



Expansion of GO-FLOW for dynamic and Living PSA applications

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目录

CONTENTS

1

GO-FLOW Methodology

2

Automatic Modeling

3

**GO-FLOW Modeling Platform
for Living PSA Application**

4

Reliability Analysis

5

Conclusions

GO-FLOW Methodology – Basic operator

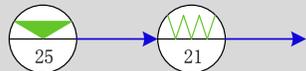
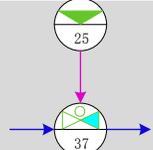
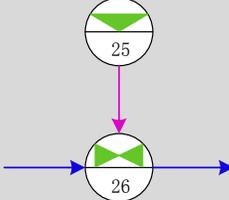
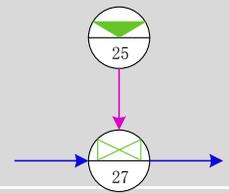
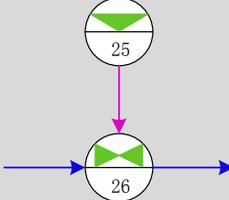
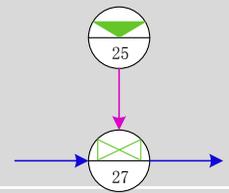
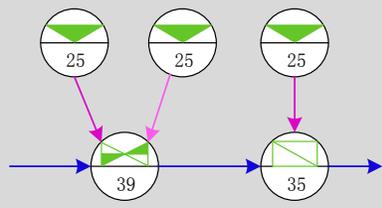
GO-FLOW methodology is a success-oriented system reliability/availability and safety analysis method for **time-dependent** and **phased-mission** system.

A total of 14 standard GO-FLOW operators are roughly classified into four categories:

- **Signal generator**
Represent the signal sources
- **General functional operators**
represent the failure mode of component
- **Logical generators**
describe the logical relationship
- **Case-specific operators**
use for specific application solution

kind	Type	shape	Name
Signal generator	25		Signal generator
General function operators	21		Two-state Component
	26		Normally Closed Component
	27		Normally Opened Component
	35		Operating Failure of Component
	37		Standby Failure of Component
	38		Maintenance of Component
	39		Opening and closing action component
Logic generators	22		OR Gate
	23		NOT Gate
	30		AND Gate
Case-specific operators	24		Difference operator
	28		Delay operator
	40		Phased-Mission operator

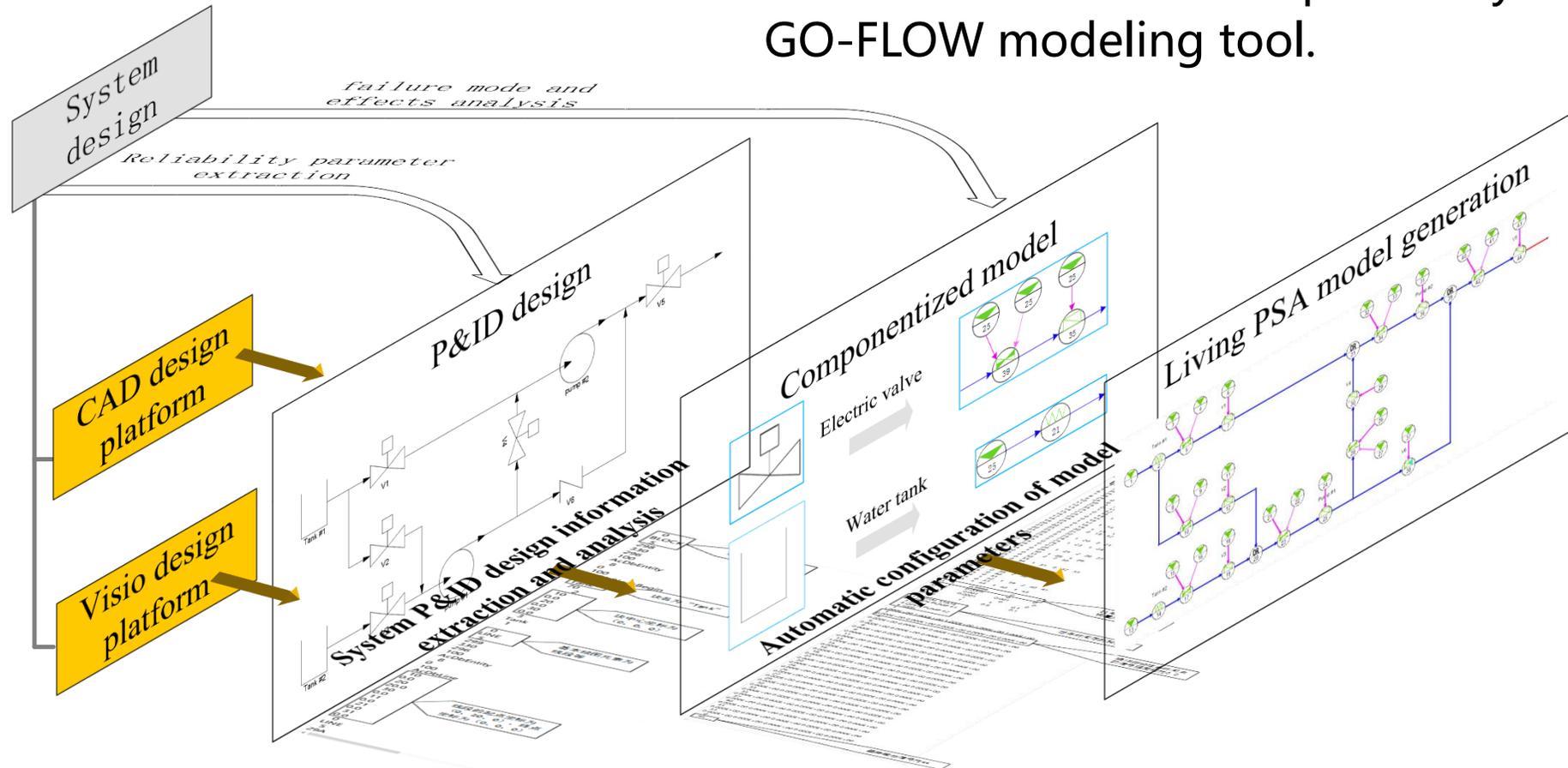
GO-FLOW Methodology – Componentization model

Categories	Sub-categories	Type of component	Failure mode	Reliability parameter	Componentized GO-FLOW model
Non-action component	Source component	container	leakage	Probability of Failure on demand P_g	
	Non-source component	Heat exchanger	Blockage, leakage	Failure rate λ Repair rate μ	
Check valve					
Action component	Normally closed component	Relief valve Safety valve	Leakage, Fail open	Probability of action ahead of time P_p Probability of Failure on demand P_g	
		Relay	Overload, Wear out		
	Normally open component	Fuse and circuit breaker	Fail closed	Probability of action ahead of time P_p Probability of Failure on demand P_g	
	Switching component	regulating control valve	Failure on demand	Failure of demand, operating failure	Probability of action ahead of time P_p Shutdown failure P_c Startup failure P_o Failure rate λ Repair rate μ
pump					

Automatic Modeling – Overview of framework

- Avoid human error
- Improve modeling speed
- Map the system model correctly

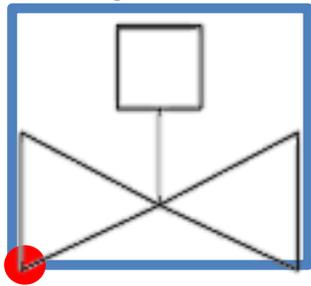
Based on the similarity of flow connection in both actual physical flows and GO-FLOW signal flows, a 'flow-based' method are used to describe the specifically customized GO-FLOW modeling tool.



Automatic Modeling – Implementation procedure

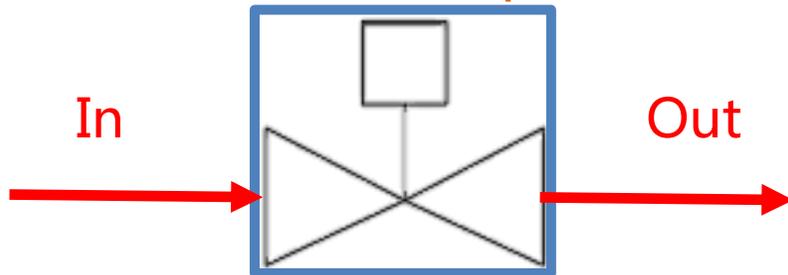
Automated GO-FLOW modeling process consists of three steps:

1. System P&ID design information extraction and analysis.

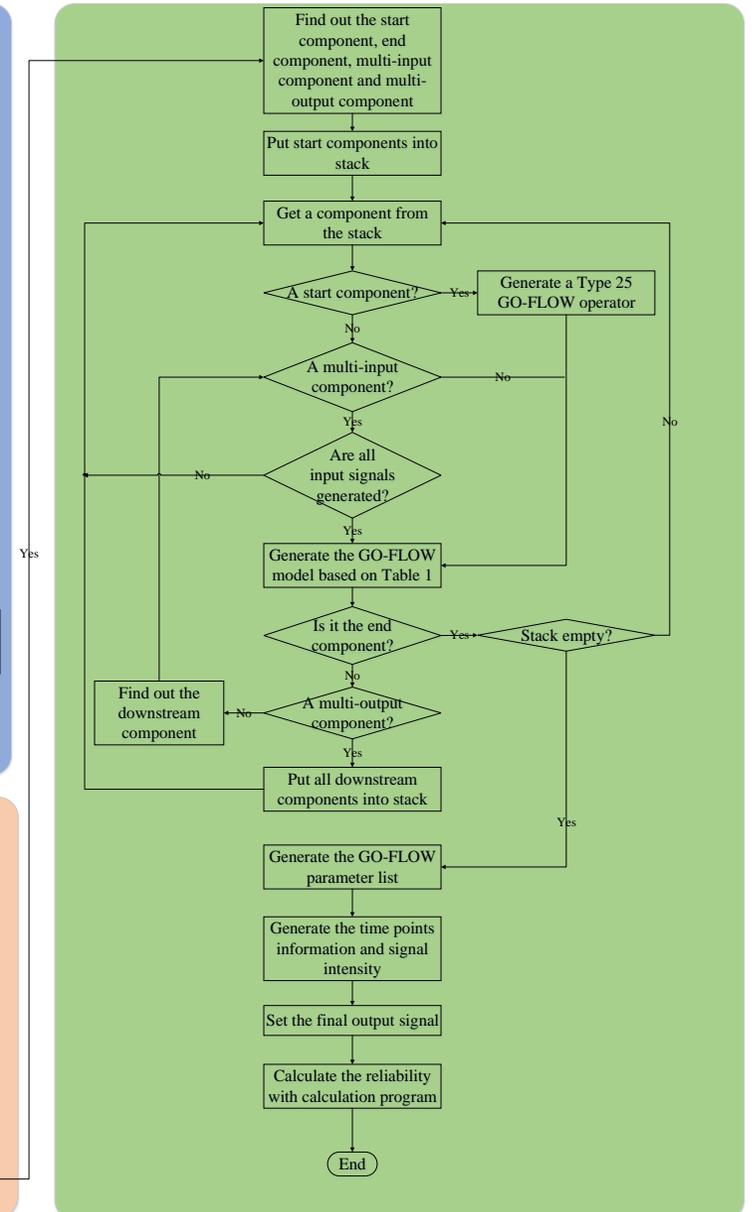
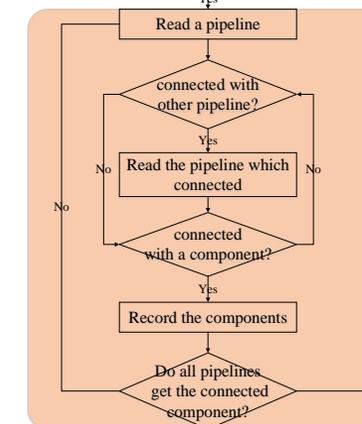
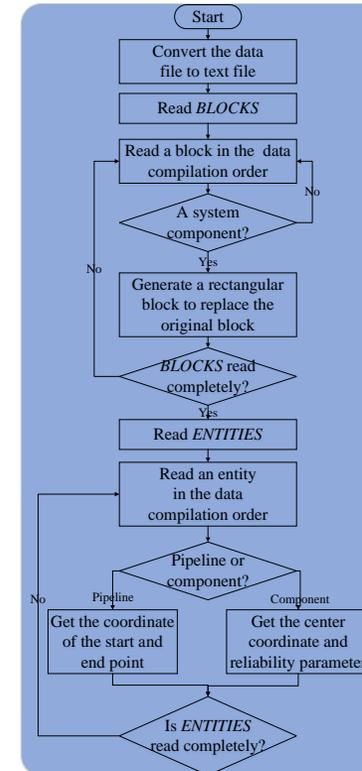


Minimum coordinate (0,0,0)
Maximum coordinate (15,20,0)

2. Connection relationship identification.



3. GO-FLOW model generation.
system structural model generation



Automatic Modeling – Case demonstration

Step 1: information extraction and analysis

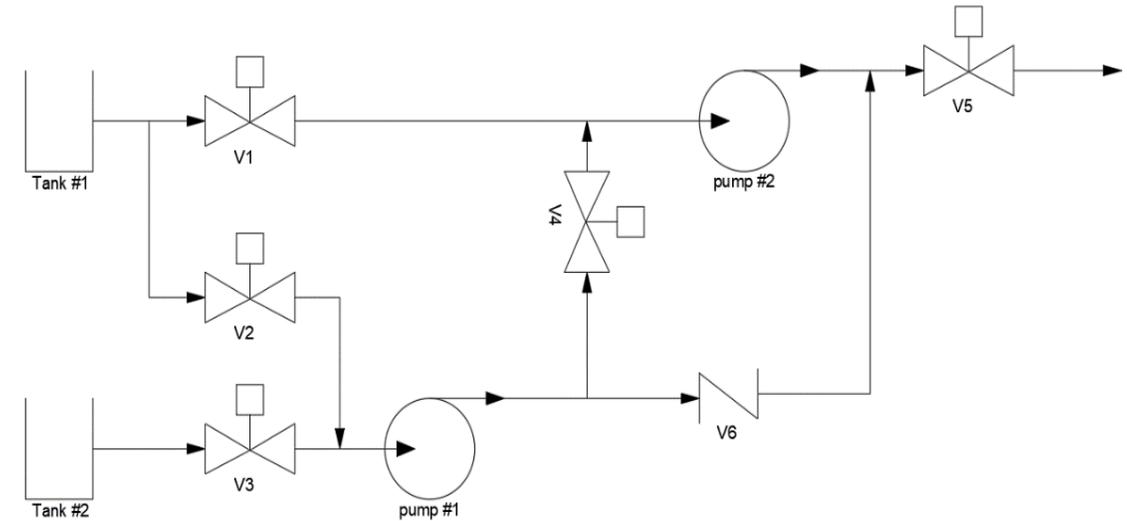
- Water storage tank
- Electric isolation valve
- Water transport pump
- Check valve

Step 2: Connection relationship identification

- Multi-input: Pump #1, Pump #2, V5
- Multi-output: Tank #1, Pump #1
- Starting component: Tank #1, Tank #2
- Ending component: V5

Step 3: GO-FLOW model generation

- System structural model generation
- Time series supplement



Depth-first traversal algorithm:

Tank #1 → V1 → V2 → Tank #2 → V3 →
Pump #1 → V4 → Pump #2 → V6 → V5

GO-FLOW Modeling Platform for Living PSA Application

GO-FLOW
file operator signal system component

delete all

operators and signals | time points and intensities
supplement modeling | reliability analysis

title [] set

Operator
operator number 10 OK

operator type
 21/2SC 22/OR 23/NOT 24/DIF 25/SG
 26/NCV 27/NOV 28/DLY 30/AND 35/FLB
 37/FVOS 38/FVCS 39/OCA 40/PMC 99/day
 41/TANK 42/PUMP 43/CV 44/MOV 31/k/N

reliability parameter
 parameter [1] lambda 1.0 E -1
 parameter [2] mu 0 E 0
 parameter [3] 0 E 0

comment
 comment 1 [] show hide
 comment 2 [] font select position

Signal
 signal number [] OK
 signal type
 normal final sub-input 2nd sub-input
 direction unchange change connection type continuous line open end

GO-FLOW
file operator signal system component

basic information
 name: electric pum keyword: pump
 function: liquid compression
 type: 42 abbreviation: PUMP
 delay: 0
 input signal zero (source) multi (logic AND)
 one (normal) multi (logic OR)

operator information

name	keyword	function	type	abbreviation	operator	delay	input_signal
water tank	tank	provide water source	41	TANK	2	0	0
check pump	pump	start/stop operation	42	PUMP	4	0	1
check valve	cv	prevent liquid backflow	43	CV	2	0	1
electric valve	valve	control liquid flow rate	44	MOV	2	0	1

operators and signals | time points and intensities
supplement modeling | reliability analysis

title [] set

Operator
operator number [] OK

operator type
 21/2SC 22/OR 23/NOT 24/DIF 25/SG
 26/NCV 27/NOV 28/DLY 30/AND 35/FLB
 37/FVOS 38/FVCS 39/OCA 40/PMC 99/day
 41/TANK 42/PUMP 43/CV 44/MOV 31/k/N

reliability parameter
 parameter [1] 0 E 0
 parameter [2] 0 E 0
 parameter [3] 0 E 0

comment
 comment 1 [] show hide
 comment 2 [] font select position

Signal
 signal number [] OK
 signal type
 normal final sub-input 2nd sub-input
 direction unchange change connection type continuous line open end

GO-FLOW
file operator signal system component

delete all

Time points 3 OK

Description
 time point 1 []
 time point 2 []
 time point 3 []

Intensities

operator	t1:	t2:	t3:
15.0	1.0	1.0	1.0
17.0	0.0	1.0	0.0
19.0	0.0	1.0	0.0
21.0	1.0	1.0	1.0
23.0	0.0	1.0	0.0
25.0	0.0	1.0	0.0
26.0	0.0	0.0	0.0
28.0	0.0	0.0	24.0
30.0	0.0	1.0	0.0
32.0	0.0	0.0	24.0
34.0	0.0	1.0	0.0
35.0	0.0	0.0	0.0
37.0	0.0	0.0	24.0

refresh reset

GO-FLOW
file operator signal system component

delete all

operators and signals | time points and intensities
supplement modeling | reliability analysis

Ideal signal
 operator_number original signal 1: 2: 3:
 original signal
 original signal

operator_number	original signal 1:	2:	3:
15	NaN	1.0	1.0
16	NaN	0.999	0.999
17	NaN	0.0	1.0
18	NaN	0.0	0.9
19	NaN	0.0	1.0
20	NaN	0.0	0.9
21	NaN	1.0	1.0
22	NaN	0.999	0.999
23	NaN	0.0	1.0

Final reliability
 final signal 1: 2: 3:
 #13 0.0 0.8990019981 0.8989380598495631

select operator 13 OK

MPS analysis
 path success path 1: 2: 3:
 #2 41,42,44,45,53,54,0.0 0.821271 0.821271
 #3 43,44,46,48,49,52,54,0.0 0.728271 0.728271
 #1 41,47,49,50,54,0.0 0.80919 0.80725
 #4 41,42,44,45,53,54,0.0 0.80919 0.807057
 #5 43,44,46,53,54,0.0 0.80919 0.807057

GO-FLOW Modeling Platform for Living PSA Application

GO-FLOW
file operator signal system component

delete all

Standard GO-FLOW operators

Componentized operators

operators and signals	time points and intensities
supplement modeling	reliability analysis
title	set
Operator	
operator number	10 OK
operator type	
<input type="radio"/> 21/2SC <input type="radio"/> 22/OR <input type="radio"/> 23/NOT <input type="radio"/> 24/DIF <input type="radio"/> 25/SG	
<input type="radio"/> 26/NCV <input type="radio"/> 27/NOV <input type="radio"/> 28/DLY <input type="radio"/> 30/AND <input checked="" type="radio"/> 35/FLB	
<input type="radio"/> 37/FVOS <input type="radio"/> 38/FVCS <input type="radio"/> 39/OCA <input type="radio"/> 40/PMC <input type="radio"/> 99/dmy	
<input type="radio"/> 41/TANK <input type="radio"/> 42/PUMP <input type="radio"/> 43/CV <input type="radio"/> 44/MOV <input type="radio"/> 31/k/N	
reliability parameter	
parameter [1] lambda	1.0 E -1
parameter [2] mu	0 E 0
parameter [3]	0 E 0
comment	
comment 1	show <input type="radio"/> hide <input type="radio"/>
comment 2	font select position
Signal	
signal number	OK
signal type	
<input checked="" type="radio"/> normal <input type="radio"/> final <input type="radio"/> sub-input <input type="radio"/> 2nd sub-input	
direction	
<input checked="" type="radio"/> unchange <input type="radio"/> change	
connection type	
<input checked="" type="radio"/> continuous line <input type="radio"/> open end	

GO-FLOW Modeling Platform for Living PSA Application

GO-FLOW
file operator signal system component

basic information

name: electric pum keyword: pump

function: liquid compression

type: 42 abbreviation: PUMP

delay: 0

input signal zero (source) multi (logic AND)

 one (normal) multi (logic OR)

operator information

	name	keyword	function	type	abbreviation	operators	delay	input_signal
1	water tank	tank	provide water source	41	TANK	2	0	0
2	electric pump	pump	liquid compression	42	PUMP	5	0	1
3	check valve	cv	prevent liquid backflow	43	CV	2	0	1
4	electric valve	valve	control liquid flow rate	44	MOV	2	0	1

Default reliability parameter

operators and signals **time points and intensities**

supplement modeling **reliability analysis**

title:

Operator

operator number:

operator type

21/2SC 22/OR 23/NOT 24/DIF 25/SG

26/NCV 27/NOV 28/DLY 30/AND 35/FLB

37/FVOS 38/FVCS 39/OCA 40/PMC 99/dmy

41/TANK 42/PUMP 43/CV 44/MOV 31/k/N

reliability parameter

parameter [1]: 0 E 0

parameter [2]: 0 E 0

parameter [3]: 0 E 0

comment

comment 1: show hide

comment 2:

Signal

signal number:

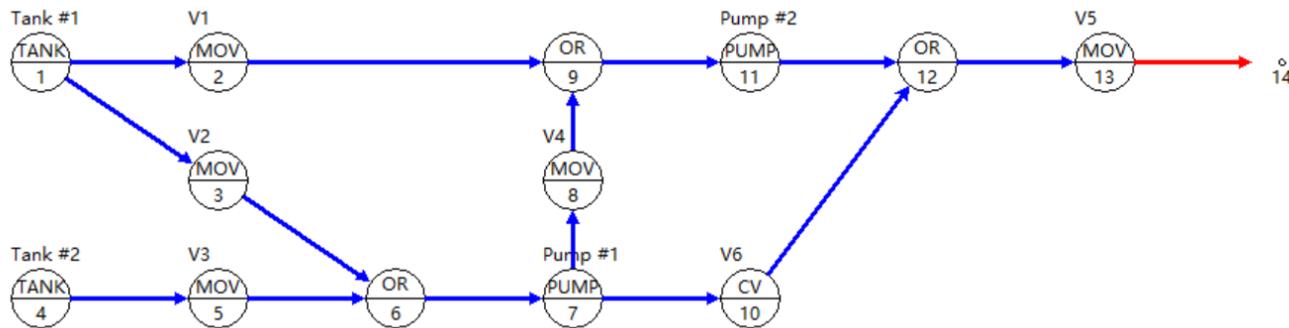
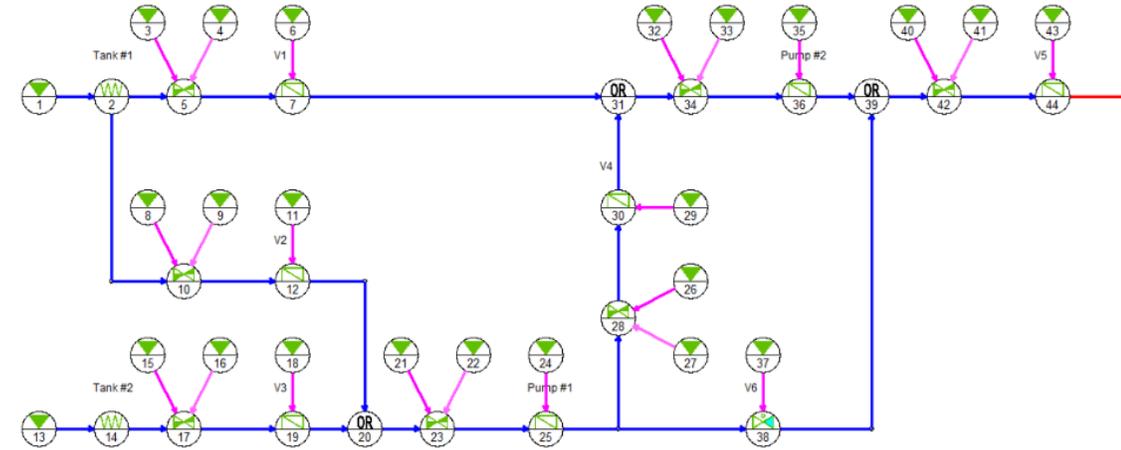
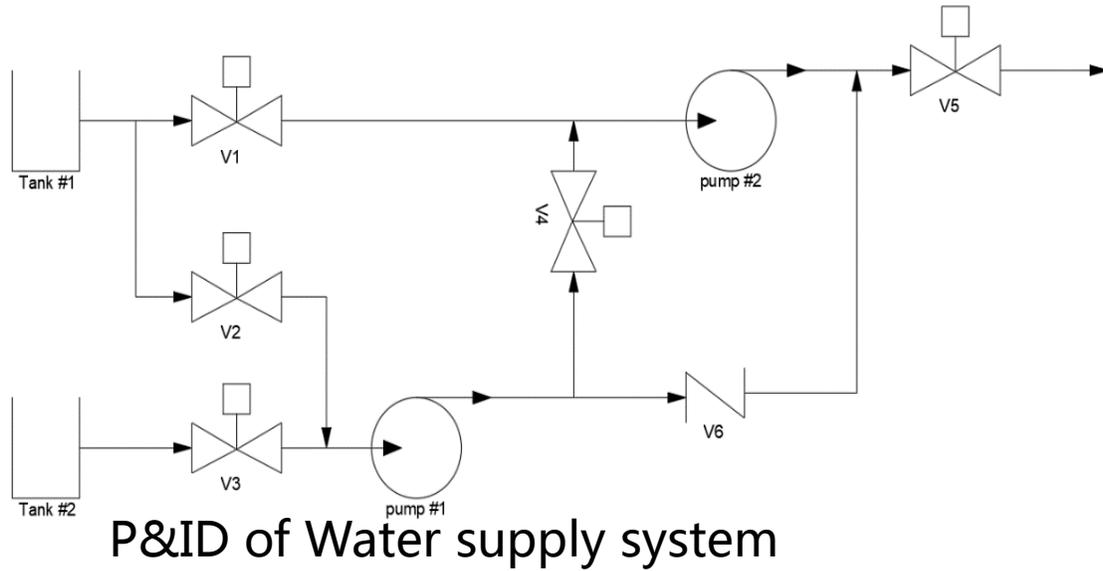
signal type

normal final sub-input 2nd sub-input

direction connection type

unchange change continuous line open end

GO-FLOW Modeling Platform for Living PSA Application



- ❑ GO-FLOW platform provides a clearer model with the help of componentized operators.
- ❑ Users do not need to pay attention to the failure mode of the components.

GO-FLOW Modeling Platform for Living PSA Application

GO-FLOW

file operator signal system component

delete all

Time points: 3

Description

time point 1

time point 2

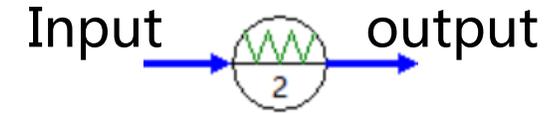
time point 3

all source intensity

Intensities

operator	t1:	t2:	t3:
15.0	1.0	1.0	1.0
17.0	0.0	1.0	0.0
19.0	0.0	1.0	0.0
21.0	1.0	1.0	1.0
23.0	0.0	1.0	0.0
25.0	0.0	1.0	0.0
26.0	0.0	0.0	0.0
28.0	0.0	0.0	24.0
30.0	0.0	1.0	0.0
32.0	0.0	0.0	24.0
34.0	0.0	1.0	0.0
35.0	0.0	0.0	0.0
37.0	0.0	0.0	24.0

Reliability Analysis – Signal rename



	Original ideal signal	renamed signal	2 nd renamed signal
definition	Ratio of input signal to output signal	Conjunction of one or more original ideal signal	Processing of renamed signal by specific operators
aim	Obtain reliability of component	Improve calculation efficiency	Show signal dependency
generation	Functional GO-FLOW operators and customized GO-FLOW operator	Processing before type 22, 23, 24, 28, 30, 35, 40 GO-FLOW operator	Type 23, 24, 28, 40 GO-FLOW operator
Characteristic	Does not exist in final signal calculation	Independent between each other	dependent with renamed signal

Reliability Analysis – Signal processing

- 2nd renamed signal in one success path:

signal merging: $S(t_i) = \min[S_1(t_i), S_2(t_i), \dots]$

- 2nd renamed signal in different success paths:

signal splitting: $S(t_i) = \max[S_1(t_i), S_2(t_i), \dots]$

$$S_1(t_i) = \boxed{S(t_i)} * \boxed{S'(t_i)}$$
$$S_2(t_i) = \boxed{S(t_i)} * \boxed{S''(t_i)}$$

Independent
signal

dependent
signal

Reliability Analysis – NEA algorithm

- No repeated signal:

$$R = 1 - \prod P_i(S_1, S_2, \dots)$$

- One repeated signal:

$$\begin{aligned} R &= R_{S_i^1} \cdot S_i + R_{S_i^0} \cdot (1 - S_i) \\ &= P(S_1, S_2, \dots, S_i = 1, \dots) \cdot S_i + P(S_1, S_2, \dots, S_i = 0, \dots) \cdot (1 - S_i) \end{aligned}$$

- More than one repeated signals:

$$\begin{aligned} R &= R_{S_i^1} \cdot S_i + R_{S_i^0} \cdot (1 - S_i) \\ &= R_{S_i^1 S_j^1} \cdot S_i \cdot S_j + R_{S_i^1 S_j^0} \cdot S_i \cdot (1 - S_j) + R_{S_i^0 S_j^1} \cdot (1 - S_i) \cdot S_j + R_{S_i^0 S_j^0} \cdot (1 - S_i) \cdot (1 - S_j) \\ &= \dots \end{aligned}$$

Reliability Analysis – Supplement modeling

The screenshot displays the GO-FLOW software interface. On the left, a process flow diagram shows two tanks (Tank #1 and Tank #2) feeding into a series of operations: Tank #1 (TANK 1) feeds into MOV 2, which then feeds into OR 9. Tank #2 (TANK 4) feeds into MOV 3, which feeds into OR 6. OR 6 feeds into PUMP 7, which feeds into CV 10. PUMP 7 also feeds into MOV 8, which feeds into OR 9. PUMP 7 feeds into PUMP 11, which feeds into OR 12. OR 12 feeds into MOV 13, which feeds into a final output point 14. The diagram includes various operators like TANK, MOV, OR, PUMP, and CV, connected by arrows representing flow paths.

On the right, the configuration panel is divided into several sections:

- operators and signals**
- time points and intensities**
- supplement modeling**
- reliability analysis**

The **Truncation** section includes:

- truncation value: 0
- truncation time point: -1
- radio buttons for **conservative** (selected) and **optimistic**.
- reserved decimal: []

The **CCF analysis** section includes:

- radio buttons for **NO CCF** (selected), **alpha-factor**, and **beta-factor**.
- select operator: []
- beta = []

The **CCF group** section contains a table:

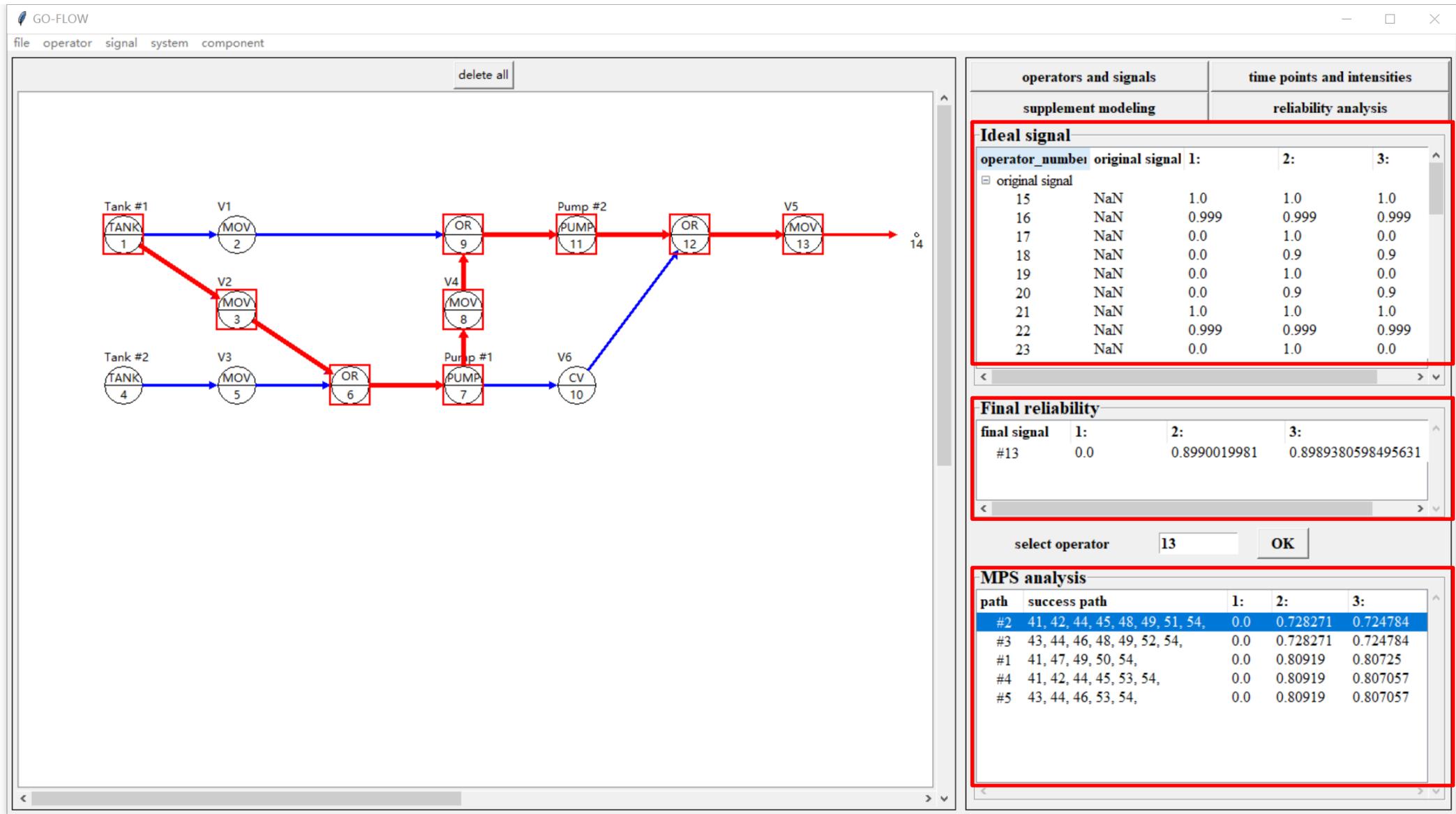
group	operators	CCF type	beta
1	2, 3	beta	0.01
2	4, 5, 6	alpha	0.03

At the bottom right, there is a **calculate** button.

Red annotations on the image include:

- A red box around the Truncation and CCF analysis sections.
- Red text "accuracy requirement" next to the CCF model options.
- Red text "Alpha and beta factor can be identify automatically" at the bottom.

Reliability Analysis – Final result



Ideal signal

Final result

Success path set

Conclusions

- We build the table of **componentization models** which used to merge the GO-FLOW operator and map system components
- An **automated GO-FLOW modeling tool** is proposed to extract information from P&ID to GO-FLOW model data file.
- A **new GO-FLOW platform** is built with **CCF analysis** and **success path analysis** in addition to the original functions.
- **NEA algorithm** is used to improve the computational efficiency and accuracy of reliability analysis.

Thanks for listening!