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Implementation of a Safety Instrumented System: A Comprehensive Review and Conceptual Framework

Arief Goeritno[1]*, Muhidin Muhidin[1], Sarah Chairul Annisa[1], Fitriani Fitriani[1], Irham Muhammad Azama[2], Roy Waluyo[1], Suratun Suratun[1], Fithri Muliawati[1], Joki Irawan[1], and Afham Ramadhan[1]

[1] Universitas Ibn Khaldun Bogor, Indonesia

[2] Universitas Muhammadiyah Purwokerto, Indonesia

*email: arief.goeritno@uika-bogor.ac.id

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ABSTRACT– A safety instrumented system (SIS) is specifically designed to protect personnel, pieces of equipment, and the environment by reducing the likelihood or severity of the impact of identified emergency events. This review has five objectives, i.e., (i) to find the layers of protection, (ii) to figure out and implement the SIS through life cycle step design, (iii) to find the Safety Integrity Level (SIL), (iv) to find the Safety Requirement Specification (SRS), and (v) to figure out and think about the SIS design that will be used. The study's methods are algorithms that a researcher uses to carry out research in stages of achievement and accordance with research objectives. Referring to the review proposed, five results have been achieved, which are guided by the process stages. The SIS design has been implemented and can be used as a reference for understanding the basic concepts and instrumentation of process control systems. The second is figuring out and implementing the SIS, which is an essential stage in the life-cycle step process. The third, the SIL determination, can be done using qualitative or quantitative methods that involve evaluating two risk components, e.g., probability and severity, and lies in the risk levels and the weighting structure. Furthermore, a matrix shows many of the factors that are used to determine the SIL levels. Fourth, the SRS consists of two parts, i.e., requirement specification of the functional and the integrity. Fifth, one of the considerations in designing the SIS is the separation between the SIS and the BPCS, thereby reducing the possibility of both systems failing simultaneously. Finally, the consequences range from minor injury to high death, and the main conclusion in this article is that the concept system will make it easier to find references or get predictions for determining instrumentations and creating a process control system.

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Introduction

A safety instrumented system (SIS) is a system that monitors the parameters and values of processes within the status of an essential condition and remains within defined limits. An SIS contains sensors, logic solvers, and final elements [1, 2]. An SIS is specifically designed to protect personnel, pieces of equipment, and the environment by reducing the likelihood or severity of the impact of identified emergency events [3-5]. The use of an SIS when operated for an action is to prevent or reduce risks during processing under abnormal conditions that may be dangerous [6]. An SIS is an embedded system in industrial control and automation systems, together with the Basic Process Control System (BPCS). This is a development of conventional SIS-based processes [5]. Conventional process control in industry or otherwise, often consisting of a set of software black boxes, is accessible only to a minimal number of specialized and highly technical personnel [7].

The issue of safety instrumented systems (SIS), which are components of a system, encompasses a variety of themes [8-11, 1, 3, 4, 12, 6]. In addition to being published in the form of technical reports or scientific publications, practical demonstrations of the idea of the SIS's significant role have been installed and put into practice [8-11, 1, 3, 4, 12, 6, 7]. The examination of the steam purification system's instrumentation and process control system is just one of its several facets [7]. In addition to programmable logic controllers (PLCs), distributed control systems (DCSs), national standards, and regulatory concerns in each country, the SIS is one of the primary process control subjects and plays a significant role in the major sectors. From design to implementation, or from start to finish, instrumentation and control systems are the most crucial components in the field of process automation [13]. Businesses are constantly presented with chances by automation to realize greater operational performance through higher productivity and lower costs, as well as increased safety and dependability [14-17]. As a result, it is essential to explain in simple terms the significant role of the SIS, which is intimately tied to instrumentation and process control, through lectures [18, 19].

Implementing the conception of safety instrumented systems were examined through -describing the variety of sensors, -explaining the logic solver, and -describing the variety of final elements which used to examine the systems of instrumentation and process control in order to implement the concept of safety instrumented systems [9]. An explanation of the definition, function, and types accomplishes both description and example. The benefits of implementation of an SIS comes from using various sensors as examples to explain the logic solver, the logic solver as examples for various final elements, and various final elements as examples for a basic overview of how crucial safety instrumented systems are [9]. A system is, broadly speaking, a group of items that are connected to one another [20]. The systems may be conceptual, physical, or a combination of the two. While conceptually the systems are abstract systems of pure information that do directly exhibit "meaning but but not behavior," the physical universes are made of matter and energy, may include information encoded in matter-energy carriers, and display observable behavior [18, 20].

The basic concepts of a control system aim to minimize error and time response, while the instrumentation for the control system at least aims to monitor, record, and log the condition status and process parameters [21, 22]. The basic concept of a control system for a process or process, currently better known as a Basic Process Control System (BPCS), is a system mechanism for handling a process in monitoring and controlling a facility or equipment. For the implementation of this basic concept, a number of parameters are actually needed on the input line, which are derived from the monitoring results of the sensors installed according to the strategic and control system design [23]. Basic process control systems are a crucial element in the proper operation of a process or plant and, in many instances, are used as the first layer of protection against unsafe conditions or emergencies [24, 25]. A simple example of a basic schematic diagram of BPCS [26, 27, 24, 25, 5-7, 28] is shown in Figure 1.

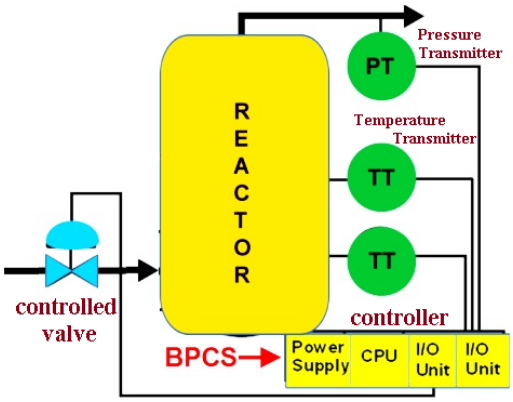


Figure 1. A simple example of a basic schematic diagram of BPCS

Based on Figure 1, it is shown and can be expalined, that an PT (pressure transmitter), an TT (temperature transmitter), and a controlled valve (CV) are used to control the steam in a reactor (process tank) based on a controller. Electronic instruments have become necessary for the needs of essential process control system functions. The fundamental conception with minimum instrumentation requirements is the basic design for meeting various industrial challenges in monitoring and operating a system in the industry [29].

Process control is an action to maintain the desired condition of a physical system by setting certain variables in the system even though there are disturbances that affect the system and observation noise [30]. Process control systems offer a number of advantages, such as automated production processes, cost savings, and reduced downtime for a facility [31]. In a process control system in the industry, quantities are often needed that require special conditions or requirements, such as high accuracy, constant prices for specific time intervals, varying values in a particular range, a fixed ratio between user variables, or one quantity as a function of another [32, 33]. Obviously, more than this needs to be done just by measuring; it also requires a control method so that these requirements can be met. It is for this reason that a control concept called the control system was introduced [34, 29].

According to the reason for choosing the title in the background paragraph and supported by a number of paragraphs regarding the state-of-the-art from previous research that are related to the topic and theme of this study, i.e., a paragraph is made for determining the formulation of the problem so that some objectives of the research can be determined. Some stages for solving the problem formulation related to each research objective include the description of the layers of protection, the safety instrumented system, the safety integrity level, and the safety requirement specification.

Guided by the problem formulation of this study, the five objectives of the comprehensive review are discussed further, i.e., (i) to get the layers of protection, (ii) to guide on determining and implementing an SIS through life cycle step design, (iii) to obtain the Safety Integrity Level (SIL), (iv) to determine the Safety Requirement Specification (SRS), and (v) to determine and consider the SIS design to be implemented. After achieving each research objective, it can be hoped for some benefits, namely that getting the layers of protection can be used as a reference for determining and implementing the SIS, designing the SIS through the life cycle step can be used as a reference for obtaining the SIL, and after the SIL is obtained, it can be used as a reference for determining the SRS. After the SRS is obtained, it can be used as a reference for determining and considering the design of the SIS. Finally, the SIS design is to be implemented and can be used as a reference for understanding the basic concept and instrumentation of the process control system. The rest of this article is organized as previous articles [35-37] as follows: chapter 2 presents our proposed materials and methods of the studies; Chapter 3 presents the results and discussion; and Chapter 4 presents the conclusion.

Materials and Methods

A. Materials of the Study

Several materials in this study are needed for data and information enrichment [38]. Research materials can come from various sources. These sources include reference books, regular books, special collections, magazines, scientific articles in different journals, and multiple sources from the Internet [39]. Not all reference sources must be used as research material [40]. The central portion of a scientific article comes from journals containing articles from the last decade. Each source of research material has its advantages and disadvantages [41].

The category of reference books includes atlases, encyclopedias, general or specific dictionaries, almanacks, maps, specifical biography dictionaries, guides of the government, and official yearbooks that contain information about what happened during a particular year, including statistical data, other facts, highlighting events, and other similar resources. The advantages of reference books are that they provide a good overview of a topic and valuable facts and statistics [42]. However, the information in reference books is often very general and must include the most recent information. As existing encyclopedias, they may need to be published more frequently to cover trends or new topics.

In addition to reference books, entire regular books or only parts of other books may be devoted to the topic of this article. Regular essays are often helpful in providing a more in-depth look at a topic. Apart from that, the regular book may also be a pointer to how the topic is related to other topics, themes, or issues. Unlike reference books, regular books need to be examined in several libraries. The need for more regular books is related to the limited availability in each library or the need to search for them from other sources [41].

B. Methods in the Implementation of the Study

This literature study stage begins with the sources of the latest information on the topics to be discussed, which can be obtained from magazines, scientific journals, newspapers, and other recent printed materials. For any findings that have been recently published in this resource, please use the guidelines for inclusion of the most recent (and older) articles and their specific publication information. Articles provide up-to-date information, but you can only sometimes tell from the information in the index whether they contain helpful information for your assignment. We usually read the article to see if it's relevant. Also, finding the actual article can take time and effort. Not all libraries carry or store all periodicals [42].

The methods of the study is an algorithm used by the researcher in conducting research [7, 35, 37, 9] that is carried out in stages for achievement and by research objectives. A flowchart of the study methods is shown in Figure 2.

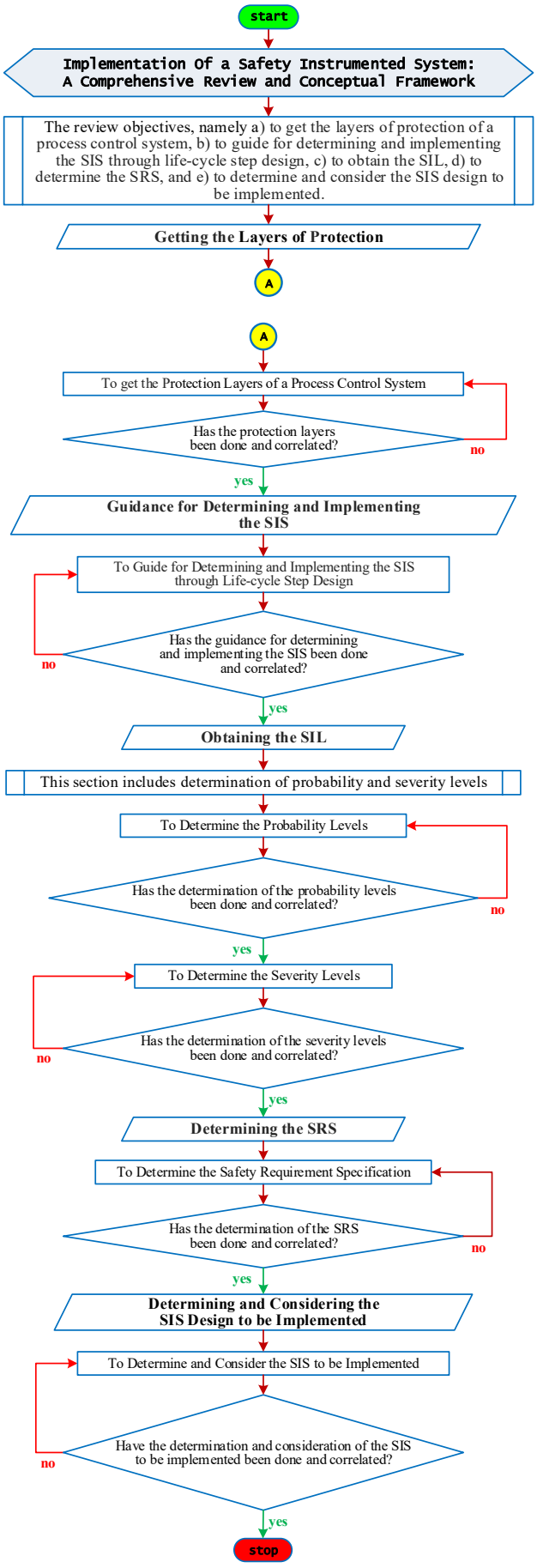


Figure 2. A flowchart of the research methods

Based on Figure 2, it is shown and can be explained, that this study has five objectives are discussed further in the chapter

of results and discussion, namely (i) getting protection layers, (ii) guidance for determining and implementing an SIS through life cycle step design, (iii) determination of SIL, (iv) determination of SRS, and (v) determination and consideration of the SIS design to be implemented.

Results and Discussion

The application of an SIS in a system must begin with a study that explores and considers all related factors of the system being installed so that, later, it will lead to a decision on whether or not to apply an SIS to the system. Several things can be taken into consideration when making this decision, including an assessment of the level of risk and reliability of the installed system. The risk level is the level of potential possibility or probability and the severity or severity of the operating process if the installed control or safety system fails. This concerns the analysis of the causal factors and consequences for the system as a whole, including mitigation actions that must be prepared and carried out. The level of reliability of the protection layer is in the form of a control and safety system that has been installed. This concerns the analysis of the level of effectiveness of the existing system in carrying out its functions.

A. Getting the Layers of Protection

The level of risk of hazardous conditions occurring in each process will depend on the level of protection installed in the system. An SIS designed to perform this function is part of a layer of protection or layers of protection of a system. An SIS and other systems ensure that a process can run smoothly and safely. The protection layer of a process control system [43, 5, 7, 28] is shown in Figure 3.

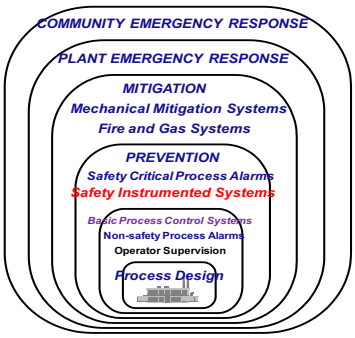


Figure 3. The protection layer of a process control system

Based on Figure 3, it is shown and can be explained that the explanation of the protection layers is preliminary design, critical alarm, and automatic SIS [41, 42].

Preliminary or basic design is protected by the Basic Process Control System (BPCS) through a design suitable for the conditions encountered. This level consists of basic controls, alarms, and operator supervision. The critical alarm at this level is facilitated by installing a crucial alarm that informs the operator that a dangerous condition will occur in a vital facility so that the operator has time to take mitigation actions. An SIS that works automatically or automatically works independently and does not depend on BPCS. An SIS can work to shut down the system if the two previous layers (BPCS and alarm) cannot prevent dangerous conditions from arising [46-48].

B. Guidance for Determining and Implementing the SIS through Life-cycle Step Design

To produce a reliable and safe system, a standard of handling is required that guides us in every step of determining and implementing an SIS. One standard commonly used for handling SIS is ANSI/ISA S84.01 of 2004, which guides the form of flowcharts called life cycle steps [49, 50]. The guide will help us determine the life cycle of the system that we will implement, starting from the initial concept creation, determining the safety aspects of the system, and the system change process that will be carried out to the system operation stage. In the initial study, information will be obtained about the level of risk and consequences for the failure of the control system of a process, which will lead us to a decision on whether or not to implement an SIS. A flowchart of the process of the life-cycle step diagram for determining and implementing an SIS [44, 45] is shown in Figure 4.

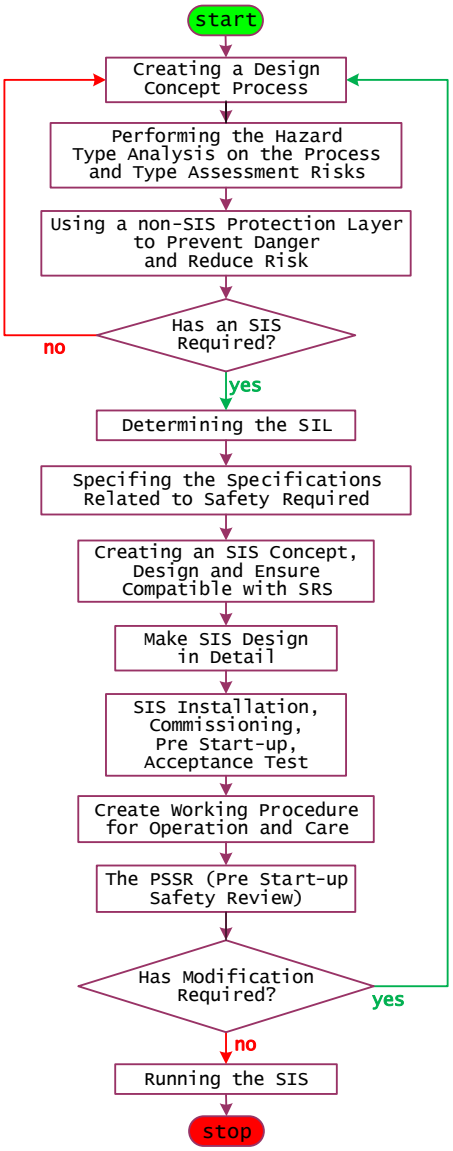


Figure 4. A Flowchart of the process of the life-cycle step diagram for determining and implementing an SIS

Figure 4 shows it, and the explanation of the flowchart can be outlined as follows.

#i) Conceptual process design: This is the first stage in the life cycle. In this stage, a deep understanding of the process, the equipment to be controlled, and the environment is developed to enable the successful execution of the subsequent stages.

#ii) Hazard and risk analysis: The next stage is to understand all the risks associated with the process through hazard and risk analysis activities. The study aims to identify all existing risks by assigning weights or rankings based on their impact. Risks can affect personnel, production, equipment, the environment, the company's reputation, etc. The effect of a risk is a function of the probability of its occurrence and its consequences. The analysis can be done qualitatively, for example, as low, medium, high, or quantitatively, using numerical values such as the number of incidents, deaths, etc.

#iii) Use non-SIS protective layers: To assess whether these risks can be controlled using non-SIS equipment, such as control system equipment.

#iv) Has SIS required? If the risks can be reduced to an acceptable level using non-SIS equipment, then the design and implementation of SIS stop at this stage. However, if there is still a high residual risk, then SIS equipment is needed.

#v) Determining Safety Integrity Level (SIL): The performance of the SIS equipment used must align with the existing risk level. The required performance level of the SIS equipment is expressed as SIL, a standard used to ensure that the installed and future SIS equipment can achieve a certain minimum performance level needed to ensure that the provided protection can safeguard all necessary aspects.

#vi) Determining the required safety specifications: The specifications created should cover the entire operational range, from startup to shutdown. Safety specifications consist of functional requirement specifications and integrity requirement specifications. The functional requirement specification describes what the safety system will do, while the integrity requirement specification describes how well the safety system functions.

#vii) The conceptual design of SIS aims to develop the initial design of SIS, including the selection of technology and equipment, configuration, testing intervals, and other factors such as size, cost, complexity, response time, and others.

#viii) The detailed design of SIS involves documenting the initial design into a thorough concept. The documents produced at this stage include PFDs, drawings, loop diagrams, and others. This activity is carried out according to strict procedures to prevent errors. Each processing activity in this stage must be well documented.

#ix) Installation and commissioning aim to ensure the installed system meets the design results and functions according to the required safety specifications. All systems must be tested before being shipped from the factory to ensure they operate according to specifications. Then, testing is carried out on-site. A certificate must be signed to show that every function and operation stage has been checked.

#x) Creating operation and maintenance procedures that explain the correct and safe method of operating and maintaining the SIS.

#xi) Review before startup Before starting the system, a pre-start-up safety review (PSSR) must be carried out. This review includes a review of the installed and tested SIS, all safety aspects, operations, maintenance, change management, and others to ensure that all elements meet the required specifications.

#xii) Modification: if the process conditions change, the safety system must also be changed. All proposed changes require a review of the related life cycle steps. Any change made, no matter how small, must go through a review process carried out by a competent team.

#xiii) Operating the SIS: after the PSSR is carried out, the system can be operated, starting with the startup phase, then regular operation and routine maintenance and testing to ensure the system functions properly. The frequency of maintenance and testing must be determined early in the life cycle. All testing must be documented.

C. Determination of Safety Integrity Level (SIL)

A SIL is a standard used to ensure that the Safety Instrumented System (SIS), both to be installed and already installed, can achieve a certain minimum performance level required to ensure that the existing protection can safeguard all necessary aspects, such as the safety of people and the environment, the operation of the processing system, and of course, the reputation of the company. Determining SIL is an essential stage in the life cycle step process. SIL determination can be done using qualitative or quantitative methods. Both methods involve evaluating two risk components: probability and severity. The difference between the two methods lies in the risk levels and the weighting structure.

In a processing unit, there are various levels of hazards, so the SIL for one safety function may differ from another, depending on the level of sources and potential hazards it handles. For example, pressure, flow, level, and temperature measurements are taken in the geothermal power plant's steam purification system. Pressure measurement is helpful to ensure sufficient steam pressure to the turbine. Temperature and flow measurements only provide data information to the operators. In contrast, level measurement becomes more critical because the operating system requires the level value to be maintained at a certain point to prevent damage to the turbine, which could disrupt and halt the production process. Based on the risk assessment, the SIL determination for these four measurements will differ, with the level measurement receiving the highest SIL value.

SIL represents the target value for the Probability of Failure on Demand (PFD) of a Safety Instrumented Function (SIF). PFD is the probability or likelihood of a system failing to respond to a potentially hazardous condition. The Safety Integrity Function (SIF) refers to the system's capability to perform its function. Knowing the frequency of events and the PFD values for each layer of protection can determine the SIL and SIF to be implemented. Four defined SIL levels (SIL 1, SIL 2, SIL 3, and SIL 4). The higher the SIL level, the

higher the potential consequences of hazardous conditions, including the risk of fatalities. Consequently, higher SIL levels require a higher level of equipment reliability. Illustrating the Safety Integrity Level (SIL) matrix for determining the SIL levels on a scale from 1 to 4 [44, 45] is shown in Table 1.

Table 1. Illustrating the Safety Integrity Level (SIL) matrix for determining the SIL levels on a scale from 1 to 4

SIL	Risk Level	Availibility (SIF)	$PFD_{avg.}$	Risk Reduction	Potential Impact/Consequences
4	High	>99.9%	10^{-5} to $<10^{-4}$	100,000 to 10,000	High Fatality
3	High	99.9%	10^{-4} to $<10^{-3}$	10,000 to 1,000	Fatality
2	Medium	99-99.9%	10^{-3} to $<10^{-2}$	1,000 to100	Serious Injury
1	Low	90-99%	10^{-2} to $<10^{-1}$	100 to10	Minor Injury

Based on Table 1, it can be explained that the probability and severity of a system must be determined if the safety system fails. The method can be qualitative or quantitative, i.e., probability (frequency) and severity levels.

C.1. Determination of probability levels

This method was first developed and used by the U.S. Military (MIL-STD 882) [48]. The probability level matrix [44, 45] is shown in Table 2.

Table 2. The probability level matrix

Level	Code Description	Qualitative Frequency	Quantitative Frequency
5	Frequent	Failures are expected to occur more than once during the operation of the plant or system	$freq. > \frac{1}{10}$ per year
4	Probable	Failures are expected to occur at a predictable time during the operation of the plant or system	$\frac{1}{100} < freq. < \frac{1}{10}$ per year
3	Occasional	Failures occur at a predictable time during the operation of the plant or system with a low probability	$\frac{1}{1{,}000} < freq. < \frac{1}{100}$ per year
2	Remote	A series of failures with a lower probability occurs during the operation of the plant or system	$\frac{1}{10{,}000} < freq. < \frac{1}{1{,}000}$ per year
1	Improbable	A series of failures with a very low probability occurs during the operation of the plant or system	$\frac{1}{100{,}000} < freq. < \frac{1}{10{,}000}$ per year

Based on Table 2, it can be explained that in this study, the probability levels are divided into five levels, i.e., the first to fifth step is to rank the probability or frequency levels.

C.2. Determination of severity levels

Severity levels are categorized based on the impact or consequences on humans, the environment, equipment, and production processes if the safety system function fails. The severity level matrix [44, 45] is shown in Table 3.

Table 3. The severity level matrix

Level	Code Description	Potential Severity/Consequences Level		
		Human	Environment	Production/Equipment
V	Catastrophic	Death Outside the Work Area	Release of energy outside the work area resulting in losses	Loss > US$1.5 million
IV	Severe	Death within the Work Area	Release of energy outside the work area without causing losses	Loss between US$1.5 million and US$500,000.00
111	Serious	Lost Work Hours	Release of energy within the work area that is not promptly contained	Loss between US$500,000.00 and $100,000.00
11	Minor	Medical Treatment	Release of energy within the work area that is promptly contained	Loss between US$100,000 and US$2,500.00
I	Negligible	First Aid	No energy release	Loss < US$2,500.00

Then, the two probability and severity tables are combined into a single table to determine the risk level. The risk categories can be divided into three levels: high, medium, and low. The risk level matrix (probability versus severity) [44, 45] is shown in Table 4.

Table 4. The risk level matrix (probability vs. severity)

Severity	Probability 1	2	3	4	5
V	1-V	2-V	3-V	4-V	5-V
IV	1-IV	2-IV	3-IV	4-IV	5-IV
111	1-III	2-III	3-III	4-III	5-III
11	1-II	2-II	3-II	4-II	5-II
I	1-I	2-I	3-I	4-I	5-I

= high = medium = low

After determining the risk level of the system, the next step is to correlate the risk level with the Safety Integrity Level (SIL) matrix in Table 1. Systems with high risk will be categorized as SIL 3, while those with medium and low risk will be classified as SIL 2 and SIL 1, respectively. SIL 4 is not used in industrial processes but only applies in nuclear and aerospace industries so it can be omitted from the calculation. The SIL matrix against severity and probability [44, 45] is shown in Table 5.

Table 5. The SIL matrix against severity and probability

		Probability Low	Medium	High
Severity	High	2	3	3
	Medium	2	2	3
	Low	1	2	2

Based on Table 5, it can be explained that the obtained SIL level will determine the configuration of the SIS components that will be implemented, namely the sensor, logic solver, and final element.

D. Determination of Safety Requirement Specification (SRS)

After obtaining the appropriate SIL level and deciding to implement an SIS, the next step is to create and develop the Safety Requirement Specification (SRS). The SRS consists of two parts: the functional requirement specification and the integrity requirement specification [44, 45]. The functional requirement specification describes the process of interlocks or what the SIS will do. For example, if there is a decrease in steam pressure in the steam purification vessel, the steam control valve will automatically close to maintain the desired pressure. On the other hand, the integrity requirement specification describes the likelihood of the steam control valve closing when there is a decrease in pressure in the purification vessel. The integrity requirement specification thus describes the capability or reliability of the SIS in operation.

When designing a facility or process, it is essential to ensure the utmost safety. The function of instrumentation equipment is to monitor the process conditions and actuate the equipment to the appropriate state to prevent hazards. The SRS determines which process variables will be monitored, the actions to be taken by the safety control, and the operational performance requirements of the system. In general, the information that should be included in the SRS consists of (a) Documentation and Required Data, (b) Functional Requirements, and (c) Safety Integrity Requirements. Documentation and Required Data, i.e., (i) instrumentation and piping drawings, (ii) logic diagrams, (iii) process data specifications, and (iv) data on regulatory requirements for SIS and others. Functional Requirements, i.e., (i) definition of a safe state for a process under all possible conditions, (ii) data on SIS operating values for both regular and emergency conditions, including normal limits, and (iii) response time data and actions are to be taken in the event of a disturbance, ensuring the process can return to regular operation, among others. Safety Integrity Requirements, i.e., (i) list of necessary safety functions and SIL assessment for each function, (ii) requirements for diagnosis to achieve the required SIL level, and (iii) failure modes for each valve, sensor, transmitter, and others [1].

E. Determination and Consideration of the SIS Design to be Implemented

One of the considerations in designing the SIS is the separation between the SIS and the BPCS control system. Separating the SIS from the BPCS reduces the possibility of both systems failing simultaneously. Additionally, this separation prevents any changes in the BPCS from affecting the functionality of the SIS. Therefore, separating the BPCS and SIS rather than combining them is generally preferable. There are two types of separation: identical separation and diverse separation. Identical separation involves using similar systems regarding technology, equipment, or design methods. On the other hand, diverse separation involves using two different systems regarding technology, equipment, or design methods. Identical separation is generally acceptable for SIL 1, while diverse separation provides additional benefits by reducing the likelihood of system errors and common causes of critical failures, making it particularly suitable for SIL 3.

There are three components of separation required for SIS-BPCS: sensors, logic solvers, and final elements, to meet SIL requirements. Details of component separation for each SIL category [44, 45] can be found in Table 6.

Table 6. Component Separation for SIS according to SIL category

SIL	Sensors	Logic Solver	Final Element or Actuator
3	Two sensors or redundant (1oo2 or 2oo3) are required.	Two safety PLCs or redundant are required	One out of two actuators operating (1oo2) is required
2	Two sensors or redundant may or may not be required	Safety PLC is required	Two actuators or redundant may or may not be required
1	Single sensor	Single PLC	Single actuator

Conclusion

Referring to the results and discussion based on methods of the study, then the conclusions can be drawn according to the five objectives. First, the SIS design has been implemented and can be used as a reference for understanding the basic concepts and instrumentation of process control systems. The second is figuring out and implement the SIS, which is an essential stage in the life-cycle step process that will be implemented, starting from the initial concept creation, determining the safety aspects of the system, and the system change process that will be carried out to the system operation stage. The third, the SIL determination, can be done using qualitative or quantitative methods that involve evaluating two risk components, e.g., probability and severity, and lies in the risk levels and the weighting structure. Furthermore, a matrix shows many of the factors that are used to determine the SIL levels. These include the SIL level, which ranges from 1 to 4; the risk level, which ranges from low to high; the availability of SIF, which ranges from 90% to more than 99%; and the PFD average, which is worth the risk reduction and ranges from 10 to 100,000. Fourth, the SRS consists of two parts, i.e., requirement specification of the functional and the integrity. Fifth, one of the considerations in designing the SIS is the separation between the SIS and the BPCS, thereby reducing the possibility of both systems failing simultaneously.

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NOMENCLATURE

SIS	safety instrumented systems
BPCS	basic process control system
PT	pressure transmitter
TT	emperature transmitter
CV	controlled valve
SIL	safety integrity levels
SRS	safety requirements specification
PFD	probability of failure on demand
SIF	safety instrumented function