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Review Article

A review of components of reliability for the evaluation of Programmable logic controller

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Abstract: The control of processes is made smooth and effective by Programmable Logic Controllers (PLCs), which are essential to industrial automation. The assessment of PLCs' reliability is crucial since more and more sectors depend on them for crucial tasks. In-depth reviews of the components necessary to evaluate PLC system reliability are presented in this study. To ensure a robust review, the review first clarifies the basic concepts of reliability, highlighting the significance of system uptime and the ramifications of failures in industrial settings. Next, it examined the different elements that go into a PLC's overall reliability, such as availability, testability, and (maintenance and maintainability). The percentage of the reviewed papers that employed (maintenance and maintainability), testability, or availability to improve the reliability of PLC systems showed that, availability and (maintenance and maintainability) has been employed the most for enhancing system reliability, accounting for 32% each of publications analyzed, followed by testability, accounting for 28% respectively. The scatter chart that depicts the progression of reliability components from 2010 to 2023 also explained that the use of availability and (maintenance and maintainability) was increasing. This upward trend can be explained by the fact that repairable systems are heavily reliant on availability, whereas (maintenance and maintainability) tend to avoid unnecessary equipment breakdown and testability, which ensures the ease with which the functionality of any system or component can be ascertained with the required level of precision.

Keywords: Programmable Logic Controllers; Maintenance and Maintainability; Availability; Testability

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1. Introduction

Programmable Logic Controllers (PLCs), which provide unmatched control and efficiency in the field of industrial automation, have emerged as the mainstay of contemporary production processes. For industrial processes to run consistently and dependably, these systems must perform flawlessly. Because of this, it is crucial to assess PLC reliability. This review focuses on the various aspects that go into making PLCs reliable, with a focus on testability, availability, maintenance, and maintainability in particular. A PLC's reliability is assessed not just on how well it can execute everyday activities but also on how well it can handle different types of stress, be available when things go tough, and support effective maintenance to save downtime. The goal of this review is to break down each component's subtleties and highlight both its unique importance and its cooperative role in improving system reliability as a whole. Testability, which includes the development and application of systems to identify errors and malfunctions in the PLC system, is the first crucial component that needs to be carefully examined. Thoroughly analyzing testability methodologies helps with early defect detection and makes troubleshooting and system diagnostics more effective. The increasing intricacy of PLC applications necessitates the inclusion of strong testability features to proactively identify and address possible problems. The PLC's capacity to continue operating during its intended use is the subject of availability, the second major focus of this evaluation. This goes beyond just functionality and includes things like recovery procedures, redundancy, and fault tolerance. A thorough examination of availability components provides information on how to reduce downtime, guarantee continuous operation, and protect against disruptions that could have serious consequences in industrial settings. The third and fourth pillars of this evaluation are maintenance and maintainability, which recognize that reliability is a continuous effort rather than being exclusively dependent on system performance at startup. Understanding maintenance procedures, including both preventative and corrective actions, offers a comprehensive perspective on reducing unscheduled downtime. At the same time, maintainability research emphasizes how simple it is to get a PLC system back to working order, underscoring the significance of design features that make maintenance and upgrades easier.

2. Components of Reliability

The following are components of reliability:

2.1. Testability

The ease with which the functionality of any system or component can be ascertained with the necessary level of precision is the best way to define testability. Better testability design is the foundation and essential to increasing the maintenance and support level of electronic equipment, and it is a significant component of the general quality characteristics of equipment (Wang et al., 2014) [1]. The test for verifying testability serves as the foundation for assessing an item's testability level, which is largely concerned with design, development, and finalization. An efficient method to assess the testability level of equipment is a testability verification test based on fault injection (Zhang et al., 2015) [2].

The correct operation of any fault diagnostic technique must incorporate a preliminary testability analysis. Testability analysis makes it possible to establish how many and which measures are required for the detection and exact localization of faults (Bindi et al., 2022) [3]. Numerous publications have been written concerning testability, including Bindi et al. 2022's proposal of a graphical method for testability evaluation that makes it easier to identify the optimal test sites and prevents ambiguity. Kaur (2017) [4] suggested creating improved dynamic metrics to increase the software's dependability and testability. To address testability at the design stage of the software development life cycle, Khanum & Tripathi (2015) [5] created a model.

Di et al. (2020) [6] suggest a method for evaluating the testability of equipment based on multisensory data fusion. Yang et al. (2018) [7] investigated the benefits, drawbacks, and conditions that apply to the current experimental systems. Utilizing a micromechanical technique, Sleiman et al. (2022) [8] sought to incorporate the impact of each parameter defining concrete's laboratory exposure circumstances. To capture three types of contracts (original contract, incentive contract, and co-creation contract) while taking production reliability uncertainty and variable diagnostic test time into account, Liu et al. (2022) [9] applied a differential game to a new product development supply chain that was composed of a client and a delegated vendor.

Using neuronavigation transcranial magnetic stimulation (nTMS) measures of cortical excitability, inhibition, and facilitation in the primary motor cortex, Therrien-Blanchet et al. (2022) [10] sought to determine the long-term stability and test-retest reliability of these data. To ensure product reliability with the fewest possible tests, Ahmed & Chateauneuf (2014) [11] suggested an optimization-based formulation that couples the expenses of product design with validation testing. Li et al. (2014) [12] investigated the Micro-Electro-Mechanical Systems (MEMS) microphone's dependability using two accelerated life tests: shock impact testing and mixed flowing gas (MFG) testing.

The impact of partial testing on the reliability of safety-instrumented systems (SISs) was investigated by Jin & Rausand (2014) [13]. Simpler formulas were created to compute the average probability of failure on demand (PFD_{avg}) with partial and proof testing included. An accelerated operational profile (OP) and an acceleration factor based on importance sampling theory were proposed by Li & Wang (2012) [14] by the traits of highly reliable software systems. Fu et al. (2010) [15] provided a summary of the current approaches to software testability analysis with regard to test cost, test sensitivity, and testable features. Kout et al. (2011) [16] provided a testability model for object-oriented programs that is metric-based. The definition of software testability and its impact on the software reliability test set were examined by Li et al. (2010) [17].

The findings of a systematic review carried out to gather data on software testability estimation of object-oriented design were provided by Srivastava (2013) [18]. Malla & Gurung (2012) [19] examined testability elements and metrics primarily with the aid of systematic literature research, and a case study was used to assess the viability of the suggested framework. Badri et al.(2012) [20] sought to objectively investigate the influence of aspect-oriented refactoring on the testability of classes in object-oriented software. Badri et al. (2010) [21] sought to empirically investigate the relationship between class cohesion and testability in object-oriented systems.

Badri & Touré, (2012) [22] explored the empirical relationship between object-oriented design metrics and class testability. Enhancing dynamic metrics to increase software's testability and dependability was the primary objective of Kaur (2017) [4]. In the testability demonstration test (TDT) of a flight control system (FCS), Qiu et al., (2015) [23] introduced and implemented the sequential probability ratio test (SPRT) approach under a binomial distribution model. Zhang et al. (2013) [24] introduced novel approaches to address the test selection problem when imperfect tests are present. The goal is to reduce the overall test costs while taking into account lower limit constraints on fault isolation and detection.

Dietrich & Kahle (2016) [25] focused on modelling the best course of maintenance for multi-state systems with two different types of failure. By comparing a vast amount of test data to design standards, Shamass et al. (2023) [26] sought to evaluate the load-carrying capacity and deflection of Fiber Reinforced Polymer (FRP)-reinforced concrete (RC) beams. A unique graph-based neural network architecture was presented by Shi et al. (2023) [27] for precisely and effectively evaluating the survival signature and network reliability. Creating an efficient reliability method to examine the hydraulic pipeline's bending fatigue life in conjunction with fatigue tests was the goal of Shen et al. (2023) [28].

A quantile-based sequential optimization and reliability assessment (QSORA) approach was put forth by Jiang & Lu (2023) [29] to address the drawbacks of the nested solution strategy in safety life analysis. For the motion mechanisms, Wei et al., (2016) [30] developed both the global reliability sensitivity (GRS) analysis and the time-dependent parametric reliability sensitivity (PRS) analysis. Awad (2016) [31] presented a novel approach to schedule Reliability Growth Testing (RGT) time for subsystems and system levels in a way that minimizes the intensity of system failures while working with constrained financial and temporal resources. According to Kim et al. (2016) [32], the reliability expression for a fixed-rated design value is defined in terms of the derating level, assuming that the nominal failure rate remains constant over time. Moustafa et al. (2021) [33] introduced a novel framework to analyze the reliability of systems with multiple components using Accelerated life testing (ALT).

The reliability of complex systems with imprecision in mind was discussed by Salomon et al. (2021) [34]. Zheng et al. (2021) [35] suggested a new proportional hazard (PH) model that was established for reliability evaluation and prediction, based on temperature and the degradation trend as covariates. The objective of Wei et al. (2018) [36] was to create practical techniques for calculating how specific failure modes and random input variables affect the safety or failure of structural systems. Seismic reliability analyses on a new timber-steel hybrid system called FFTT (Finding the Forest Through the Trees) system were carried out by Zhang et al. (2018) [37]. The objective of Nasrollahzadeh & Aghamohammadi (2018) [38] was to carry out a reliability-based evaluation of the current design codes' shear strength requirements for fiber-reinforced polymer reinforced concrete (FRP-RC) beams.

Khatri (2011) [39] used software reliability growth models in a novel way to increase the software's testability. With testability, debugging, and reliability being vitally necessary for cutting-edge circuit designs, Huhn & Drechsler (2021) [40] offered several unique ways for addressing some of the emerging issues in this area. The authors employed formal techniques, such as the Boolean satisfiability issue and bounded model checking, to greatly reduce the resulting test data volume and test application time and dramatically improve the circuit's dependability against transient errors. To thoroughly investigate the investigation of the testability field, Garousi et al. (2019) [41] offered a systematic mapping of the literature. Mona (2023) [42] provided an in-depth analysis of software testability.

While Wang et al.(2014) [43] suggested a testability evaluation method employing previous knowledge from numerous sources, Qiu et al. (2019) [44] researched a general fault injection method. The testability structure model (TSM) and the testability Bayesian networks model (TBNM) are combined in Zhang et al.'s (2015) [2] hierarchical hybrid testability modelling and evaluation technique (HHTME). By combining testability expert experience, testability prediction, and testability virtual test information, Wang et al. (2019) [45] developed a technique for testability evaluation based on improved D-S evidence theory to address the conflict of prior knowledge in standard D-S evidence theory.

2.2. *Availability*

Availability is a critical indicator for evaluating the performance of repairable systems, taking into consideration both the reliability and maintainability qualities of a component or system. Repairable systems depend heavily on availability and reliability. Systems for cloud computing, manufacturing, computer and communication networks, and industrial systems have all been thoroughly investigated (Yang & Tsao, 2019) [46]. Choi (2014) [47] put forth a rigorous approach that works well for solving the exact availability equation with reliability under fluctuating operational conditions. Levitin et al. (2019) [48] suggested a probabilistic model based on discrete-state continuous-time stochastic processes for assessing the immediate availability of these repairable system components. The general repair policy, which includes minimal repair, perfect repair, and imperfect repair, is addressed by the proposed model.

An efficient surrogate model for system reliability analysis of mechanisms based on an extreme-value kinematic error model and the Kriging approximation was provided by Wang et al. (2018) [49]. The system reliability of the retrial machine repair system with M running units, S warm standby units, and a single repair server with N-policy was examined by Chen & Wang (2018) [50]. Jensen & Jerez (2018) [51] took into consideration the hydraulic reliability and sensitivity analysis of large-scale water distribution systems in the presence of uncertainty.

The reliability and availability analysis of a repairable system including standbys, working vacations, and retrial of failing components was proposed by Yang & Tsao (2019) [46]. The steady-state availability was computed using the matrix-analytic technique. In a repairable system with warm standbys and a control policy where the service station is unreliable and prone to functioning breakdowns, Yen et al. (2016) [52] examined the system's dependability. Gao & Wang (2021) [53] offered an overview of the generic K-out-of M + W + C: G retrial machine system with a single repair facility. M primary operational components, W warm standby components, and C cold standby components are all present in such a system.

The issue of assessing dependability using linguistic data was tackled by Zhang et al. (2017) [54]. A model based on the theory of aggregated stochastic processes was created by Du et al. (2017) [55] to explain the history-dependent behaviour of Markov history-dependent repairable systems as well as the impact of neglected failures. In the face of aleatory and epistemic uncertainty, Simon & Bicking (2017) [56] proposed a technique for evaluating system reliability. For the Binary Decision Diagram (BDD)--based network reliability study, Mo et al. (2014) [57] made innovative contributions by putting forth heuristic and root node selection techniques based on the idea of boundary sets. Do et al. (2014) [58] reported the reliability evaluation and non-deterministic dynamic analysis of structures with constrained but uncertain parameters under excitations from stochastic processes.

When an operational component fails, a warm standby that is readily available takes its place right away and becomes an operating component. A cold component then changes to a warm standby component. The steady-state availability of a repairable system with an unreliable server, whose standbys are vulnerable to switching failures, was explored by Kuo & Ke (2016) [59] and Lee (2017) [60]. An M/G/1 machine maintenance model with an unreliable repairman and standby switching failures was investigated more recently by Ke et al. (2018) [61] using the supplementary variable technique. To model a smart grid system with two different power supply modes, Zheng et al. (2021) [62] considered the important measures of components in a smart electric power grid system in terms of availability and presented a hierarchical model made up of a layered fault tree (FT) and continuous-time Markov chains (CTMCs).

To identify the system's weak points and improve system design, the writers examine the significance of each system component. To assess the immediate availability of repairable system units, Levitin et al. (2019) [48] suggested a probabilistic model based on discrete-state continuous-time stochastic processes. The suggested model deals with the overall repair strategy, which includes minimal repair, ideal repair, and imperfect repair. Dynamic (short-term) availability and performability study for highly responsive large-scale networked robotic systems were reported by Lisnianski et al. (2021) [63]. These systems use robotic sensors for the exploration and measurement of many characteristics in hostile settings.

A modelling approach based on reliability analysis was presented by Macchi et al. (2012) [64] to assist maintenance management of railway systems. An electrical transmission network system was analyzed by Zio & Golea (2012) [65] to identify the goal of identifying the important components, working within the framework of a vulnerability assessment. Three issues with the application of performance shaping factors in human reliability analysis were discussed by Groth & Mosleh (2012) [66]. The fatigue reliability of a fixed jacket offshore wind turbine at a sea depth of 70 meters, intended for a northern North Sea location, is examined by Dong et al. (2012) [67]. A technique for creating a multi-state Markov model for a power-generating unit was proposed by Lisnianski et al. (2012) [68].

The application of uncertainty importance measures in risk and reliability analysis was covered by Aven & Nøkland (2010) [69]. Remenyte-Prescott et al. (2010) [70] provided an explanation of the entire decision making process for autonomous cars. A reliability-based study for determining essential tool life in machining processes was provided by Patiño & Gilberto (2010) [71]. Al-Dabbagh & Lu (2010) [72] provided an example of how the Dynamic Flowgraph Methodology (DFM) is used to describe Networked Control Systems (NCSs).

A unique condition-based maintenance system was introduced by Niu et al. (2010) [73]. It optimizes maintenance costs through a reliability-centered maintenance mechanism and uses a data fusion technique to enhance prognostics, condition monitoring, and health evaluation. Griffith & Mahadevan (2011) [74] focused on the impacts of fatigue, particularly sleep loss, on performance. They also highlighted the limits of existing human reliability analysis (HRA) including fatigue and outlined the necessary procedures for such inclusion. The objective of Anderson-Cook et al. (2011) [75] was to examine how component-level reliability data—which includes margin and catastrophic failures—affects system-level reliability. By taking risk into account as the analysis's reference in addition to reliability,

Selvik & Aven (2011) [76] proposed extending of the reliability-centered maintenance (RCM) to reliability and risk-centered maintenance (RRCM). A comparison analysis was presented by das Chagas Moura et al. (2011) [77] to assess the efficacy of SVM in predicting the reliability and time-to-failure of manufactured components using time series data. Eryilmaz, (2013) [78] conducted a reliability analysis on a k-out-of-n: G system, taking into account the functionalities of each working component as well as the system's structure functioning. A maintenance model with error-prone periodic inspections to verify the system's condition was introduced by Berrade et al. (2013) [79].

A Bayesian method for aggregating expert estimates of human error probability to ascertain a human reliability analysis (HRA) model's linkages was introduced by Podofillini & Dang (2013) [80]. A methodology for assessing human reliability based on Bayesian Belief Networks (BBNs) was described by Martins & Maturana (2013) [81]. The approach was applied to the operation of an oil tanker, with a particular emphasis on the risk of collision incidents. In Wang et al. (2013) [82] a Bayesian evaluation approach was put out to combine field failure data and Accelerated degradation testing (ADT) data from the laboratory.

Double-loop adaptive sampling (DLAS) is a confidence-based meta-modelling technique that Wang & Wang (2015) [83] introduced for effective sensitivity-free dynamic reliability analysis. A broad reliability analysis was conducted by Lin et al. (2015) [84] utilizing Bayesian semi-parametric degradation as well as classical methods. Kondakci (2015) [85] provided a succinct reliability study of network security that was decoupled from theories of queuing, reliability, and stochastic modeling. The assessment and modelling of the reliance present in two consecutive Human Failure Events (HFEs) was done by Baraldi et al. (2015) [86] through a thorough comparison of two expert systems.

A method for computing system reliability that combines Markovian and backpropagation neural networks was presented by Fazlollahtabar et al. (2015) [87]. Preventive maintenance (PM) and repair for working breakdowns were taken into consideration for the repair facility by Wang et al.'s (2022) [88] study, which focused on a linear consecutive-k-out-of-n: F repairable retrial system with an unreliable repair facility. Alkaff et al. (2020) [89] provided a precise method for analyzing the dependability of networks whose component lifetimes have matrix-based distributions. By combining stochastic process simulation and pipeline scheduling, Zhou et al. (2020) [90] presented an integrated methodology for the supply reliability study of multi-product pipeline systems under pump failure.

Using Systems Analysis for Formal Pharmaceutical Human Reliability (SAFPHR), Zheng et al. (2020) [91] examined a typical community pharmacy dispensing process, they compared the findings to reported mistake rates, and investigated potential interventions to lower error rates. The reliability and queueing properties of the fault-tolerant system (FTS) with unreliable servers, and working breakdowns were examined by Kumar & Jain (2020) [92]. Wu et al. (2023) [93] introduced a deep Bayesian network (DBN) based on Markov- Monte Carlo methodology to accurately forecast subsea wellhead systems' reliability and identify the underlying cause throughout their service life.

An investigation of the reliability of a phased mission system (PMS) with loop structures in an actual engineering system was attempted and done successfully by Matsuoka (2023) [94]. A Polynomial Chaos Expansion (PCE) method based on parameterized coefficient fine-tuning (PCFT-PCE) was presented by Zheng et al. (2023) [95]. An effective variable selection-based Kriging model approach was presented by Ding et al. (2023) [96] to approximate the finite element analysis model in slope reliability analysis.

Gao et al.(2019) [97] thought about a brand-new k-out-of-n: F repairable balanced system with m sectors. This balanced system's defining feature was that the m sectors' total number of operational components had to remain constant over time. Thus, when the balance is off, some components need to be manually turned off. Two Markov repairable system models in particular were put forth in terms of various restart procedures for shutdown components. The system reliabilities and availabilities were obtained using the excellent Markov process embedding method. A Petri net-based reliability and availability study is presented by De Andrade et al. (2022) [98] to assist in asset management decision-making on maintenance. Reliability-centred maintenance (RCM) and prioritized maintenance were coupled in a strategy by Berrell & Chakrabortty (2022) [99] research to boost the availability of critical medical devices (CMDs).

Yu et al. (2022) [100] created a generic technique for balancing a production line that considers robots, their roles, their placements, and the line's reliability by assuming unlimited human resource availability. To characterize the state of job-shop production execution, Takeda et al. (2019) [101] proposed a conceptual model for a data-driven predictive-reactive production scheduling approach combining machine learning and simulation-based optimization. To facilitate the analysis and optimization of availability as well as the support resources, Long et al., (2016) [102] employed extended coloured stochastic Petri nets (ECSPN) to simulate Industry 4.0 production systems and their availability.

2.3. Maintenance and Maintainability

Given the dangerously rising operating and maintenance costs of systems and equipment, maintainability is becoming more and more crucial (Dhillon, 2006) [103]. Contrary to maintenance, which is the act of maintaining or servicing an item or piece of equipment, maintainability is a design element used to shorten repair times. A manufacturing system's efficiency is based on how well it is designed and how well it is maintained to avoid failure (Sarkar et al., 2011) [104]. Corrective, preventive, and predictive maintenance (PdM) are the three types of maintenance that can be performed throughout the operation stage (Ding & Kamaruddin, 2015; Lee & Pan, 2017) [105, 106]. Corrective maintenance is a type of maintenance carried out to find and fix the source of a system's problems.

The engineering apparatus has several parts, numerous failure modes, and a very intricate failure mechanism (Wang et al., 2014) [1]. The idea of a comprehensive corrective maintenance program for engineering equipment (Wang et al., 2014) [1]. Preventive maintenance has been the subject of much research because of the production systems' rising complexity. The findings indicate that system maintenance is necessary to avoid equipment breakdown. Major preventive maintenance policies, such as time-based maintenance, such as periodic maintenance, implement preventive maintenance on equipment at integer multiples for a specified duration (Sheu & Chang, 2010; Doostparast et al., 2014; Lee & Cha, 2016) [107-109].

Several academics advocated a usage-based maintenance mode that integrated monitoring technologies into equipment maintenance decisions to account for the fact that the system may not be used at all or only partially at times (Safaei et al., 2010; Tinga, 2010) [110, 111]. Equipment reliability can be increased and failure rates can be decreased or eliminated through preventive maintenance. The foundation of intelligent manufacturing is predictive maintenance (PdM), which is a useful method for preventing possible problems, ensuring stable equipment functioning, and enhancing the product's quality and mission reliability. He et al. (2017) [112] therefore, developed an integrated PdM technique taking into account the product quality level and mission reliability status.

An approach for throughput capacity analysis taking the covariate effect into account was described by Barabadi et al. (2011) [113]. Nielsen & Sørensen (2011) [114] examined the effectiveness of condition-based maintenance versus corrective maintenance for offshore wind turbines in general. A new methodology for analyzing railway track behavior was provided by Rhayma et al. (2013) [115]. A case study of the technical and financial optimization of the frequency of planned preventive maintenance procedures performed on a repairable industrial system from an EDF electric power plant was provided by Remy et al. (2013) [116].

Using a genetic algorithm, Chen et al. (2013) [117] addressed the preventive maintenance (PM) scheduling problem of reusable rocket engines (RRE), which differs from regular repairable systems. A novel numerical approach that iteratively finds the best maintenance plan while adhering to a specified reliability requirement was presented by Briš & Byczanski (2013) [118]. By analyzing the effects of failures, Kim & Jeong (2013) [119] increased the effectiveness, dependability, and safety associated with train maintenance jobs.

Marais & Robichaud (2012) [120] examined and measured the frequency and severity of maintenance's contribution to passenger airline risk by examining three distinct data sets from 1999 to 2008: 7478 FAA records of fines and other legal actions brought against airlines and related entities, 3242 FAA incident reports, and 769 NTSB accident reports. For marine and offshore operations, El-Ladan & Turan (2012) [121] offered both qualitative and quantitative taxonomies and praxes of performance-shaping factors (PSF). A dynamic opportunistic preventive maintenance model was created by Zhou et al. (2012) [122] for a multi-component system while taking job shop scheduling modifications into account.

An approach was presented by Okasha et al. (2012) [123] to use the data from structural health monitoring (SHM) in an advanced structural reliability analysis. The challenge of combining tactical production planning and preventive maintenance for a production system made up of several simultaneous components in the face of common cause failures and economic reliance was addressed by Nourelfath & Châtelet (2012) [124]. For theoretical and practical purposes, a discrete-time semi-Markovian system was examined by Yi et al. (2018) [125]. A redundancy allocation problem for cold-standby systems with decaying components was examined by Wang et al. (2018) [126].

A generalized dynamic reliability model was presented by Zhang et al. (2018) [127] to calculate system dependability under complicated load. Cheng et al. (2018) [128] examined the combined issue of condition-based maintenance, quality control, and production lot size for an imperfect production system that is vulnerable to degradation in both reliability and quality. Using a probabilistic safety assessment model that has been improved by a best-estimate safety analysis and a human reliability analysis, Martorell et al. (2018) [129] suggested a three-step process to assess the risk impact of modifications to completion time within nuclear power plant technical specifications. The Vehicle Routing Problem (VRP) was examined by Jbili et al. (2018) [130] in the context of unique transcontinental transportation scenarios in which large vehicles travel great distances between cities in challenging environments, increasing the likelihood that essential components may fail.

Using the Markov analysis method, Alizadeh & Sriramula (2018) [131] presented a novel reliability model for redundant safety-related systems. Providing a logical dependability assessment of ship structures under various threats throughout their lifetime was the goal of Liu & Frangopol (2018) [132]. A flexible set of modelling patterns was presented by Meng et al. (2018) [133] and implemented in the AltaRica 3.0 language. Chen & Mehrabani (2019) [134] introduced a technique for analyzing the dependability of coastal flood defenses, such as earth sea dykes, about changing operating conditions. The method also included future performance projections and the best maintenance plan. A unique approach to reliability-centered maintenance based on artificial neural networks was introduced by Pliego Marugán et al. (2019) [135].

Zhu et al.(2019) [136] presented and examined a reliability and maintenance model of a k-out-of-n: F system. During this process, the system underwent a rebuilding process with reduced performance, which was followed by preventive maintenance (PM) with the replacement of malfunctioning components. During this rebuilding process, the system is susceptible to failure with various failure criteria. Izquierdo et al. (2019) [137] proposed a novel strategy and used a case study to validate it, which helped to reduce the uncertainty arising from the operational context. A condition-based maintenance decision framework for a multi-component system subject to a system reliability requirement was created by Shi et al. (2020) [138].

Ma et al. (2020) [139] looked into the methodologies for maintenance optimization and reliability analysis of a two-unit warm standby cooling system. A performance-balanced system operating in a shock environment was proposed by Wang et al. (2020) [140], which is hardly observed in the literature. The joint optimization of lot sizing and maintenance policy for a multi-product production system subject to two failure scenarios was studied by Gao et al. (2020) [141]. Chang et al. (2021) [142] applied the approach of minimal cuts for demand d (d-MC) to evaluate the time-related reliability of a multi-state flow network (MSFN).

The suitability of the Reliability Centered Maintenance (RCM) approach for evaluating reliability concerns and maintenance requirements for unmanned cargo ships was investigated by Eriksen et al. (2021) [143]. Bressi et al. (2021) [144] suggested that, taking into account varying degrees of reliability, minimising the present value of the life cycle maintenance expenses and maximising the trackbed's life cycle quality level. According to Niu (2021) [145], a multi-state flow network's edges are each distinguished by a maintenance cost in addition to a multi-valued capacity. The pod slewing hydraulic system was subjected to an integrated importance measure-based importance analysis, as described by Chen et al. (2021) [146]. Liu et al. (2021) [147] suggested an integrated maintenance optimization model to plan a multi-level maintenance activity for multi-component series systems.

For a system with active and standby components operating simultaneously and standby components that are prone to degradation, Golmohammadi & Ardakan (2022) [148] proposed a novel reliability model. An improved standard I&M plan for nuclear feeder piping systems was suggested by Bismut et al. (2022) [149] using a reliability-based planning paradigm. The three essential components of shop floor management—maintenance, production scheduling, and quality—were presented by Tambe & Kulkarni (2022) [150] as an integrated planning approach. An agile maintenance framework was provided by Si et al. (2022) [151] in which maintenance schedules and technician assignments are coordinated to guarantee timely operation and maintenance (O&M) services.

To balance reliability prediction and optimization, Wang et al. (2023) [152] suggested a theoretical framework that blends a semi-Markov decision process and a generalized proportional hazard model. Liao et al. (2023) [153] introduced the risk-based maintenance (RBM) approach, which serves as a guide for maximizing the maintenance plan and is based on the dependability of manufacturing process jobs. Wei et al. (2023) [154] studied a linearly degraded system that was exposed to a series of external shocks as well as a dynamically changing operating environment. They used a continuous-time Markov process to characterize the random evolution of environments and an N-critical shock model to describe the limited shock resistance of shock absorbers. Two distinct preventive maintenance approaches for industrial robot systems were put forth by Dui et al. (2023) [155].

Peng & Van Houtum (2016) [156] proposed the PdM strategy, also known as the condition-based maintenance (CBM) strategy, as technology advanced. Shi & Zeng (2016)

[157] suggested a dynamic opportunistic CBM technique for multi-component systems by taking into account economic factors and real-time estimations of the remaining usable life. By taking into account the data collected from failure history, Gilardoni et al. (2016) [158] developed a PdM policy for a repairable system. Through a reliability analysis of system components, Rafiee et al. (2015) [159] established a CBM strategy that executes imperfect repair for complex systems.

The percentage of the reviewed papers that employ (maintenance and maintainability), testability, or availability to improve the reliability of PLC systems is shown in Figure 1. According to Figure 1, availability and (maintenance and maintainability) has been employed the most for enhancing system reliability, accounting for 32% each of publications analyzed, followed by testability, accounting for 28% respectively. Figure 2 is a scatter chart that depicts the progression of reliability components from 2010 to 2023. According to Figure 2, the use of availability and (maintenance and maintainability) is increasing.

This upward trend can be explained by the fact that repairable systems are heavily reliant on availability, whereas (maintenance and maintainability) tend to avoid unnecessary equipment breakdown and testability, which ensures the ease with which the functionality of any system or component can be ascertained with the required level of precision. Figure 3 is a stacked bar chart depicting the total number of components of dependability articles published each year from 2010 to 2023. Figure 3 demonstrates how availability has been used most frequently to improve the reliability of complex systems.

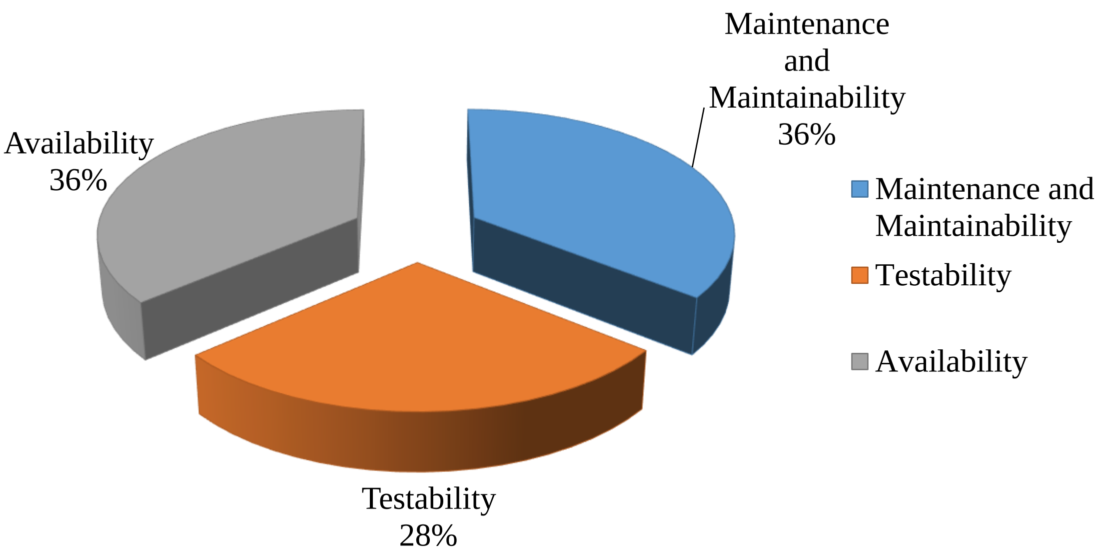

Figure 1. Percentage of reviewed reliability components.

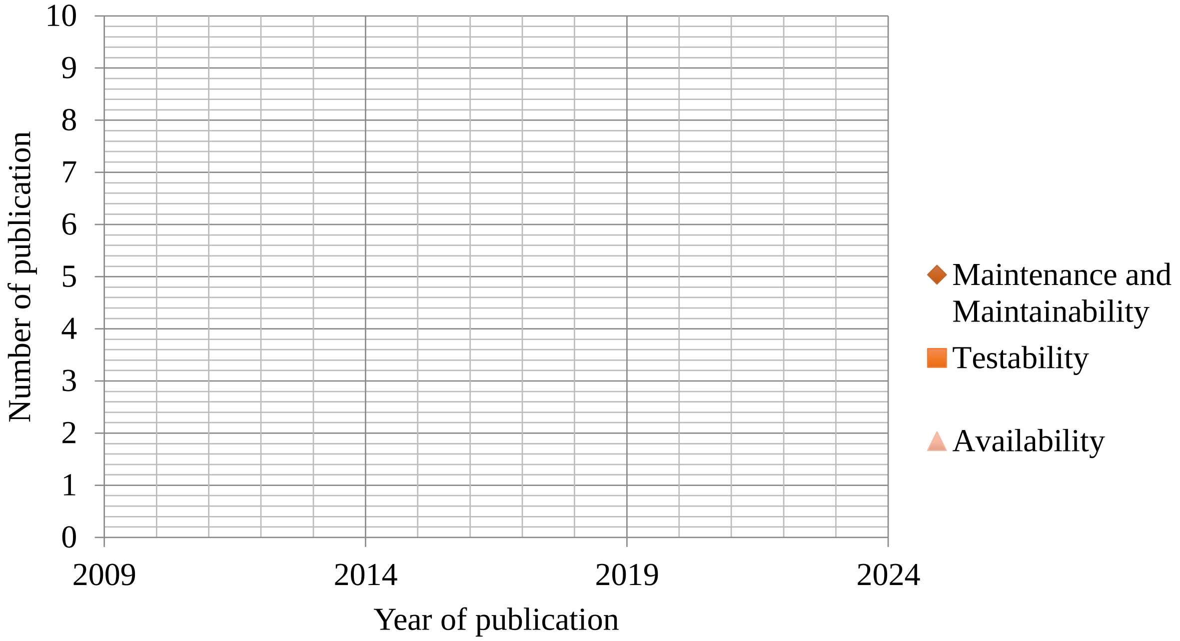

Figure 2. Review of the evolution of reliability components from 2010 to 2023.

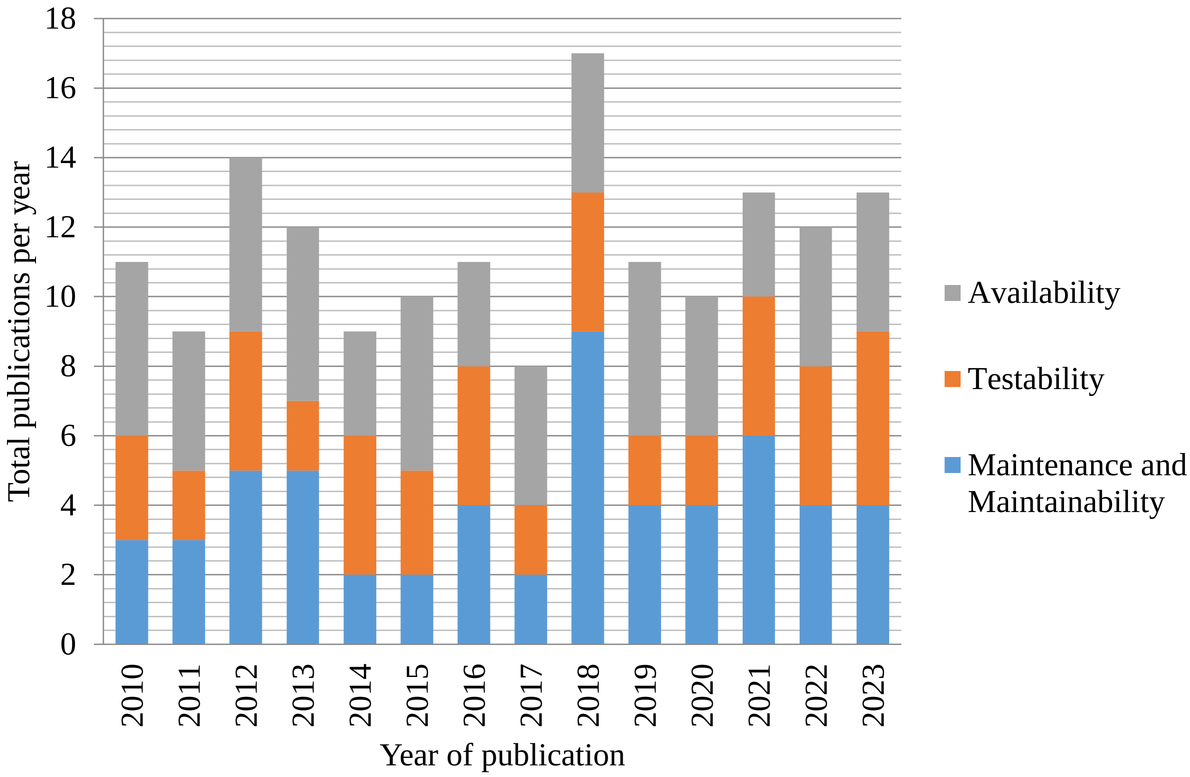

Figure 3. Total number of reliability components reviewed yearly from 2010 to 2023.

3. Conclusion

The proportion of reviewed papers that used availability, testability, or maintenance and maintainability to increase PLC system reliability was found to be highest for availability and maintenance and maintainability (32% of publications analyzed), followed by testability (28%). The scatter chart that shows the evolution of reliability components from 2010 to 2023 also revealed an increase in the use of availability and maintenance and maintainability. This increasing trend can be explained by the fact that repairable systems depend significantly on availability, whereas maintenance and maintainability tend to prevent needless equipment failure and ensure testability, which guarantees the ease with which any system's or component's functionality can be determined with the necessary degree of precision. The most common application of availability to enhance the reliability of complex systems is shown by the stacked bar chart showing the total number of components of reliability articles published year between 2010 and 2023.

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