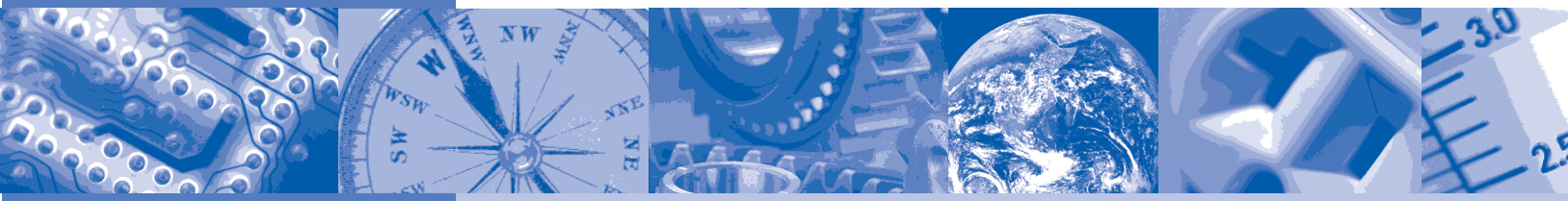
ISA-TR84.00.02-2002 - Part 4



Safety Instrumented Functions (SIF)-Safety Integrity Level (SIL) Evaluation Techniques Part 4: Determining the SIL of a SIF via Markov Analysis

Approved 17 June 2002

ISA–The Instrumentation, Systems, and Automation Society

ISA-TR84.00.02-2002 – Part 4
Safety Instrumented Functions (SIF) — Safety Integrity Levels (SIL) Evaluation Techniques Part 4: Determining the SIL of a SIF via Markov Analysis

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Preface

This preface, as well as all footnotes and annexes, is included for information purposes and is not part of ISA-TR84.00.02-2002 – Part 4.

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Foreword

The information contained in ISA-TR84.00.02-2002 is provided for information only and is not part of the ANSI/ISA-84.01-1996 Standard [1] requirements.

The purpose of ISA-TR84.00.02-2002 [2] is to provide the process industry with a description of various methodologies that can be used to evaluate the Safety Integrity Level (SIL) of Safety Instrumented Functions (SIF).

ANSI/ISA-84.01-1996 provides the minimum requirements for implementing a SIS given that a set of functional requirements have been defined and a SIL requirement has been established for each safety instrumented function. Additional information of an informative nature is provided in the annexes to ANSI/ISA-84.01-1996 to assist the designer in applying the concepts necessary to achieve an acceptable design. However, Standards Project 84 (SP84) determined that it was appropriate to provide supplemental information that would assist the user in evaluating the capability of any given SIF design to achieve its required SIL. A secondary purpose of this document is to reinforce the concept of the performance based evaluation of SIF. The performance parameters that satisfactorily service the process industry are derived from the SIL and reliability evaluation of SIF, namely the probability of the SIF to fail to respond to a demand and the probability that the SIF creates a nuisance trip. Such evaluation addresses the design elements (hardware, software, redundancy, etc.) and the operational attributes (inspection/maintenance policy, frequency and quality of testing, etc.) of the SIF. The basis for the performance evaluation of the SIF is safety targets determined through hazard analysis and risk assessment [6] of the process. This document demonstrates methodologies for the SIL and reliability evaluation of SIF.

The document focuses on methodologies that can be used without promoting a single methodology. It provides information on the benefits of various methodologies as well as some of the drawbacks they may have.

> **THE METHODOLOGIES ARE DEMONSTRATED THROUGH EXAMPLES (SIS ARCHITECTURES) THAT REPRESENT POSSIBLE SYSTEM CONFIGURATIONS AND SHOULD NOT BE INTERPRETED AS RECOMMENDATIONS FOR SIS. THE USER IS CAUTIONED TO CLEARLY UNDERSTAND THE ASSUMPTIONS AND DATA ASSOCIATED WITH THE METHODOLOGIES IN THIS DOCUMENT BEFORE ATTEMPTING TO UTILIZE THE METHODS PRESENTED HEREIN.**

The users of ISA-TR84.00.02-2002 include:

- Process Hazards Analysis teams that wish to develop understanding of different methodologies in determining SIL
- SIS designers who want a better understanding of how redundancy, diagnostic coverage, diversity, etc., fit into the development of a proper SIS architecture
- Logic solver and field device suppliers

- National and International standard bodies providing guidance in the use of reliability techniques for SIS architectures
- Reliability engineers (or any engineer performing this function) can use this information to develop better methods for determining SIL in the rapidly changing SIS field
- Parties who do not have a large installed base of operating equipment sufficient to establish appropriate statistical analysis for PFD_{avg} and $MTTF^{spurious}$ for SIS components
- Operations and maintenance personnel

ISA-TR84.00.02-2002 consists of the following parts, under the general title “Safety Instrumented Functions (SIF) — Safety Integrity Level (SIL) Evaluation Techniques.”

Part 1: Introduction

Part 2: Determining the SIL of a SIF via Simplified Equations

Part 3: Determining the SIL of a SIF via Fault Tree Analysis

Part 4: Determining the SIL of a SIF via Markov Analysis

Part 5: Determining the PFD of Logic Solvers via Markov Analysis

Introduction

ANSI/ISA-84.01-1996 describes a safety lifecycle model for the implementation of risk reduction measures for the process industry (Clause 4). The standard then proceeds to provide specific guidance in the application of SIS, which may be one of the risk reduction methods used. The standard defines three levels of safety integrity (Safety Integrity Levels, SIL) that may be used to specify the capability that a safety instrumented function must achieve to accomplish the required risk reduction. ISA-TR84.00.02-2002 provides methodologies for evaluating SIF to determine if they achieve the specific SIL. This may be referred to as a probability of failure on demand (PFD) evaluation of the SIF.

ISA-TR84.00.02-2002 only addresses SIF operating in demand mode.

The evaluation approaches outlined in this document are performance-based approaches and do not provide specific results that can be used to select a specific architectural configuration for a given SIL.

THE READER IS CAUTIONED TO CLEARLY UNDERSTAND THE ASSUMPTIONS ASSOCIATED WITH THE METHODOLOGY AND EXAMPLES IN THIS DOCUMENT BEFORE DERIVING ANY CONCLUSIONS REGARDING THE EVALUATION OF ANY SPECIFIC SIF.

The evaluation processes described in this document take place before the SIS detailed design phase of the life cycle (see Figure I.1, Safety Lifecycle Model).

This document assumes that a SIS is required. It does not provide guidance in the determination of the need for a SIS. The user is referred to ANSI/ISA-84.01-1996 Annex A for methodologies that might be used in making this determination.

This document involves the evaluation of the whole SIF from the sensors through the logic solver to the final elements. Process industry experience shows that sensors and final elements are major contributors to loss of SIS integrity (high PFD). When evaluating the performance of sensors and final elements, issues such as component technology, installation, and maintenance should be considered.

Frequently multiple safety instrumented functions are included in a single logic solver. The logic solver should be carefully evaluated since a problem in the logic solver may adversely impact the performance of all of the safety instrumented functions (i.e., the logic solver could be the common cause failure that disables all of the SIFs.).

This principle (i.e., common cause) applies to any

- element of a SIS that is common to more than one safety instrumented function; and
- redundant element with one or more safety instrumented function.

Each element should be evaluated with respect to all the safety instrumented functions with which it is associated

- to ensure that it meets the integrity level required for each safety instrumented function;
- to understand the interactions of all the safety instrumented functions; and
- to understand the impact of failure of each component.

This document does not provide guidance in the determination of the specific SIL required (e.g., SIL I, 2, and 3) for the SIS. The user is again referred to ANSI/ISA-84.01-1996 or to other references.

The primary focus of this document is on evaluation methodologies for assessing the capability of the SIS. The SIS lifecycle model is defined in ANSI/ISA-84.01-1996. Figure I.2 shows the boundaries of the SIS and how it relates to other systems.

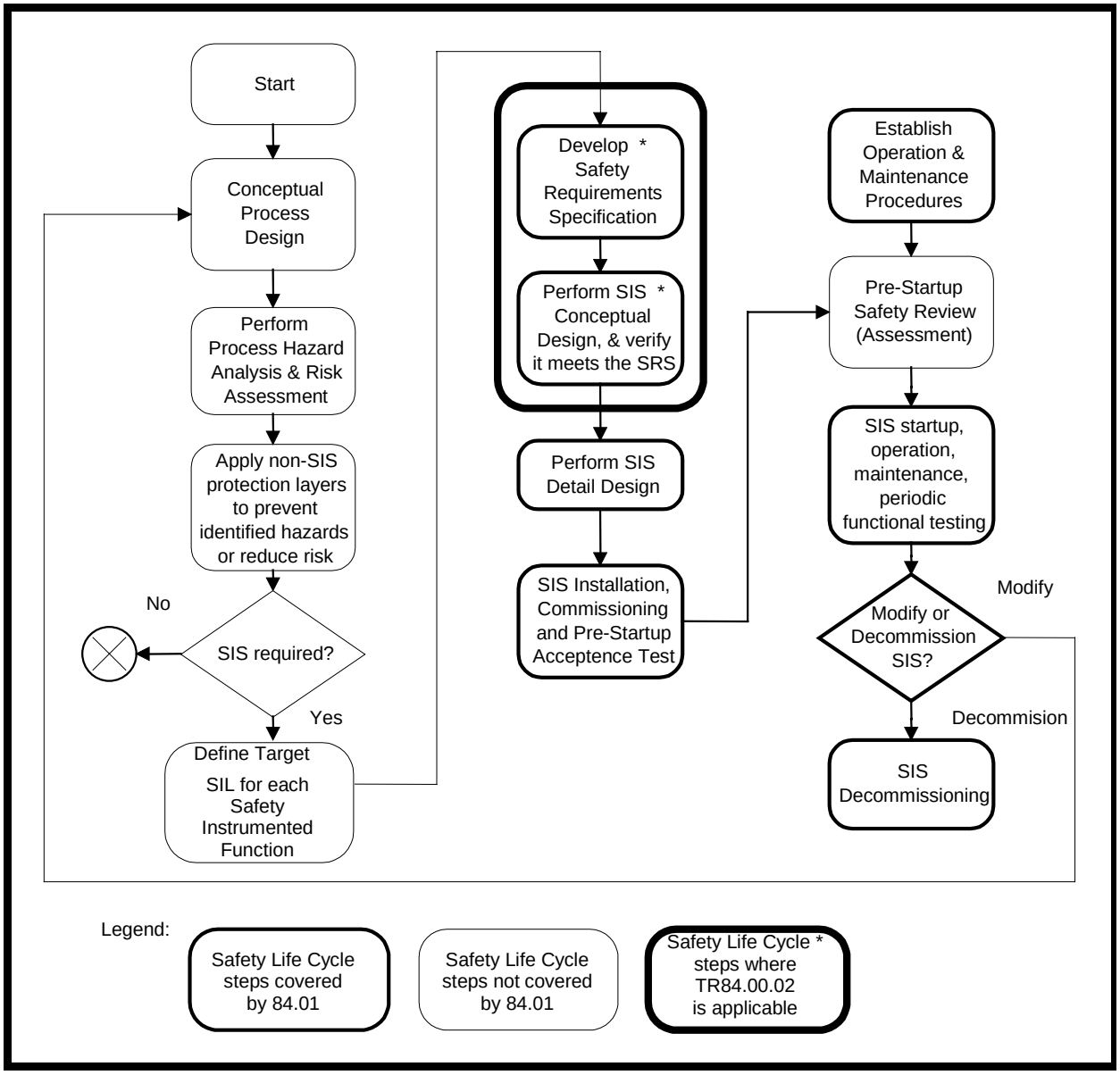

Figure I.1 — Safety life cycle model

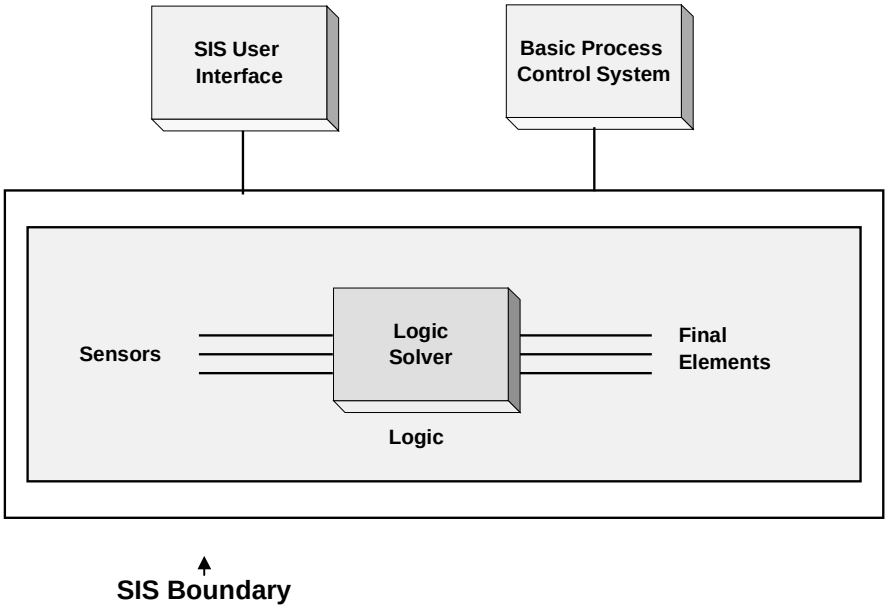

Figure I.2 — Definition of Safety Instrumented System (SIS)

The safety requirements specification addresses the design elements (hardware, software, redundancy, etc.) and the operational attributes (inspection/maintenance policy, frequency and quality of testing, etc.) of the SIS. These elements affect the PFD of each safety instrumented function.

The PFD of these systems can be determined using historical system performance data (e.g., statistical analysis). Where systems, subsystems, components, etc. have not been in use for a sufficiently long time and in large enough numbers to have a statistically significant population available for the evaluation of their performance solely based on actuarial data, a systematic evaluation of the performance of a system may be obtained through the use of PFD analysis techniques.

PFD analysis techniques employ systematic methodologies that decompose a complex system to its basic components. The performance and interactions of these basic components are merged into reliability models (such as simplified equations, fault trees, Markov models) to determine the overall system safety availability.

This document provides users with a number of PFD evaluation techniques that allow a user to determine if a SIF meets the required safety integrity level.

Safety integrity is defined as “The probability of a Safety Instrumented Function satisfactorily performing the required safety functions under all stated conditions within a stated period of time.” Safety integrity consists of two elements: 1) hardware safety integrity and 2) systematic safety integrity. Hardware safety integrity which is based upon random hardware failures can normally be estimated to a reasonable level of accuracy. ANSI/ISA-84.01-1996 addresses the hardware safety integrity by specifying target failure measures for each SIL. For SIF operating in the demand mode the target failure measure is **PFD_{avg}** (average probability of failure to perform its design function on demand). **PFD_{avg}** is also commonly referred to as the average probability of failure on demand. Systematic integrity is difficult to quantify due to the diversity of causes of failures; systematic failures may be introduced during the specification, design, implementation, operational and modification phase and may affect hardware as well as software. ANSI/ISA-84.01-1996 addresses systematic safety integrity by specifying procedures, techniques, measures, etc. that reduce systematic failures.

An acceptable safe failure rate is also normally specified for a SIF. The safe failure rate is commonly referred to as the false trip, nuisance trip, or spurious trip rate. The spurious trip rate is included in the evaluation of a SIF, since process start up and shutdown are frequently periods where chances of a hazardous event are high. Hence in many cases, the reduction of spurious trips will increase the safety of the process. The acceptable safe failure rate is typically expressed as the mean time to a spurious trip (**$MTTF^{spurious}$**).

NOTE In addition to the safety issue(s) associated with spurious trips the user of the SIS may also want the acceptable $MTTF^{spurious}$ to be increased to reduce the effect of spurious trips on the productivity of the process under control. This increase in the acceptable $MTTF^{spurious}$ can usually be justified because of the high cost associated with a spurious trip.

The objective of this technical report is to provide users with techniques for the evaluation of the hardware safety integrity of SIF (**PFD_{avg}**) and the determination of **$MTTF^{spurious}$**. Methods of modeling systematic failures are also presented so a quantitative analysis can be performed if the systematic failure rates are known.

ISA-TR84.00.02-2002 shows how to model complete SIF, which includes the sensors, the logic solver and final elements. To the extent possible the system analysis techniques allow these elements to be independently analyzed. This allows the safety system designer to select the proper system configuration to achieve the required safety integrity level.

ISA-TR84.00.02-2002 - Part 1 provides

- a detailed listing of the definition of all terms used in this document. These are consistent with the ANSI/ISA-84.01-1996, IEC 61508 and IEC 61511 standards.

- the background information on how to model all the elements or components of a SIF. It focuses on the hardware components, provides some component failure rate data that are used in the examples calculations and discusses other important parameters such as common cause failures and functional failures.

- a brief introduction to the methodologies that will be used in the examples shown in this document. They are Simplified equations [3], Fault Tree Analysis [4], and Markov Analysis [5].

ISA-TR84.00.02-2002 - Part 2 provides simplified equations for calculating the SIL values for Demand Mode Safety Instrumented Functions (SIF) installed in accordance with ANSI/ISA-84.01-1996, “Applications of Safety Instrumented Systems for the Process Industries”. Part 2 should not be interpreted as the only evaluation technique that might be used. It does, however, provide the engineer(s) performing design for a SIS with an overall technique for assessing the capability of the designed SIF.

ISA-TR84.00.02-2002 - Part 3 provides fault tree analysis techniques for calculating the SIL for Demand Mode Safety Instrumented Functions (SIF) installed in accordance with ANSI/ISA-84.01-1996, “Applications of Safety Instrumented Systems for the Process Industries”. Part 3 should not be interpreted as the only evaluation technique that might be used. It does, however, provide the engineer(s) performing design for a SIS with an overall technique for assessing the capability of the designed SIF.

ISA-TR84.00.02-2002 - Part 4 provides Markov analysis techniques for calculating the SIL values for Demand Mode Safety Instrumented Functions (SIF) installed in accordance with ANSI/ISA-84.01-1996, “Applications of Safety Instrumented Systems for the Process Industries”. Part 4 should not be interpreted as the only evaluation technique that might be used. It does, however, provide the engineer(s) performing design for a SIS with an overall technique for assessing the capability of the designed SIF.

ISA-TR84.00.02-2002 - Part 5 addresses the logic solver only, using Markov Models for calculating the PFD of E/E/PE logic solvers because it allows the modeling of maintenance and repairs as a function of time, treats time as a model parameter, explicitly allows the treatment of diagnostic coverage, and models the systematic failures (i.e., operator failures, software failures, etc.) and common cause failures.

Figure I.3 illustrates the relationship of each part to all other parts.

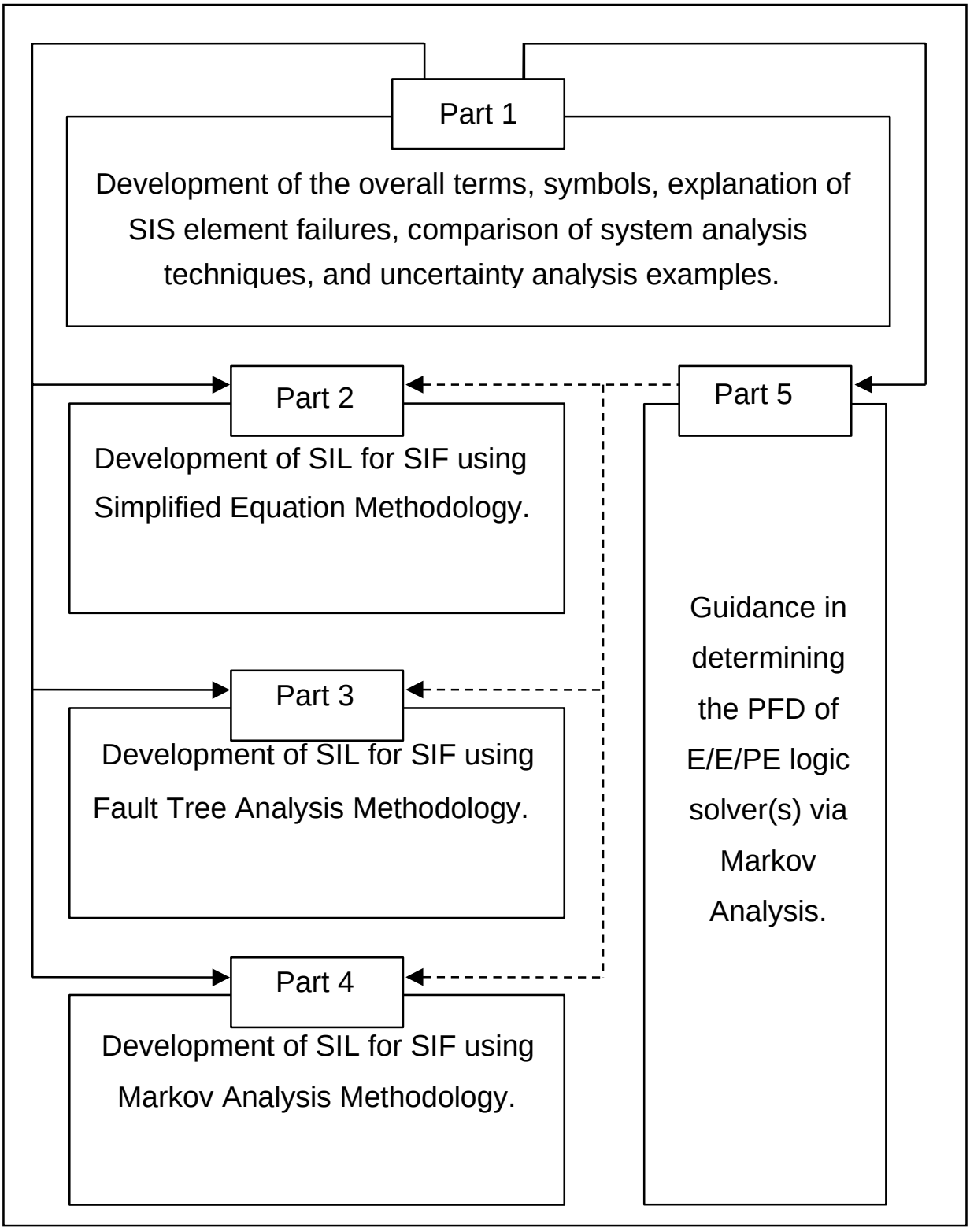

Figure I.3 — ISA-TR84.00.02-2002 overall framework

1 Scope

1.1 ISA-TR84.00.02-2002 - Part 4 is informative and does not contain any mandatory requirements. ISA-TR84.00.02-2002 - Part 4 is intended to be used only after a thorough understanding of ISA-TR84.00.02-2002 – Part 1. This technical report is intended to provide

a) technical guidance in Safety Integrity Level (SIL) Analysis;

b) ways to implement Safety Instrumented Functions (SIF) to achieve a specified SIL;

c) failure rates and failure modes of SIF components;

d) diagnostics, diagnostic coverage, covert faults, test intervals, redundancy of SIF components; and

e) tool(s) for SIL verification of SIF.

1.2 ISA-TR84.00.02-2002 - Part 4 provides one possible technique for calculating PFD_{avg} values for Safety Instrumented Systems (SIS) installed in accordance with ANSI/ISA-84.01-1996, "Application of Safety Instrumented Systems for the Process Industries."

1.3 Persons using ISA-TR84.00.02-2002 - Part 4 require knowledge of the Markov modeling technique. The reader who is interested in learning more about Markov modeling is referred to:

- Evaluating Control Systems Reliability[5], Chapter 5;
- Reliability Evaluation of Engineering Systems[12], Chapter 8 and 9;
- Introduction to Reliability Engineering[13], Chapter 9;
- ISA-TR84.00.02-2002 - Part 5.

1.4 ISA-TR84.00.02-2002 - Part 4 introduces the reader to three examples, which explain the Markov theory and capabilities. These three examples make it possible to better understand the Base Example, which is also presented in ISA-TR84.00.02-2002 – Part 2 and ISA-TR84.00.02-2002 – Part 3.

2 References

1. ANSI/ISA-84.01-1996 “Application of Safety Instrumented Systems for the Process Industries,” Instrumentation, Systems, and Automation Society," ISA, Research Triangle Park, NC, 27709, February 1996.

2. ISA-TR84.00.02-2002, "Safety Instrumented Functions (SIF) – Safety Integrity Level Evaluation Techniques, Part 1: Introduction; Part 2: Determining the SIL of a SIF via Simplified Equations; Part 3: Determining the SIL of a SIF via Fault Tree Analysis; Part 4: Determining the SIL of a SIF via Markov Analysis; Part 5: Determining the PFD of SIS Logic Solvers via Markov Analysis," Instrumentation, Systems and Automation Society, Technical Report, Research Triangle Park, NC, 27709, 2002.

3. “Reliability, Maintainability and Risk (Practical Methods for Engineers),” 4th Edition, D.J. Smith, Butterworth-Heinemann, 1993. ISBN 0-7506-0854-4.

4. “Guidelines for Safe Automation of Chemical Processes,” Center for Chemical Process Safety, American Institute of Chemical Engineers, New York, NY 10017, 1993.

5. “Evaluating Control Systems Reliability,” W. M. Goble, Instrument Society of America, Research Triangle Park, NC, 27709, 1990.