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A Benefit /Cost Approach for Prioritizing Plant Modifications to Reduce Risk below Acceptance Limit

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The paper describes practical experience with the application of a benefit/cost approach for prioritization of plant improvement expenditure to reduce both Health Safety and Environmental (HSE) risk and production loss risk below acceptable level. The method has been developed during a three-year SIL allocation programme implemented in more than 10 petrochemical plants where risk associated to safety functions failing upon request has been determined in order to establish safety function required availability to meet risk level requirements.
Conducting a SIL analysis using a combination of technical documentation (P&I Diagrams, Cause and Effect Matrix), safety documentation (HazOp, Fire Fighting System data) and economical parameters (equipment cost, product prices, raw material cost) leads to the identification of initial risk level of petrochemical plant units with regards to three categories, i.e. Safety, Environment and Economic. Resulting SIL level of each safety function corresponds to the highest reduction rate required to lower initial risk within tolerable range. Plants built before the issue of IEC 61508/61511 typically result in high SIL level associated to safety functions, being that safety system architecture was developed without considering reliability requirements for safety loops. Criteria to achieve adequate risk reduction minimizing SIL level of safety functions, e.g. ensuring full independence of safety functions final elements, minimizing frequency of causes, etc. have been evaluated considering the benefit in less severe maintenance requirements and lower cost for modifications.

1. SIL Analysis

1.1 Requirements

Allocated SIL is the indicator of reliability required for a safety function in order to reduce initial risk level to an acceptable level; therefore a Risk Matrix needs to be defined prior to start SIL allocation. For each safety function, the initial risk of the scenario needs to be assessed in first place and protection granted from independent protection layers has to be subsequently considered to establish actual reliability required to achieve acceptable risk level. The following information is required to perform initial risk assessment:

- Technical data (Process Conditions, Mechanical Design, etc.)
- Safety data (Properties of Chemicals, Hazard Identification, etc.)
- Economic data (Asset/Equipment cost, Plant Contribution Margin, etc.)

1.2 Issues

Recurring issues which may hamper SIL allocation can be summarized in:

- Plant documentation incomplete or not updated to “As Built”
- Team members inexperienced or not covering all required competencies
- Unclear criteria to evaluate frequency for human errors
- Unclear criteria to evaluate reliability and effectiveness of human intervention when responding to an alarm
- Unclear criteria to evaluate probability of ignition

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- Analysis of Instrumented Systems designed before IEC61511 issue that have no segregation between control functions and safety functions

2. Versalis Case

2.1 Approach

With 14 different production sites spread across Europe (Italy, Germany, France, Hungary, United Kingdom), Versalis priority was identified in finding an adequate evaluation process that would have allowed the assessment of reliability requirements for each of the more than 5000 active SIF in a reasonable time.
In consideration of the considerable amount of existing safety functions to be analyzed, Risk Graph methodology has been chosen to carry out the SIL allocation.
With respect to quantitative approaches (e.g. LOPA, QRA), Risk Graph methodology allows a rather quick identification of required safety integrity level, typically with narrow margin with respect to results that could be obtained through more sophisticated tools. However, use of LOPA or QRA would still prove useful to deepen and confirm the evaluation obtained via Risk Graph methodology for SIF that have been allocated with highest SIL level (e.g. SIL 3 / SIL 4) where target reliability would be technically difficult or highly expensive to achieve.
A pilot study on a plant has been carried out in order to fine tune Risk Matrix that has been used thereafter to allocate all safety functions analyzed during the programme. Specifically, a comparison between pilot study results and SIL typically allocated in petrochemical industry has been evaluated with Versalis HSE management to set the appropriate tolerable risk level, thus defining the Risk Matrix.
The SIL programme should be based on some criteria to optimize costs of the analyses and plant staff involvement:

- Information availability: to ensure full effectiveness of the SIL analysis execution it is necessary to have HAZOP study reports available, including HAZOP worksheets complete and detailed, plant documents complete and updated (P&ID, cause & effect diagrams, data sheet, etc.); production data and income/margins for plant/product; costs of equipment and assets (including piping, buildings, etc.).
- Investments/interventions planning: SIL activities should be programmed considering interventions/investments expected in the plants (as major modifications, revamping, new plant) can be useful planning the SIL analysis in a coordinate way.
- HAZOP activity planning: perform the SIL analysis concurrently or immediately after a HAZOP study, when possible.
- Type of plant: perform the SIL analysis on similar type of plants in sequence in order to take advantage in terms of economies of scale.

A dedicated Corporate Guideline has been developed by Versalis on the basis of IEC 61511 requirements. In addition to IEC requirements, the Guideline establishes criteria that allow the definition of a homogenous and structured approach to determine the frequency of typical events (e.g. pump failure, control loop failure) as well as the effectiveness of human operator intervention in case of emergency condition.

2.2 Objectives

By carrying out a systematic SIL allocation, Versalis expect various benefits which will enable the development of a detailed action plan oriented to risk reduction and prioritization of future investments on the basis of risk level. Such benefits are:

a) Improved awareness of risk level associated to each plant in terms of possible undesired events affecting safety, environment and economic factors
b) Use of a homogeneous criterion for risk evaluation for all plants
c) Identification of the critical process equipment/asset
d) Opportunity to assign specific fault rates to control loops leading to a more accurate statistical predictability of incident scenarios and therefore increasing quality of plants’ safety report
e) Change instrumentation maintenance philosophy from reactive to predictive approach leveraging on reliability requirements set by SIL allocation and gap analysis with SIL verification
f) Development of specific recommendations resulting from the risk assessment
g) Assessment of influence determined by detailed design (e.g. control valve failure position, check valves)
h) Opportunity to lower insurance fees (e.g. business interruption) through an increased knowledge of plant risk exposure

2.3 Results

Comparison of analysis results for similar plants (e.g. High Pressure LDPE production) showed that allocated SIL distribution resulted to be highly dependent on plant design criteria and adopted technology rather than on process type (see Figure 1 to Figure 4). In general, allocated SIL resulted higher where independence of final elements capable to prevent scenarios was limited.

Allocated SIL	SIF #
SIL a	75
SIL 1	49
SIL 2	39
SIL 3	12
SIL 4	0
SIL b	0
Totale	**175**

Allocated SIL distribution

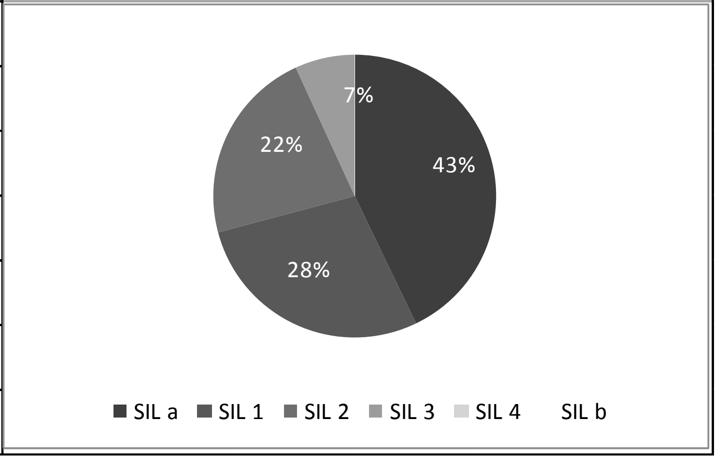

Figure 1: Low density Polyethylene Plant 1

Allocated SIL	SIF #
SIL a	45
SIL 1	47
SIL 2	9
SIL 3	0
SIL 4	0
SIL b	0
Totale	**101**

Allocated SIL distribution

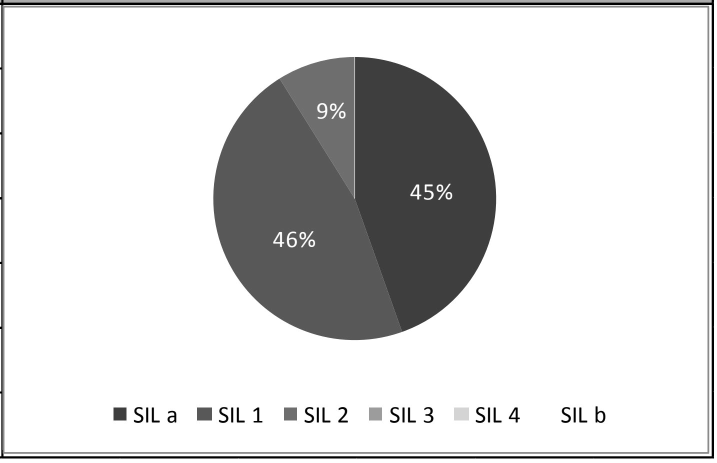

Figure 2: Low density Polyethylene Plant 2

Allocated SIL	SIF #	Allocated SIL distribution
SIL a	79	
SIL 1	73	
SIL 2	46	
SIL 3	8	
SIL 4	0	
SIL b	0	
Totale	**206**	

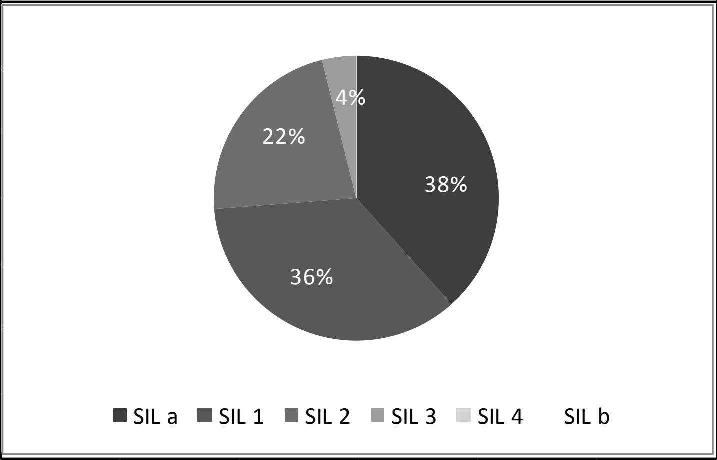

Figure 3: Steam Cracking Plant 1

Allocated SIL	SIF #	Allocated SIL distribution
SIL a	75	
SIL 1	22	
SIL 2	51	
SIL 3	3	
SIL 4	0	
SIL b	0	
Totale	**151**	

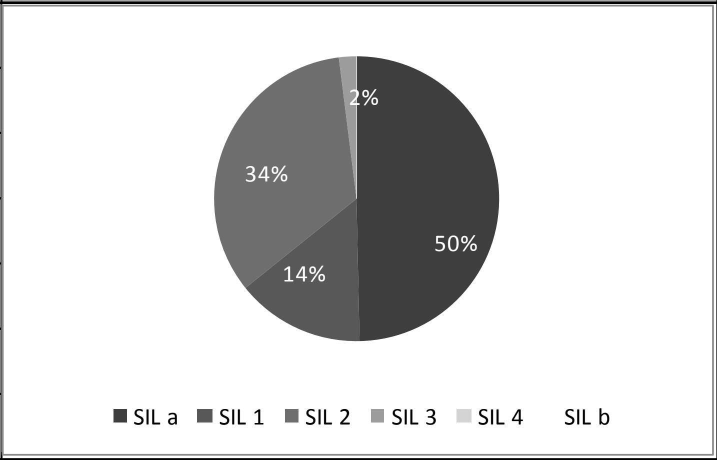

Figure 4: Steam Cracking Plant 2

2.4 Recommendations

While performing evaluation of causes and consequences that could originate in case of SIF failure on demand, Arthur D. Little identified and recommended possible interventions capable to reduce reliability requirements of safety functions.

Table 1: Recommendations provided to reduce Risk

SIF Description	SIL	Recommendation
Pentane pump high discharge pressure	2	To prevent pump seals damage and loss of containment, evaluate implementation of control logic to automatically stop pentane pump when high level of destination drum is reached
Liquid polyethylene separator high pressure	2	To prevent exceeding of downstream evaluate installation of an independent safety logic capable to cut off liquid/gas flow to downstream system
Styrene column low level	3	To grant adequate intervention time to operator in case of SIF malfunctioning, evaluate installation of level transmitter on pump seals pot and implementation of level alarm
Cracked gas compressor suction K.O. drum high level	3	To prevent liquid carry over to compressor with consequent seal damage and loss of containment, evaluate implementation of K.O. drum automatic drain logic to blow down

3. Managing Gaps between Allocated SIL and Verified SIL

A dedicated analysis is required for Safety Functions that have been identified during SIL verification to be less reliable than required to reduce risk below acceptable value. Engineering of an improvement requires often a considerable amount of time in consideration of the different aspects that need to be evaluated, both technical and economical.

3.1 Optimization

An optimization of plant safety systems can be enacted through several different criteria (Table 2)

Table 2: Optimization opportunities

Scenario	Optimization Opportunity
Highest allocated SIL is determined by the frequency of occurrence of a single cause with respect of all other applicable ones	Evaluate how to reduce frequency of occurrence of the cause leading to scenario (e.g. Control Valve failure position)
Highest allocated SIL is determined by prolonged loss of production as a consequence of equipment damage	Evaluate cost benefit of having available spare asset
Highest allocated SIL is determined by inability of operators to escape from scenario	Evaluate benefit of installation of gas detectors with local alarm to alert operators before flammable conditions are reached. Evaluate access restriction to areas subject to high risk scenario
Availability of independent alarm function	Modify alarm thresholds to ensure that 30' are available for operator to intervene in order to avoid occurrence of scenario (e.g. reduce high level alarm threshold of a compressor suction K.O. drum to ensure that at

Scenario	Optimization Opportunity
	least 30’ are required from alarm activation to overfilling
No redundancy among final elements of multiple safety functions protecting same equipment/process section	Install independent final elements associated to safety function which is applicable as Independent Protection Layers (IPL) for the largest number of other SIF (e.g. independent furnace fuel supply block valve closure activated by flame detectors; independent electric breaker on motor power supply activated by high vibrations of a compressor)
Available improvements in equipment design / technology	Install non-instrumental safety devices (e.g. replace traditional pumps with canned pumps, install controlled torque shafts, fusible instrument air tubing, sprinklers activated by glass capsules)

3.2 Temporary Solution

As long as the required modifications are not in place, organizational/procedural (including maintenance and test intervals) changes should be put in place to reduce risk at minimum. Changes should ensure that deviations leading to undesired scenarios are tackled by plant operators. It is therefore envisaged to train personnel on how to react in case such deviations may occur.

4. Conclusions

The analysis of all safety instrumented functions performed as part of a SIL allocation programme conducted on existing plants ensures use of a homogeneous criterion for risk evaluation and allows collection of information useful to companies’ management when evaluating risk mitigation measures and related investment needs.

The difference between allocated SIL and verified SIL is the risk to which a company is exposed in excess to acceptable level and can be easily adopted as criterion to define prioritization of plant improvement expenditure targeted to risk reduction.

Once that priority for improvement is known, optimization of investment can be carried out through a detailed analysis of causes and frequency factors determining higher SIL in order to evaluate cost effective opportunities leading to reduction of initial risk or improving effectiveness of existing IPL.

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