14th Chemical Process Safety Sharing (CPSS)

Designing an effective cause and effect matrix for use in PHA and at shop floor level

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Introduction

OSHA's PSM standard requires a management system with 14 elements.
Process Safety Information (PSI) is one of these elements.

Information on the equipment in the process must include the following:

- Materials of construction,
- . . . . .
- Safety systems (e.g., interlocks, detection, or suppression systems).

It is a common practice to use a **cause and effect matrix** to provide necessary information on safety systems.

Typical SIF matrix

A Safety Instrumented Function (SIF) matrix is a tool used to document and visualize the relationships between various process conditions (causes) and the corresponding safety actions (effects) that need to be taken to mitigate risks. Common information included in a SIF cause and effect matrix typically encompasses the following elements:

- Unique identification number
- TAG number related to PID
- Threshold
- Actions
- SIL level

Typical SIF matrix

								Effect	V0901 feed valve from truck	V0901 balance valve to truck	V0901 bottom valve	V0901 recirc. valve	Loading pump	Unloading pump
									XV9011	XV9012	XV9013	XV9014	P902	P903
Cause														
Interlock Item	**System**	**Description**	**SIL level**	**Tag No.**	**Set point**	**Delay [s]**	**Reset**		FC	FC	FC	FC	Stop	Stop
I-2901-01	V0901	High level in V0901	1	LS0902	6000 mm	0	M		Cls				Stop	
I-2901-02	V0901	Low level in V0901	1	LS0902	100 mm	0	M				Cls			Stop
I-2901-03	V0901	High pressure in V0901	1	PS0903	4 kPa	0	M		Cls		Cls	Cls	Stop	
I-2901-04	V0901	Low pressure in V0901	1	PS0903	-1 kPa	0	M							Stop

Typical SIF matrix

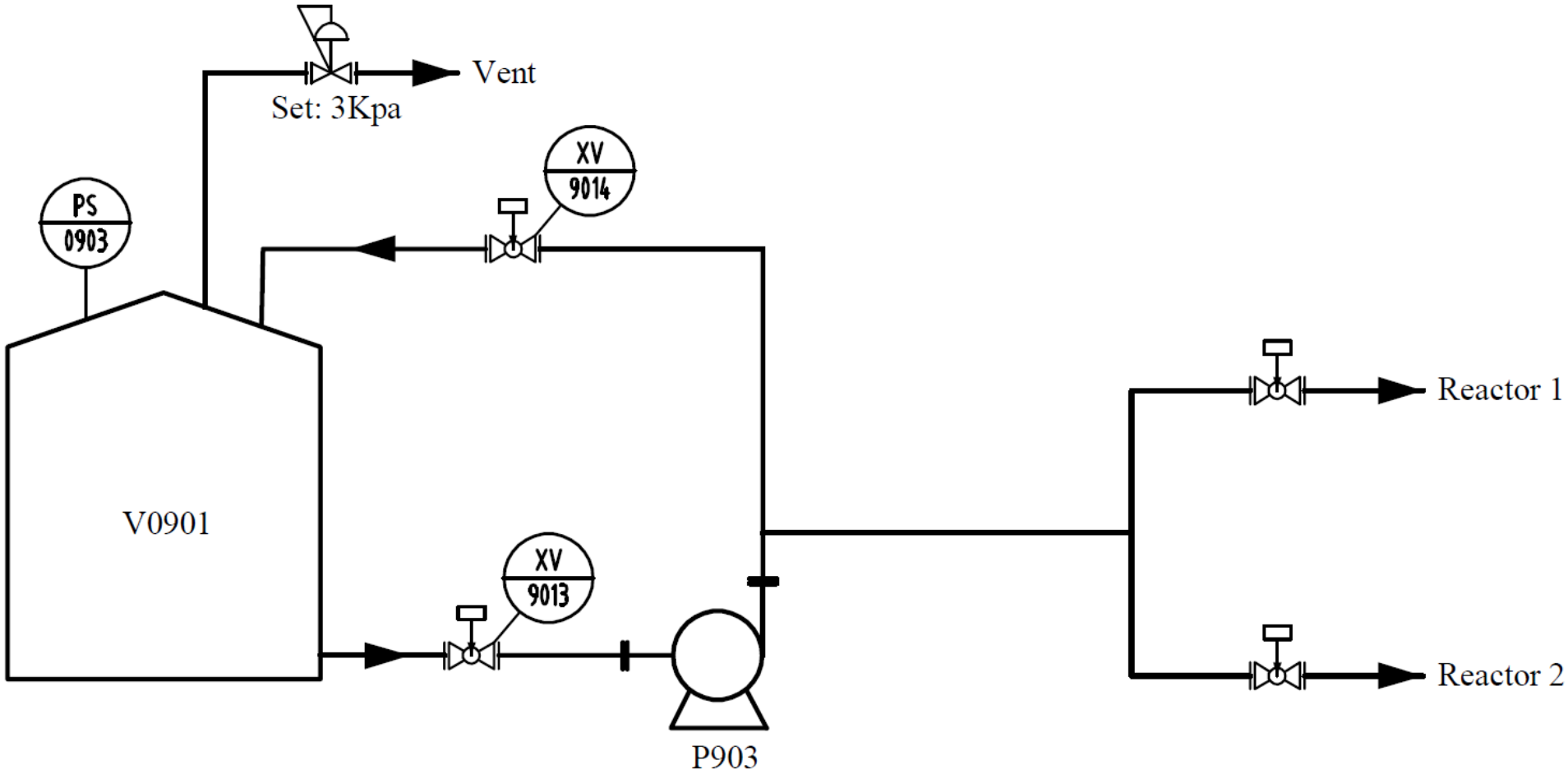
	Safeguard number	S91501A	S91501B	S91501C	S91501D	S91501E
	Description	F91501 chamber Temperature	F91501 chamber Temperature	F91501 chamber Temperature	Main pipeline FID VOC-LEL	Main pipeline FTA VOC-LEL
	TAG	TICAY9150101	TICAY9150103	TICAY9150105	LELAY9150301	LELAY9150302
	Level	LY	LY	LY	HHY	HHY
	Set point	760°C	760°C	760°C	25% LEL	25% LEL
	SIL level	SIL1	SIL1	SIL1	SIL2	SIL2
TAG Number						
HXYV9150301 (way 1: vent to atmosphere)		open	open	open	open	open
HXYV9150301 (way 2: enter to RTO inlet)		close	close	close	close	close
HXYV9150302 (way 1: vent to atmosphere)		open	open	open	open	open
HXYV9150302 (way 2: enter to RTO inlet)		close	close	close	close	close

Typical SIF matrix

These common information allow defining a safeguard regarding its three fundamental characteristics:

- effectiveness
- reliability
- independence

Application to a storage tank

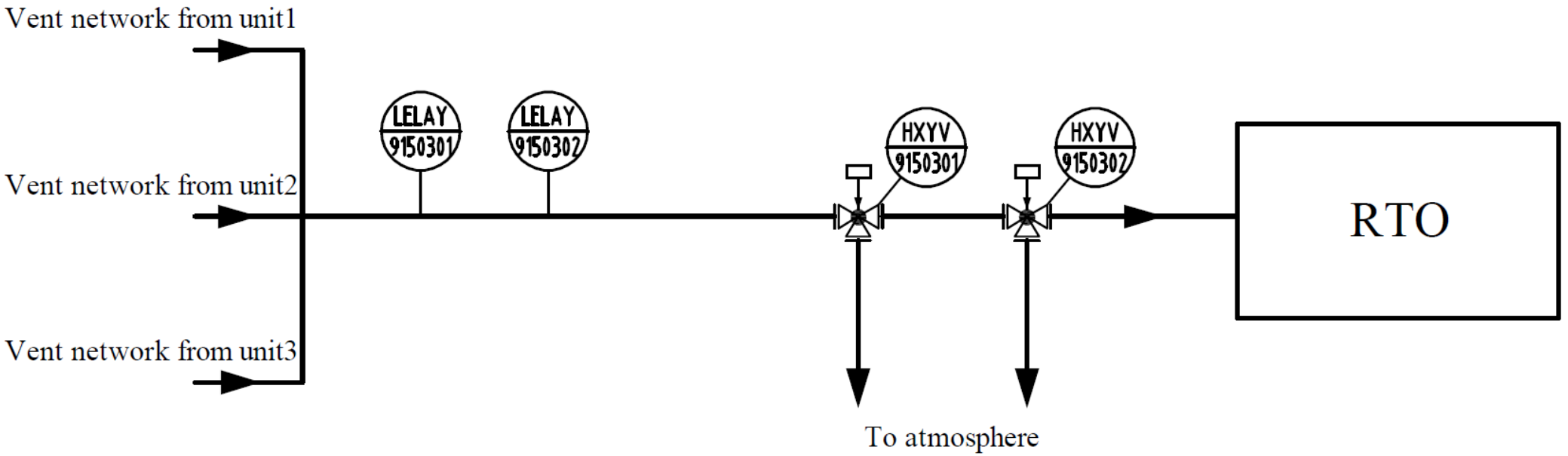


Application to a storage tank

Deviation	Cause	Frequency	Scenario	Severity	Risk	LOPA	PFD	Residual risk
High pressure	Operator fault	One mistake every 1 to 10 years	If operator does not close alcohol feeding valve to reactor. During N2 feeding in reactor, N2 backflow to storage V0901. When pressure reaches 3 kPa, storage vent valve opens. If the vent valve fails, it does not open. Pressure in storage increases to 3 barg. Storage design pressure is 6 kPa. **Storage burst**	high	intermediate	PS0903 SP: 4 kPa Actions: closes V0901bottom valve XV9013 and recirculation valve XV9014 (SIL1)	0.1	acceptable
	Storage vent valve fails	Failure once every 10years						

Application to a RTO

RTO: Regenerative Thermal Oxidizer



Application to a RTO

Deviation	Cause	Frequency	Scenario	Severity	Risk	LOPA	PFD	Residual risk
Composition (high flammable vapor concentration in vent network)	high flammable vapor concentration in one reactor or several reactors vent at the same time	Several times per year based on site feedback	If several reactors vent at the same time, flammable vapor concentration in vent network increases above LEL. When flammable vapor reach the RTO, it is ignited due to the open flame inside the RTO. Explosion backflow in vent network causes **explosion** in equipment connected to it	high	unacceptable	two LEL detectors SP: 25% LEL Actions: open HXYV9150301 and HXYV9150302 to the atmosphere (SIL2)	0.01	intermediate

Drawbacks and suggestions for PHA

If a cause and effect matrix is presented as in two above examples, it can mislead the PHA working group to a false sense of safety.

What information is missing in the matrix?

Drawbacks and suggestions for PHA

The SIF response time!

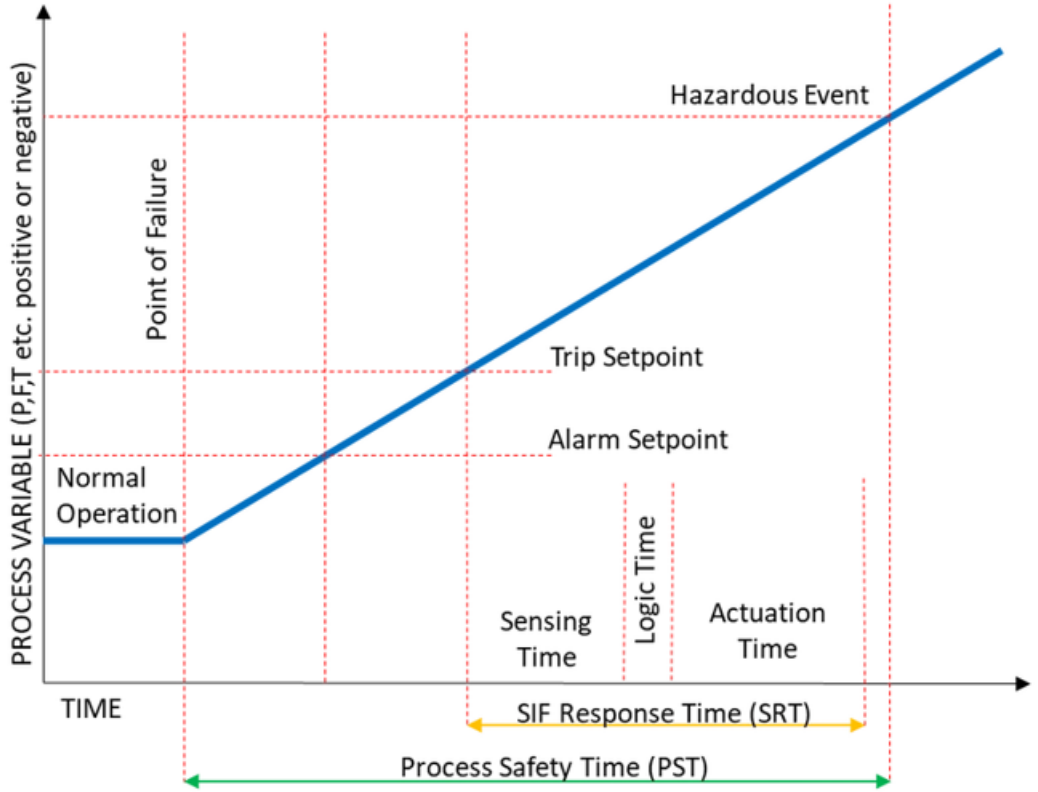


Image source: Process Group Limited

SIF Response Time (SRT) is a function of:

- Speed of detection
- Logic processing
- Final element completion

SRT must be shorter than the length of time between the SIF set point being reached and the unwanted even being mitigated.

Drawbacks and suggestions for PHA

The response time is part of the effectiveness of the safeguard and it should be as important as the “effect” part in a cause and effect matrix but surprisingly this information is usually missing from the matrix.

If a matrix indicates the response times, people will probably think about it during the PHA.

Application to a storage tank

									Effect	V0901 feed valve from truck	V0901 balance valve to truck	V0901 bottom valve	V0901 recirc. valve	Loading pump	Unloading pump
										XV9011	XV9012	XV9013	XV9014	P902	P903
Interlock Item	**System**	**Description**	**SIL level**	**Tag No.**	**Set point**	**Delay [s]**	**Reset**	**SIF response time**	**Cause**	FC	FC	FC	FC	Stop	Stop
I-2901-01	V0901	High level in V0901	1	LS0902	6000 mm	0	M			Cls				Stop	
I-2901-02	V0901	Low level in V0901	1	LS0902	100 mm	0	M					Cls			Stop
I-2901-03	V0901	High pressure in V0901	1	PS0903	4 kPa	0	M	5 sec.		Cls		Cls	Cls	Stop	
I-2901-04	V0901	Low pressure in V0901	1	PS0903	-1 kPa	0	M								Stop

Application to a storage tank

Storage design pressure	6	[kPa]
Storage volume	60	[m3]
Maximum filling ratio	80	[%]
Minimum free space	12	[m3]
N2 valve Cv on reactor	4.8	[gpm - 1 PSI]
N2 valve upstream pressure	3	[barg]
Maximum N2 flowrate	318	[kg/h]
Maximum N2 flowrate	265	Nm3/h
PS0903 set point	4	[kPa]
Temperature	288	[deg. C]
n (mole needed to increase pressure from PS0903 set point to storage deign pressure)	10.0	[mol]
N2 molar mass	0.028	[kg/mol]
Time to increase pressure from PS0903 set point to storage design pressure	**3.2**	[s]

PS0903 is not efficient for this case.

The risk increases from acceptable to intermediate.

Application to a RTO

	Safeguard number	S91501A	S91501B	S91501C	S91501D	S91501E
	Description	F91501 chamber Temperature	F91501 chamber Temperature	F91501 chamber Temperature	Main pipeline FID VOC-LEL	Main pipeline FTA VOC-LEL
	TAG	TICAY9150101	TICAY9150103	TICAY9150105	LELAY9150301	LELAY9150302
	Level	LY	LY	LY	HHY	HHY
	Set point	760°C	760°C	760°C	25% LEL	25% LEL
	SIL level	SIL1	SIL1	SIL1	SIL2	SIL2
	response time				18 sec.	18 sec.
TAG Number						
HXYV9150301 (way 1: vent to atmosphere)		open	open	open	open	open
HXYV9150301 (way 2: enter to RTO inlet)		close	close	close	close	close
HXYV9150302 (way 1: vent to atmosphere)		open	open	open	open	open
HXYV9150302 (way 2: enter to RTO inlet)		close	close	close	close	close

Application to a RTO

Pipe diameter	1.2	[m]
Pipe length between LEL detectors and vent valves to atmosphere HXYV9150301/HXYV9150302	175	[m]
Maximum vent flowrate to RTO	42000	[m3/h]
Time for gas to flow down from LEL detector to vent valves to atmosphere HXYV9150301/HXYV9150302	**17.0**	[s]

LELAY 9150301 and 9150302 are not efficient for this case.

The risk increases from intermediate to unacceptable.

Drawbacks and suggestions for PHA

Warning!

The theoretical SIF response time provided by the supplier and the real response time may not be the same.

For RTO case the theoretical response time was **8 seconds**:

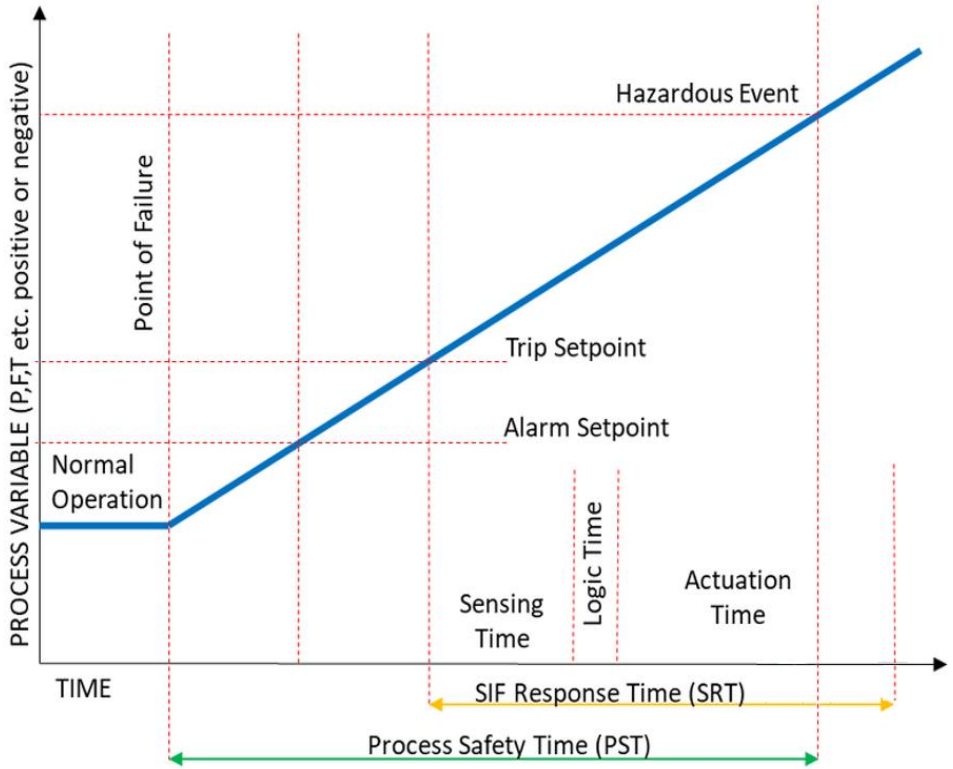
- Sampling time 3 seconds
- Analysis time 2 seconds
- Valve closing/opening time: 3 seconds

However the site measured a response time of **18 seconds**.

-> if response time is included in the matrix, it must be measured on real conditions during the initial SIF test and then during all periodic SIF tests.

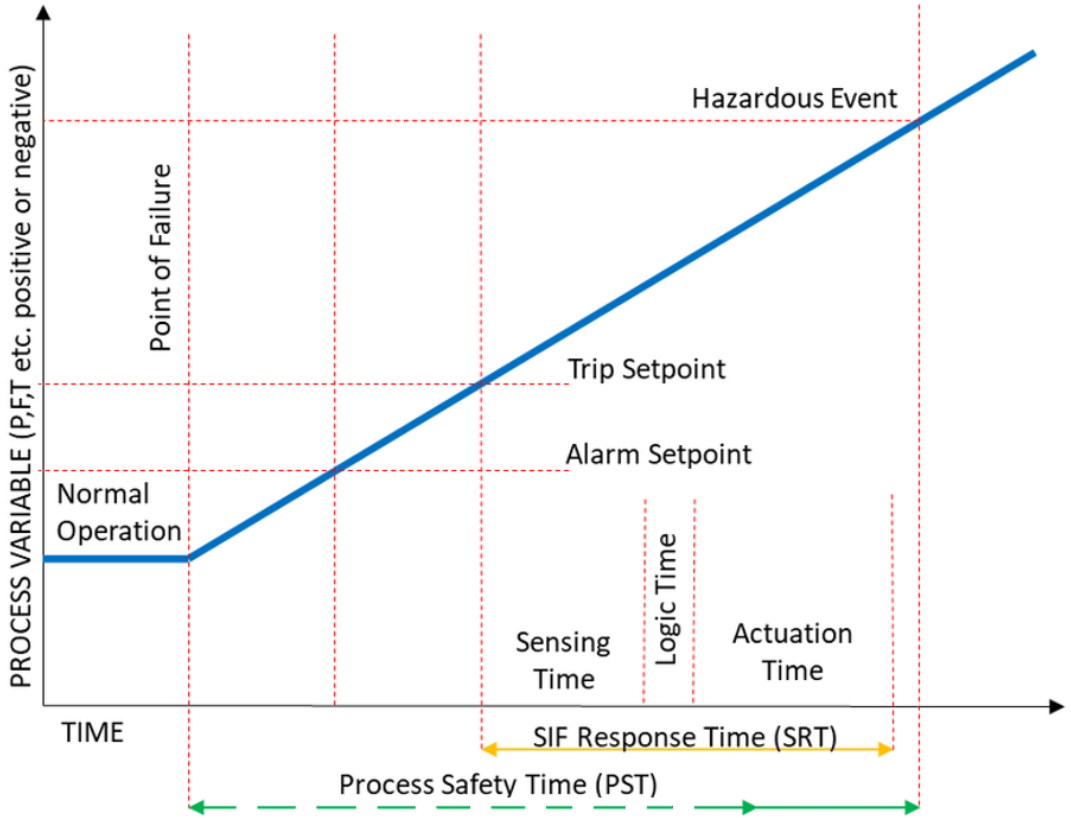
Drawbacks and suggestions for PHA

What can we do if the SIF response time is too long to prevent the unwanted event?



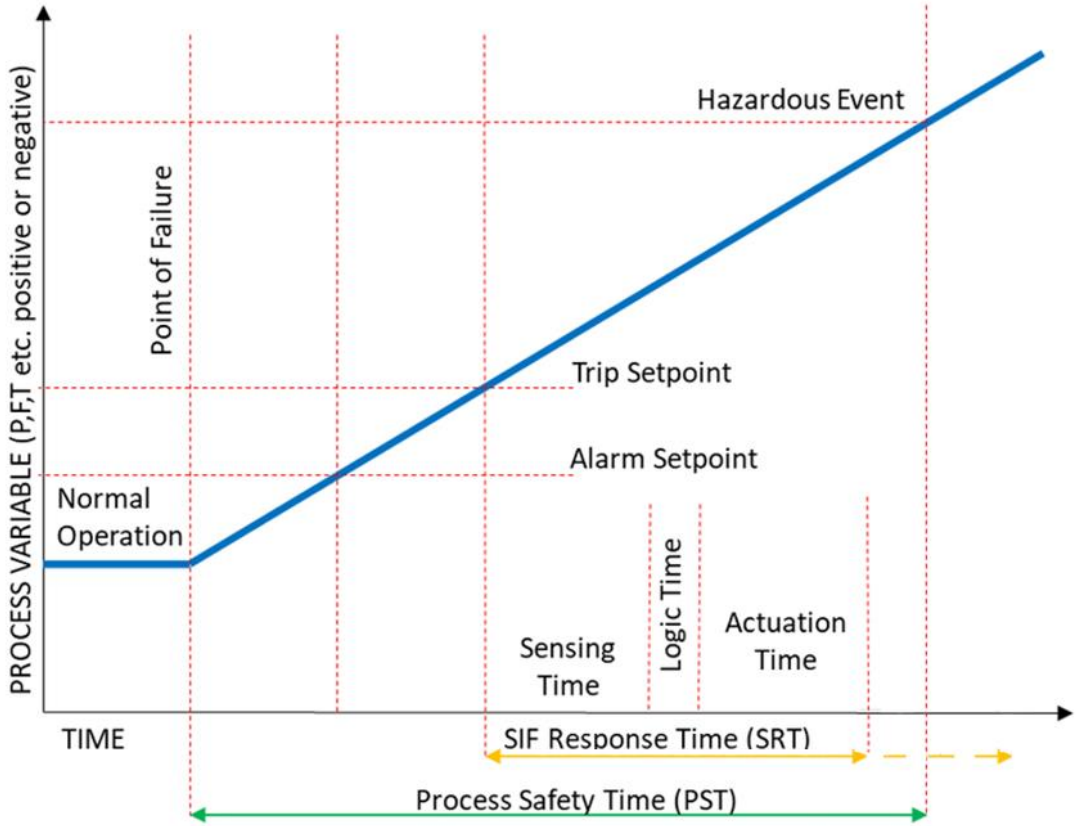
Drawbacks and suggestions for PHA

Increase the process safety time



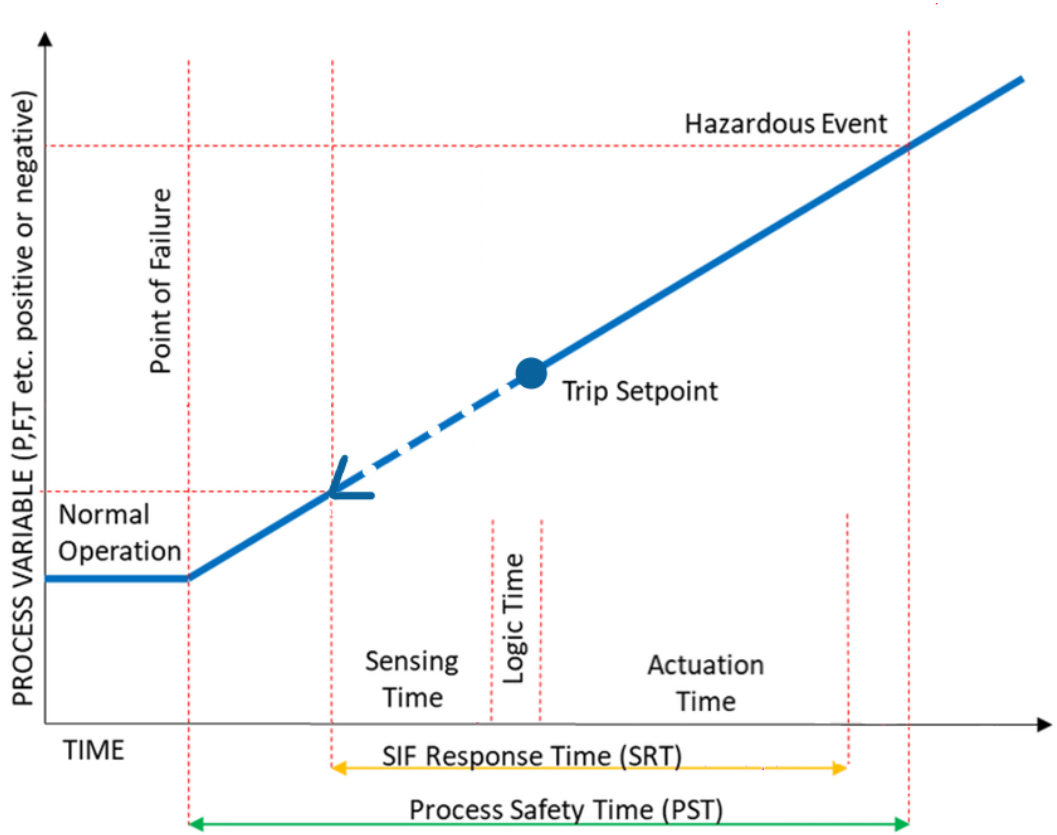
Drawbacks and suggestions for PHA

Reduce the SIF response time



Drawbacks and suggestions for PHA

Lower the SIF set point



Suggestions for shop floor application

Indicating the response times of the safeguards is the first improvement we can bring to a standard matrix.

The second improvement is also linked to one of the 14 PSM elements: MOC - and more specifically to temporary MOC: bypassing of a safeguard.

Suggestions for shop floor application

Requirements and observations:

- approval process
- risk assessment
- compensatory measures
- by bass duration
- record and communication to concerned employees.

Bypassing a safeguard is usually approved by shift leader or production manager. But in some sites, the risk assessment is not done because these people don't have easy access to PHA or they don't know where to find the information in the PHA tables.

Suggestions for shop floor application

Proposed solution:

Use the cause and effect matrix to indicate the risk level when the safeguard is bypassed that is to say if the PFD of the safeguard is taken as 1 in the PHA.

									Effect	V0901 feed valve from truck	V0901 balance valve to truck	V0901 bottom valve	V0901 recirc. valve	Loading pump	Unloading pump
										XV9011	XV9012	XV9013	XV9014	P902	P903
Cause															
System	**Description**	**SIL level**	**Tag No.**	**Set point**	**Delay [s]**	**Reset**	**SIF response time**	**Risk after bypass**		FC	FC	FC	FC	Stop	Stop
V0901	High level in V0901	1	LS0902	6000 mm	0	M		**Accept.**		Cls				Stop	
V0901	Low level in V0901	1	LS0902	100 mm	0	M		**Accept.**				Cls			Stop
V0901	High pressure in V0901	1	PS0903	4 kPa	0	M	5 sec.	**Interm.**		Cls		Cls	Cls	Stop	
V0901	Low pressure in V0901	1	PS0903	-1 kPa	0	M		**Interm.**							Stop

Safeguard number	S91501A	S91501B	S91501C	S91501D	S91501E
Description	F91501 chamber Temperature	F91501 chamber Temperature	F91501 chamber Temperature	Main pipeline FID VOC-LEL	Main pipeline FTA VOC-LEL
TAG	TICAY9150101	TICAY9150103	TICAY9150105	LELAY9150301	LELAY9150302
Level	LY	LY	LY	HHY	HHY
Set point	760°C	760°C	760°C	25% LEL	25% LEL
SIL level	SIL1	SIL1	SIL1	SIL2	SIL2
Response time				18 sec.	18 sec.
Risk after bypass	**Interm.**	**Interm.**	**Interm.**	**Unac.**	**Unac.**
TAG Number					
HXYV9150301 (way 1: vent to atmosphere)	open	open	open	open	open
HXYV9150301 (way 2: enter to RTO inlet)	close	close	close	close	close
HXYV9150302 (way 1: vent to atmosphere)	open	open	open	open	open
HXYV9150302 (way 2: enter to RTO inlet)	close	close	close	close	close

Suggestions for shop floor application

Pros and cons:

- Easy and formal risk assessment accessible to everyone, including workshop operators
- Possibility to adjust compensatory measures and approval process based on the risk level

- Need to update the matrix regularly. If not, it provides wrong information so people might underestimate the risk of bypassing a safeguard. However with ongoing digitalization of sites and AI, this updating task may become fully automatic in the future.

Conclusion

- Each matrix is different from one site to another.

- It should contain the basic information necessary to characterize a safeguard (independency, efficiency, reliability)

- SIF response time is an integral part of the efficiency of the SIF

- Listen to on-site personnel and customize your matrix based on everyone needs

Thank you for your attention