analysis of the Chemical Reactor Control System

The potential hazardous incident are shown as follows.

Symbol	Description	Location	Inducement
e09	explosion	reactor 1	occurrence of e04
e10	heater dry fired	reactor 1	occurrence of e08
e11	liquid overflow	reactor 1	occurrence of e07
e12	excessive pressure	reactor 2	failure of f21
e13	low pressure	reactor 2	failure of f21
e14	temperature anomaly	reactor 2	failure of f20
e15	excessive liquid level	reactor 2	failure of f22
e16	low liquid level	reactor 2	failure of f22

The Analysis of the Chemical Reactor Control System

The potential hazardous incident are shown as follows.

Symbol	Description	Location	Inducement
e17	explosion	reactor 2	occurrence of e12
e18	heater dry fired	reactor 2	occurrence of e16
e19	liquid overflow	reactor 2	occurrence of e15
e20	blender stop	reactor 2	failure of f30
e21	out of control	distillation column	failure of f34
e22	out of control	reactor 1	failure of f35
e23	out of control	reactor 2	failure of f36
e24	production scheduling error	control layer	failure of f31 , f32 , f33

The Analysis of the Chemical Reactor Control System

The potential hazardous incident are shown as follows.

Symbol	Description	Location	Inducement
e25	production scheduling error	plant	failure of f37

The Analysis of the Chemical Reactor Control System

The potential hazardous incident are shown as follows.

Symbol	Description	Value($)	Hazardous Incident
x01	semi-product s01 and s02	30,000	e01, e02, e03, e21
x02	product s03	60,000	e06, e09, e11, e22
x03	product s04	70,000	e14, e17, e20, e23
x04	tank and sensors of reactor 1	200,000	e09
x05	heater of reactor 1	40,000	e09, e10
x06	tank, sensors and blender of reactor 2	300,000	e17
x07	heater of reactor 2	50,000	e17, e18
x08	staff 1-4	800,000	e09, e11

The Analysis of the Chemical Reactor Control System

The potential hazardous incident are shown as follows.

Symbol	Description	Value($)	Hazardous Incident
x09	staff 5-9	100,000	e17 , e19
x10	river and solid	900,000	e09 , e11 , e17 , e19
x11	air	400,000	e09 , e17

The Analysis of the Chemical Reactor Control System

The security strategies of the system are shown as follows.

Symbol	Description	Prevented Attacks	Invalidated Functions
m01	disconnect the security gateway	a01	f37
m02	shut down the web server	a03 , a04	f37
m03	shut down the personal computer 1	a05	f38
m04	shut down the personal computer 2	a06	f39
m05	shut down the personal computer 3	a07	f40
m06	disconnect the security gateway 1	a08	f31
m07	shut down the data server 1	a10 , a11	f31
m08	shut down the engineer station 1	a12	f34

The Analysis of the Chemical Reactor Control System

The security strategies of the system are shown as follows.

Symbol	Description	Prevented Attacks	Invalidated Functions
m09	encrypt the data amongst the PLC 1-4	a35, a36, a37, a38	—
m10	disconnect the security gateway 2	a13	f32
m11	shut down the data server 2	a15, a16	f32
m12	shut down the engineer station 2	a17	f35
m13	encrypt the data amongst the PLC 5-8	a39, a40, a41, a42	—
m14	disconnect the security gateway 3	a18	f33
m15	shut down the data server 3	a20, a21	f33
m16	shut down the engineer station 3	a22	f36

The Analysis of the Chemical Reactor Control System

The security strategies of the system are shown as follows.

Symbol	Description	Prevented Attacks	Invalidated Functions
m17	encrypt the data amongst the PLC 9-12	a43 , a44 , a45 , a46	—

The Analysis of the Chemical Reactor Control System

The recover strategies of the system are shown as follows.

Symbol	Description	Rocovered Functions	Cost($)
n01	reboot PLC1	f03	9,000
n02	reboot PLC2	f06	9,000
n03	reboot PLC3	f07 , f08	10,000
n04	reboot PLC4	f04 , f05	15,000
n05	reboot PLC5	f12 , f13	8,000
n06	reboot PLC6	f16	10,000
n07	reboot PLC7	f17 , f18 , f19	2,000
n08	reboot PLC8	f14 , f15	13,000

The Analysis of the Chemical Reactor Control System

The recover strategies of the system are shown as follows.

Symbol	Description	Rocovered Functions	Cost($)
n09	reboot PLC9	f23	14,000
n10	reboot PLC10	f26 , f30	7,500
n11	reboot PLC11	f27 , f28 , f29	14,000
n12	reboot PLC12	f24 , f25	11,000

Task Planning

Task Planning

- Finish the simulation of 2nd paper.
- Finish the 3rd paper for the special issue on Fuzzy Systems.