Spurious Trip Rate Modelisation and Quantitative assessment of Emergency ShutDown system in the oil and gaz industry

Abstract

The main purpose of Safety-related implementation systems is to maintain safety condition of a plant or equipment from the hazardous events, but even if no indications of impairment are present, the instrumented safety system is may spuriously trip. These activations are characterized in terms of spurious trip frequency rate and their occurrence can lead to significant technical and economic losses.

The identification of these trips, their causes, their effects and their evaluations have been the subject of several studies. Therefore , this work aims to propose a risk analysis modelling of Spurious Trip (ST) to safety instrumented system (SIS) installed in an industrial installation of Edjelet gas flares recovery project The risk analysis tool, the fault-tree analysis method and the STR estimation according to different approaches are drawn from literature .

Keywords— Saftey instumented systems , Spurious activation, Spurious trip rat , Fault tree Analysis.

I. Introduction

Industrial plants are technically becoming very complex and if dangers are not properly controlled the potential hazard will be increasing accordingly. In this view, risk management required the implementation of risk control measurements commonly referred as safety barriers, such as the Safety Instrumented System (SIS). This SIS are implemented in order to ensure safety envelope operating of such installations i.e. reducing risks to level below or equal to a tolerable risk.

The activation of SIS may observe after the occurrence of specific impairment (dangerous situations) compared to the normal operation (normal situations), but in some cases SIS are activated in the absence of deviations or demands: it is spurious activation (Ref).

Indeed, the unpredictability of these activations makes them critical. The functional analysis and feedback related to ST has shown that their occurrence lead to significant techno-economic losses (loss of production, maintenance costs, cost of restarting the Process, decreasing the SIS confidence level, Clients complaints, etc). Consequently, the identification of these activations, their causes, their effects and their assessment is necessary.

The quantitative assessment of these activations is used for calculating the Spurious Trip Rate (STR). According to different approaches, several analytical formulas related to the estimation of STR are developed in the literature [3], [8], [13], [17].

Company owners think that it is undeniable to minimize this type of trip as much as possible. The analysis and the quantitative assessment of these risks will provide a useful tool in the decision-making for improving the performance of SIS, hence the main target of this work.

To achieve this objective, the rest of this paper is structured as follows. Section II contains a description of a SIS and its spurious trip. In section III, an examinations and comparisons of different approaches, providing the analytical formulations of spurious trip rate is developed. The section IV offers a presentation of the proposed approach. Finally, the section V is dedicated to an application to an industrial installation RGTE (Gas Flares recovery of the field of Edjelet In Amens ILLIZI Algeria) with a summary of the presented work and suggestions for future contributions.

II. Instrumented Safety Systems and Spurious Trip

IEC 61508 [12] defines systems for safety applications by "an E / E/EP system (electrical / electronic / programmable electronics) that includes all system components necessary to fulfil the safety function".

IEC 61511 [13] defines instrumented safety systems as "an instrumented system used to implement one or more instrumented safety functions (SIFs)". SIS includes any combination of (Fig.1):

Subsystem S (Sensor): it comprises a set of input elements (sensors, detectors) that monitors the physico-chemical parameters evolution typical of the process behaviour (temperature, pressure, flow, level ...). This change is recognized by the relevant sensors which transmit a signal to the subsystem LS (Logic-Solver).

Subsystem LS: This subset of logical elements executes the decision-making process through the activation of the third FE (Final Element) subsystem.

Subsystem FE: these elements act directly (emergency stop valves) or indirectly (solenoid valves) the drift on the process is neutralized and the system automatically shuts down (safe status) after a duration that must be specified for each security function.

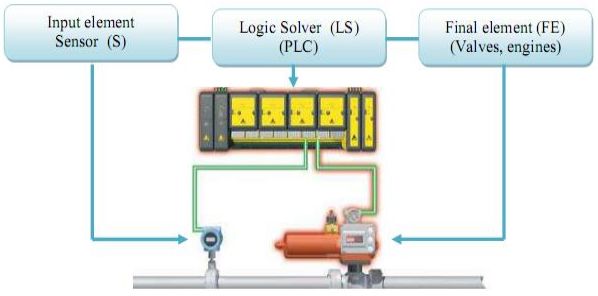

Fig. 1. SIS Example [12].

A safety instrumented function (SIF) is a function to be performed by SIS intended to ensure or maintain a state of safety of the relevant equipment (EUC: Equipment under Control) with respect to a specific hazardous event.

SIS can implement one or more SIFs. For a given situation, several safety functions may lead to a decrease in the occurrence frequency of the hazard.

The functional architecture of SIS is a set of SIFs comprising three basic features, detection (or measurement), processing (or decision), and operation.

A. *Classification of SIS failures*

IEC 61508 [12] *standad adopts a classification comprising two faults categories: physical (random hardware) and functional (systematic) (Fig.2).*

Random faults of the material described by the above standard is the following: "faults occurring randomly and resulting from various mechanisms of damage in the hardware":

- Aging equipment: Failures due to aging are called natural or primary failures. !!

- Excessive constraints: these constraints can be induced by external factors or by human errors these failures are called secondary failures.

Systematic failure is defined by the same standard as a "deterministically related failure" that can only be eliminated by a change in the design or manufacturing process, operating procedures, documentation or other appropriate factors".

- Design failures: These failures are introduced during one of the phases of the system lifecycle. They are dormant, and revealed during the operation of the system and can generally be eliminated only by a modification of the design or manufacturing process. Typical examples of such failures are design defects in software and hardware.

- Interaction failures: these failures are caused by human errors during operation, maintenance …

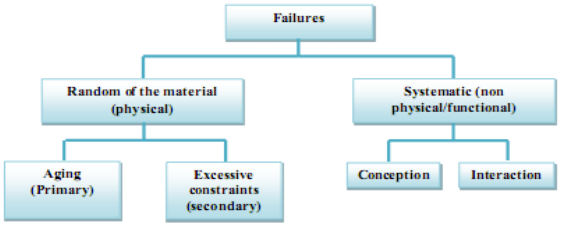

Fig. 2. Failures classification based on their causes [16].

All faults (random hardware and systematic), according to their effects, can be classified in one of two categories: (safe failures) or (dangerous failures) Fig 3.

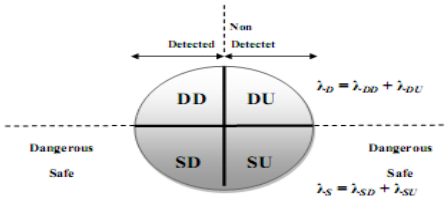

Fig. 3. Failures classification based on IEC 61508 [3].

As defined below, and according to **SINTEF [17]**: a more realistic classification than the previous one has been developed to include the spurious failures and non-critical failures as summarized by the tree indicated in Fig.4

At the component level SINTEF's PDS method considers, three types of failures: dangerous, spurious and non-critical.

From this classification, a classification of the failure rates summarized below has been developed [3]:

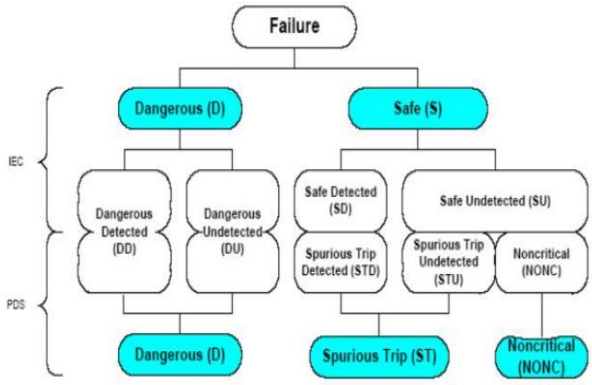

Fig.4 Faults Classifications acoording to SINEF [17]

- λ_{DD} and λ_{DU} are those defined by the standard.
- λ_{STD} is the failures trip rate detected. It corresponds to the λ_{SD} of the standard.
- The sum of ($\lambda_{STD} + \lambda_{NONC}$) corresponds to the λ_{SU} of the norm.
- The sum ($\lambda_D + \lambda_{STD} + \lambda_{STU}$) is called λ_{crit}.

Spurious failures are not even mentioned in the classification used by IEC 61508 standard, whereas the SINTEF classification considers these failures as a subclass of safe failures. The examples, often mentioned, of the spurious trip of an airbag or the inadvertent inversion of the thrust flow of a reactor in full flight are enough to show that this classification is more realistic [3].

B. *SIS Spurious Trip*

The first monothematic study dealing with the subject of spurious trips of SIS is that presented by A. Lundteigen and Rausand [8]. The authors used the collective term "spurious activation" which indicates that there is a certain transition from one state to another and the word "spurious" indicates that the trip causes are false, incorrect and non-real [8]. In an industrial process, spurious activations of SIS can cause partial or complete shutdowns of installations; hence, it is necessary to reduce their number of appearances in order to:

1) Avoid production losses after shutdowns,

(2) Avoid the risks that may appear during the restart phase.

The Fig. 5 shows the different types of spurious activations of SIS [8]:

- **Spurious operation**

Spurious operation (SO): is an activation of an element of a single SIS without a specific activation demand (real deviations). As if issuing an alarm from level transmitter without exceeding liquid level limit, because of the failure to distinguish from the foam the actual level of the liquid in a separator.

- **Spurious trip**

Spurious trip (ST): is an activation of one or more elements of SIS knowing that the SIF is performed in the absence of a specific activation demand process (real deviations). For example, two flame detectors in a 2oo3 configuration (The system will react if at least 2 components out of the 3) gives a false signal on the fire which causes the trips of the final elements and the activation of the safety instrumented function (SIF).

- **Spurious shut-down**

A spurious shut-down of the system can be partial or complete without any demand of activation (actual deviations)

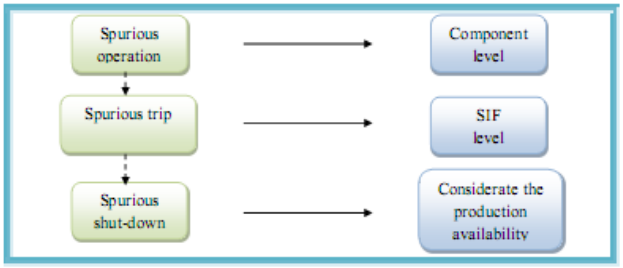

Fig.5. Different types of Spurious activations

According to [3], the different types of spurious trips haven't been stimulated by a specific request process; this brings us to the idea that requests for SIS activations are of low demand. There is no justification for this restriction; only from the fact that the area of demand continues, and the associated PFH, have been less widely studied than that of low demand and its characteristic indicator PFD_{moy}.

Indeed, « a *a spurious failure can only be defined in association to a specified safety function; it either allows the activation without any previous demand, or annihilate this function after its successful activation*" [3]. We can argue that the demand for requests in the first part of this definition is low but the second parts focus on continuous operation mode.

Another point to emphasize, is that the Spurious activation of SIS can be considered safe (perhaps temporarily), while it is dangerous. In other words, it again leads us to assert that spurious activations are not a subset of failures, or dangerous failures [3].

C. Causes of Spurious activations

Fig. 6 illustrates the main causes of spurious activations represented in an influence diagram [8].

Spurious operation, spurious activation and spurious shut-down are described as performance knots (rounded rectangles) since their occurrence rate are performance issues to be minimized in order to reduce production losses [9].

Chance knots (Circles) are indicated as factors that have an impact on spurious activations rates. These factors are out of control, but we can indirectly impact their process by applying a set of decisions.

A decision can be by choosing an element with a reliability superior than specified. Another decision is to invest in training and in personnel competencies in order to reduce human errors during maintenance and operations activities. Irrelevant decisions are illustrated in Fig. 6 as decision knots (rectangles). Arrows show the relations between decisions, impacting factors, and performance measures, dotted arrows in Fig 6, to indicate that the link is established, under some conditions, as for any given material configuration.

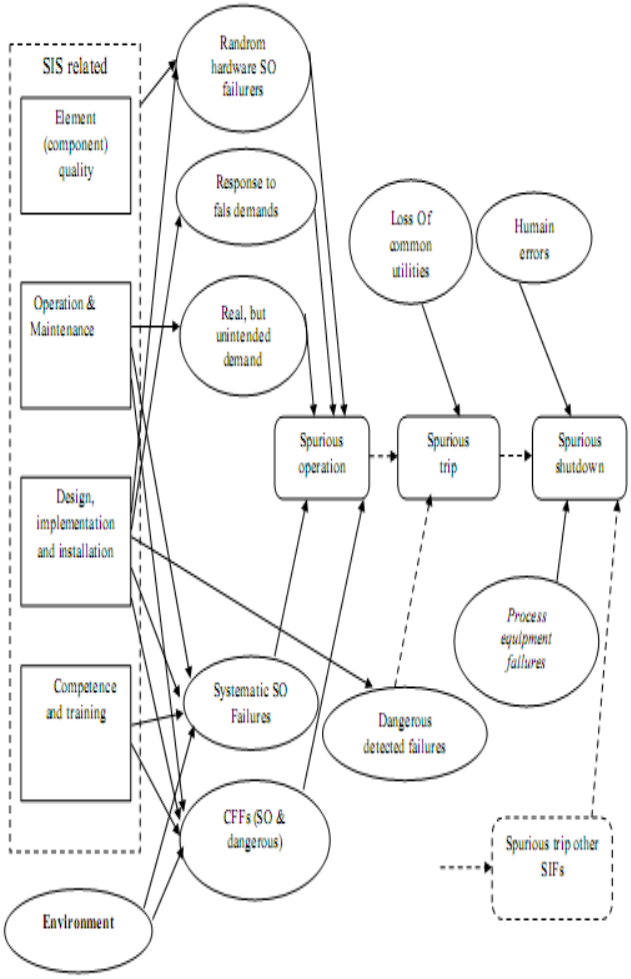

Fig. 6 Decisions and factors influencing spurious activation [8].

III. STR estimation approaches literature review

Let us first recall that the spurious trips rates STR is defined as the average number of spurious activations of the safety-instrumented function (SIF) by a unit of time [14].

This literature provides interesting works about analytic formulas related to spurious trips rates STR.

In general, for a *KooN* architecture, (N - K + 1) represents the number of dangerous failures whose occurrence induces the loss of the security function and K represents the number of spurious operations whose occurrence leads to the spurious activation of this same function.

The spurious trip rate (STR) of a well-defined safety function, provided by a given SIS, is determined by the calculation and

combination of the STR of its three subsystems (S, LS and FE). This can be expressed by the following general formula

$$STR^{SLS}_{may} = STR^{S}_{may} + STR^{LS}_{may} + STR^{FE}_{may} \qquad (1)$$

The table 1 presents a set of analytical formulas, involved with the estimation of the Spurious trip rate (STR) dedicated from the different approaches [2], [5], [6], [7], [8], [15], [16], [18].

Architecture	*Lundteigen/ Rausand)*	ISA	SINTEF	Markov
1001	$\lambda_{SO} + \lambda_{DD}$	$\lambda_S + \lambda_{DD}$	λ_{SU}	$\lambda_{SU} + \lambda_{SD}$
1003	$(3 - 2\beta_{SO})\,\lambda_{SO} + \beta_{DD}\,\lambda_{DD}$	$3.\,[\lambda_S + \lambda_{DD}] + \beta\,(\lambda_S + \lambda_{DD})$	$3\,\lambda_{SU}$	$3\cdot((1-\beta_{SD})\,\lambda_{SD} + (1-\beta_{SU})\,\lambda_{SU}) + \beta_{SD}\,\lambda_{SD} + \beta_{SU}\,\lambda_{SU}$
2002	$\beta_{SO}\,\lambda_{SO} + \beta_{DD}\,\lambda_{DD}$	$2\lambda_S\,[\lambda_S + \lambda_{DD}].MTTR + \beta\,(\lambda_S + \lambda_{DD})$	$\beta\,\lambda_{SU}$	$2\cdot(\lambda_{SD} + \lambda_{SU})\,[(1-\beta_{SD})\,.\,\lambda_{SD}.MTTR_{SD} + (1-\beta_{SU})\lambda_{SU}(T_1/2+MTTR_{SD})] + \lambda_S D_{CC}$

Tab.1. STR formulas of different approaches

IV. Case Study

In order to confirm the proposed approach, which consists in modelling and quantifying the STR, an operational SIS has be selected from the boosting section of the RGTE facilities of the Edjelet-In Amens W-ILLIZI Algeria field. This section mainly comprises two essential parts: a Boosting section and a compression section. The blower section has been chosen as a case study given its importance in the process of gas recovery (Fig.7). The recovered gases from the four (04) separation centres are collected by the buried low-pressure collection pipes and transported to the intake manifold of the blower section. Then the compressed gas is sent to the compression structure [10], [11].

In order to avoid any immediate loss of control of the blower section operations, and the potential personnel injuries and proprieties damages thus, anomalies should be immediately handled. Therefore, the activation of the emergency shut-down system (ESD).

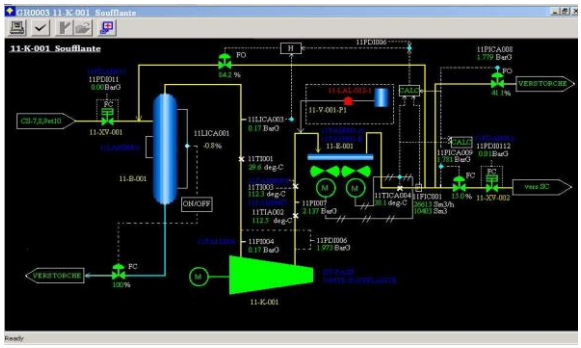

Fig.7. Blower Section.

The ESD system installed in the blower section is a low-demand SIS type that, when activated, provides automatic total RGTE shut-down (blower and compression sections). Its activation provides minimization of the risk consequences. The ESD system comprises a set of input elements (transmitters, detectors) that monitor the evolution of physico-chemical characteristics of the blowing section process behaviour (temperature, pressure, level). If at least one of these parameters deviates beyond normal operational standards, and remains there, this deviation refers to demand or request. It is detected by the involved sensors which send a signal to the logic programmable controller unit. The architecture of the logical drive is based on a redundancy called Triple-Modular Redundant (TMR). It includes three identical, parallel and isolated processing modules with diagnostic execution by a single card which, in case of deviation, gives the order to carry out the following actions:

Shut-down of compresseur11-K-001;

- Closing of the suction isolation valve of 11-K-001: 11-XV-001 Closing of the discharge isolation valve of the 11-K-001: 11-XV-002
- Opening the vent valve on the 11-K-001: 11-PV-008;
- Opening the anti-pumping valve of 11-K-001: 11-FV-001

Figs 8 indicate the structure of the elements of the blower section system ESD.

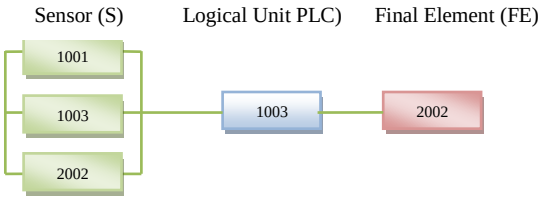

Fig.8. ESD system structure.

A. STR Modelling by FT

In order to determine the root causes of spurious trip of the blower section, the modelling of ST's will be performed by the Failure Tree method (FT).

Fault Tree or "FT" is a graphical tool widely used in operating safety; it enables a graphic representation of possible combinations related to causes leading to predefined undesirable events (UE). The FT is made up of successive levels of events revolving through logical gates. FT is a deductive method that can be used as a design assessment tool. Minimal cuts are recognized thanks to FT qualitative processing, which represent the smallest combinations of causes enabling the occurrence of the Undesirable event. Probability or frequency of occurrence of undesired events is calculated using quantitative treatment method [18].

System Spurious Trip (SST) of blower section is considered as critical or undesirable event of the FT (Fig. 9). It is worth noting that common cause failures are taken into consideration during modelling. The Development and processing of FT is performed by GRIF software.

The obtained Boolean expression of UE is::

$$S = C_1 + C_2 + \cdots + C_n = \sum_{i=1}^{n} C_i \qquad (2)$$

$S = ST\,(Spurious\,Trip)$

$$= MP1 + MP2 + MP3 + (V1 \times V2) + L1 + L2 + P1 + P2 + P3 + P4 + T1 + T2 + T3 + T4 + T5 + T6 + T7 + (T8 \times T9) + (T10 \times T11) + (T12 \times T13) + (T14 \times T15) + (T16 \times T17) + (T18 \times T19) + (T20 \times T21) + (T22 \times T23) + (T24 \times T25) + (T26 \times T27) + (T28 \times T29) + (T30 \times T31) + DC \qquad (3)$$

The qualitative treatment of FT shows a minimum of 33

cuts:

- 17 cuts of type 1
- 13 cuts of type 2.

As first interpretation of these results, we conclude that ST occurrence is caused by logical units and temperature sensors failures

in particular. The number of minimal cuts indicates the weakness of studied SIS, which allows spurious trip or UE occurrence.

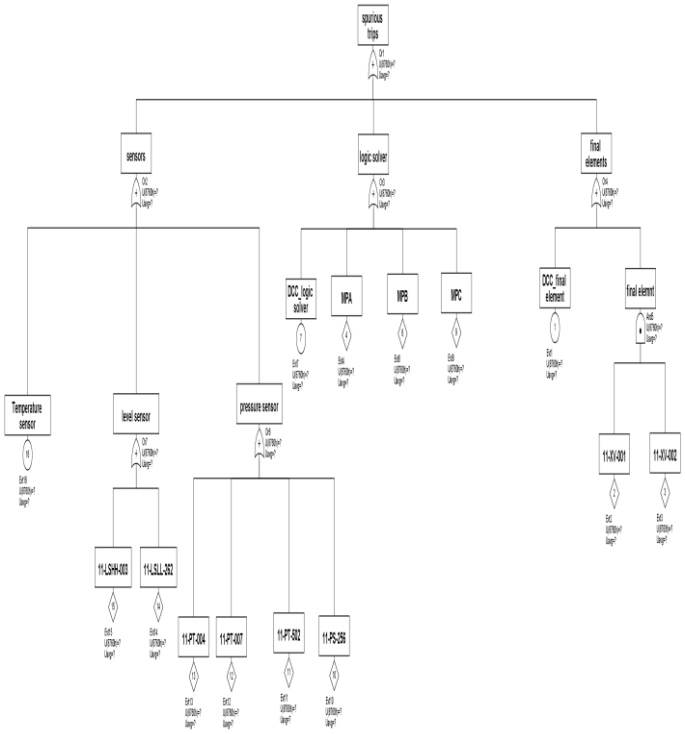

Fig.9. STR Modeling by FT

The obtained Boolean expression of UE is::

$$S = C_1 + C_2 + \cdots + C_n = \sum_{i=1}^{n} C_i \qquad (2)$$

$$\begin{aligned} S = ST\,(Spurious\ Trip) \\ = MP1 + MP2 + MP3 + (V1 \times V2) + L1 + L2 + P1 + P2 + P3 + P4 + T1 + T2 + T3 + T4 + T5 + T6 + T7 + (T8 \times T9) \\ + (T10 \times T11) + (T12 \times T13) + (T14 \times T15) + (T16 \times T17) + (T18 \times T19) + (T20 \times T21) + (T22 \times T23) + (T24 \times T25) \\ + (T26 \times T27) + (T28 \times T29) + (T30 \times T31) + DC \end{aligned} \qquad (3)$$

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Quantification of STR by FT

It was stated in the third part technical report of ISA-TR 84.00.02 [4]; spurious trip rate estimation is different from the Probability Failure on Demand (PFD), whereas STR is a frequency. For the OR gate two basic events of STR is the total of STRs for each component, and for the 'ET' gate, the STR is mathematically calculated as two basic events shown herein:

STR = Probability of component 1 failing x *Frequency of Component failing 2+ Probability of Component 2 failing* x *Frequency of Component 1 Failing* (4)

The probability of occurrence of the undesirable element is:

$$P(S) = P[C_1 + C_2 + \cdots + C_n] = P[\sum_{i=1}^{n} C_i] \qquad (5)$$

The data used to evaluate the STR of Emergency System Shutdown (ESD) for the blower section is taken from PDS Data Handbook, Edition 2006 [**18**].

$$\begin{aligned} P(S) = P(ST) = STR \\ = P[MP1 + MP2 + MP3 + (V1 \times V2) + L1 + L2 + P1 + P2 + P3 + P4 + T1 + T2 + T3 + T4 + T5 + T6 + T7 + (T8 \times T9) \\ + (T10 \times T11) + (T12 \times T13) + (T14 \times T15) + (T16 \times T17) + (T18 \times T19) + (T20 \times T21) + (T22 \times T23) + (T24 \times T25) \\ + (T26 \times T27) + (T28 \times T29) + (T30 \times T31) + DC] \end{aligned} \qquad (6)$$

These data are used for characterization of common cause failures (CCF):

- $\beta_{DD} \approx \beta_{SO}$
- $\beta_{DD} \approx \beta_{SO} \approx 10\%$ for input element parts (S) and final elements (FE).
- $\beta_{DD} \approx \beta_{SO} \approx 1\%$ for the logical partial unit (LPU).

After the numerical applications, the estimated STR value is **5.97 E-05 hours (h)-1.**

A comparison of the obtained mathematical and analytical results is shown in the table 2:

Designation	STR LUND/RAUSA (h^{-1})	STR ISA (h^{-1})	STR SINTEF (h^{-1})	STR Markov (h^{-1})	STR ADD (h^{-1})
Sensor (S)	1.91 E-05	2.22 E-05	8.42 E-06	1.48 E-05	**1.45 E-05**
Logic solver (LS)	4.48 E-05	7.53 E-05	3.60 E-05	4.47 E-05	**4.47 E-05**
Final Element (FE)	3.40 E-07	3.40 E-07	2.70 E-07	3.28 E-07	**5.40 E-07**
STR_{ESD}	6.43 E-05	9.78 E-05	4.47 E-05	5.99 E-05	**5.97 E-05**

Tab.2. STR estimation by different approaches

Comments:

- The obtained value of the STR estimated by FT and Markov Model are similar.

- STR value for FE subsystem « Final elements (FE) » is relatively small compared to the other two subsystems values. Therefore, one can approximate the equation (1) of STR, and would become:

- Results Comparisons

$$STR_{ESD} \approx STRSi + STR_{LS} \qquad (7)$$

V. Conclusion

As a reminder, this work aims to quantitatively asses and model the rate of spurious trip implemented in an operating industrial facility, through the application of failures tree Analysis (FTA) method. A comparison of the results obtained with those given by applying the analytical formulas found in the literature, indicates that the application of FTA method is a very adequate

tool for risk analysis and quantification related to spurious trip of SIS.

It's noteworthy, that spurious trip should be reduced to the maximum as their activation may lead to increase the company losses. Neither less, an appropriate maintenance strategy is highly recommended to decrease the STR, this strategy leads to achieve a safety balance compromise – availability. These strategies might be developed in the future works.

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Nomenclature and notations

$\boldsymbol{\lambda}$ failure rate.
$\boldsymbol{\lambda_D}$ dangerous failure rate.
$\boldsymbol{\lambda_{DD}}$ dangerous detected rate.
$\boldsymbol{\lambda_{DU}}$ dangerous undetected rate.
$\boldsymbol{\lambda_S}$ safe rate.
$\boldsymbol{\lambda_{SD}}$ safe detected rate.
$\boldsymbol{\lambda_{SU}}$ safe undetected rate.
$\boldsymbol{\lambda_{STD}}$ spurious trip detected rate.
$\boldsymbol{\lambda_{STU}}$ spurious trip undetected rate.
$\boldsymbol{\lambda_{NONC}}$ no critical failure rate.
$\boldsymbol{\lambda_{SO}}$ spurious operation rate.
$\boldsymbol{T_1}$ test interval.
$\boldsymbol{MTTR_{SD}}$ mean time to repair safe detected.
$\boldsymbol{\beta_D}$ beta factor for dangerous detected failures.
$\boldsymbol{\beta_{SD}}$ beta factor for safe (spurious) detected failures.
$\boldsymbol{\beta_{SU}}$ beta factor for safe (spurious) undetected failures.