# Quantification of Software Quality Attributes

The project submitted to the

SRM University – AP, Andhra Pradesh

for the partial fulfillment of the requirements to award the degree of

**Bachelor of Technology**

In

**Computer Science and Engineering**

**School of Engineering and Sciences**

Submitted by

**Neelofar Shaik (AP21110010047)**

Under the Guidance of

**Dr. Pramod Kumar**

**Assistant Professor**

**SRM University–AP**

**Andhra Pradesh – 522 240**

**Nov, 2023**

# Certificate

Date: 28-Nov-23

This is to certify that the work present in this Project entitled "**Quantification of Software Quality Attributes**" has been carried out by **Neelofar Shaik, Namratha Addagada, Kavya Sri Gullipalli, Rohith Kamal Kumar Yenduri** under my supervision. The work is genuine, original, and suitable for submission to the SRM University – AP for the award of Bachelor of Technology in **School of Engineering and Sciences**.

**Supervisor**

Signature

Dr. Pramod Kumar

Assistant Professor

Dept. of CSE, SRM University-AP

Andhra Pradesh, India

# Acknowledgement

We express our profound gratitude to the individuals whose unwavering dedication and guidance have been paramount to the successful completion of this project. Dr. Pramod Kumar, our esteemed supervisor, deserves special acknowledgement for his continuous support and insightful advice, which have been instrumental throughout the project's evolution. His generosity in sharing expertise and navigating us through the complexities of our work has significantly contributed to our achievements.

Additionally, we extend heartfelt thanks to our friends and all contributors who, either directly or indirectly, played a crucial role in supporting this endeavour. The project's significant progress from its initial conceptualization is a testament to the collective efforts of everyone involved. Recognizing the collaborative nature of this project, we are acutely aware that its success is attributed to the contributions of many. We express our deepest appreciation to everyone who has been part of this journey. In summary, we are sincerely thankful to all those who have been integral to the realization of this project, and we extend our gratitude for their invaluable contributions.

# Table of Contents


Certificate 3
Acknowledgement 5
Table of Contents 7
Abbreviations 12
List of Tables 14
List of Figures 16
List of Equations 18
1. Introduction 20
2. Case Study 22
3. Methodology 25
    Strategic Integration of Time-Net Tool: 25
    Precision-Enhanced Findings: 25
    Methodical Analysis with Time-Net Tool: 25
    Critical Insights and Comprehensive Understanding: 25
    Integrated Approach Impact: 25
4. Discussion 27
    1. Learning Petri Nets: 27
    2. Time-Net Tool Application: 27
    3. Token Game Analysis: 27
    4. Reachability Graph Construction: 28
    5. Markov Model Translation: 29
    5. Transition Throughput Values: 30
    7. Transition Probability Matrix Derivation: 31
    9. Code Implementation 33
5. Concluding Remarks 36
6. Future Work 38
    Precision in Modeling Techniques: 38
    Real-Time Data Integration: 38
    Robust Stress Testing: 38
    Empirical Validation through Rigorous Testing: 38
    Integration of Human Factors: 38
    Interdisciplinary Collaborative Frameworks: 38
    Continuous Adaptive Strategies: 39

References 41

# Abstract

This research delves into the quantitative analysis of software quality attributes within the framework of a Digital Feed Water Control System (DFWCS). Employing Petri nets as a modelling tool, the study meticulously represents the system's behaviour through throughput values, a transition rate matrix, and a transition probability matrix. The critical outcome of our approach lies in the successful identification of failure states in the DFWCS, offering invaluable insights for predicting system reliability.

The literature review positions the research within the broader landscape of software quality and control systems, providing a comprehensive foundation for the study. The methodology section elucidates the application of Petri nets and the acquisition of key matrices. Results underscore the method's efficacy in pinpointing failure states, significantly augmenting the overall comprehension of system reliability. The implications of these findings are carefully examined in the context of existing literature, amplifying the relevance and significance of the study.

In conclusion, this research makes a substantial contribution to the ongoing discourse on software quality and system reliability. The study's significance is summarized, and avenues for future work are proposed to further advance our understanding of the system's behaviour, solidifying its place in the evolving landscape of software engineering and control systems.

# Abbreviations

- DFWCS:- Digital Feed Water Control System
- PN:- Petri Net
- SPN:- Stochastic Petri Net
- P/T:- Place/Transition

# List of Tables

Table 1: Transition throughput values……………………………………………30

Table 2: Steady-state probability Values…...………………………………………..34

# List of Figures

Figure-1……………………………………………………………22
Figure-2……………………………………………………………27
Figure-3……………………………...…………………………….28
Figure-4…………………………………………………………....29
Figure-5……………………………………………………………31
Figure-6…………………………………..………………….…..31
Figure-7…………………………………..…………………..33

# List of Equations

Balance equations……………………………………………………………………32

# 1. Introduction

The Digital Feed Water Control System (DFWCS), a critical component in the field of nuclear power plants, stands as a testament to the intersection of technology and the intricate processes governing nuclear energy production. In this highly regulated and safety-critical domain, the DFWCS play a pivotal role in ensuring the efficient and secure regulation of feed water, contributing directly to nuclear power generation's reliability and safety standards.

The rapid evolution of technology has ushered in an era where software systems play a pivotal role in various domains, ensuring efficiency, reliability, and adaptability. In alignment with this trajectory, this UROP project delves into the realm of software quality attributes, focusing on a Digital Feed Water Control System (DFWCS). The DFWCS, a critical component in [mention the relevant industry or context], stands as a testament to the intersection of technology and industrial processes.

To comprehend and enhance the software quality attributes of the DFWCS, this research employs Petri nets, a versatile graphical modelling language widely utilized in the analysis and design of dynamic systems. The utilization of Petri nets allows for a comprehensive representation of the system's behaviour, facilitating the extraction of crucial quantitative parameters such as transition throughput values, transition rate matrix, and transition probability matrix.

The primary objective of this UROP project is to employ a systematic approach to assess the reliability of the DFWCS. Through the quantitative analysis facilitated by Petri nets, we aim to uncover insights into the system's performance, identify potential bottlenecks, and propose modifications that contribute to enhanced reliability and overall software quality.

This report unfolds the methodology employed in modelling the DFWCS using Petri nets, the subsequent quantitative analysis, and the implications derived from the reliability assessment. By the conclusion of this research endeavour, we anticipate contributing valuable insights to the field of software engineering, particularly in the context of industrial control systems.

## 2. Case Study

The fission process inside NPP produces an enormous amount of heat, sufficient enough to cause damage to the plant and fuel as well, if not removed within the specified time. Various systems are designed and installed in NPP for the removal of decay from the core and transferring the heat to the environment, even when the plant is in shutdown mode. DFWCS, shown in Fig. 1, is one of the systems installed in NPP for the removal of decay from it. There are two central processing units termed the main computer (MC) and the backup computer (BC) considered as brains of the DFWCS. MC executes all the control algorithms, while the other processing unit is in standby mode.

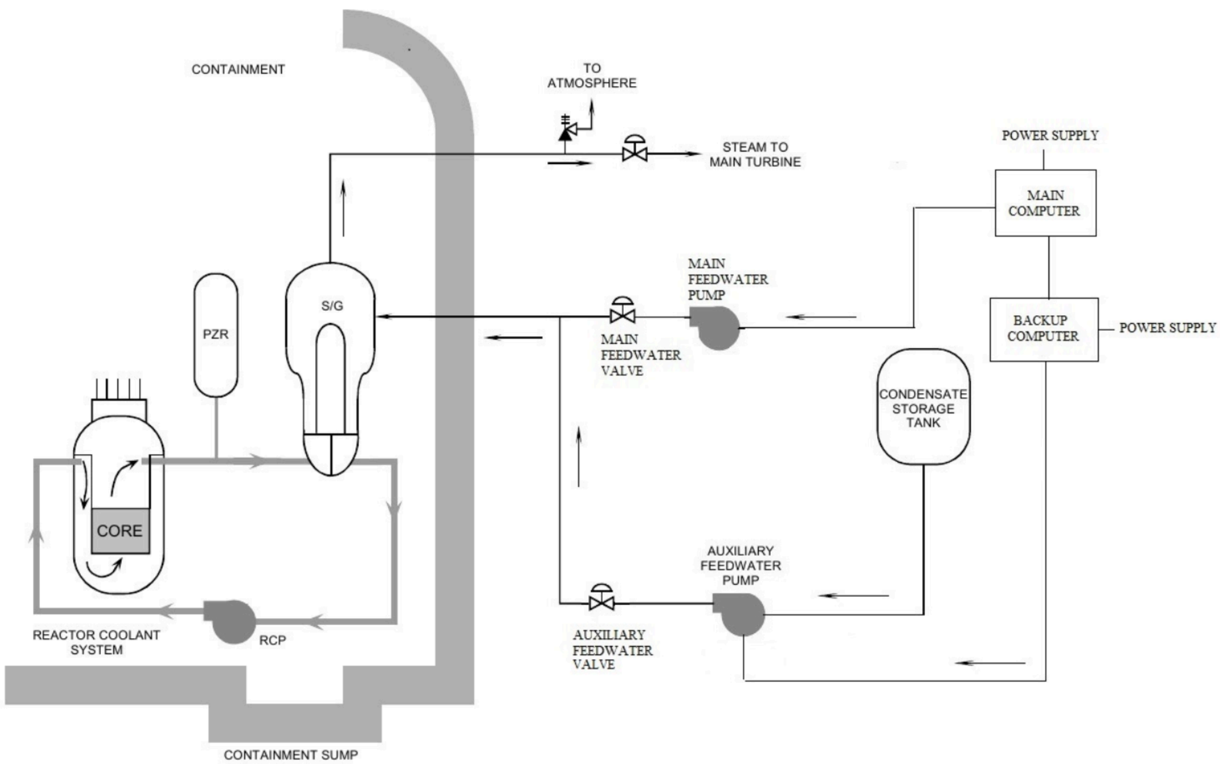


Figure 1: DFWCS of a Nuclear Power Plant

During the execution of control algorithms, if the MC fails, it automatically triggers the BC to switch from standby to active mode. DFWCS also consists of two feedwater systems, namely: the Main Feedwater System (MFWS) connected to MC, and the Auxiliary Feedwater System (AFWS) connected to the BC through a power bus. The MFWS is the primary feedwater system, while the AFWS becomes active when the MFWS is down or fails for any reason. The MFWS/AFWS, along with the steam dump system, work together to ensure that the operators can successfully remove the heat caused by the decay process from the reactor. The main/auxiliary feedwater pump delivers water to the steam generators from the main/condensate storage tank. This water is allowed to boil to produce steam. The steam dump valves allow the steam to be released into the main condenser. The circulating water will then condense the steam and take the heat to the environment. If the steam dump system is not available, the steam can be dumped directly into the atmosphere through the atmospheric relief valves. Using any method of steam removal, heat is removed from the reactor coolant system, and the system's temperature is lowered to the required level.

# 3. Methodology

**Strategic Integration of Time-Net Tool:**

- Our project strategically harnessed the capabilities of the Time-Net tool, seamlessly incorporating it as a pivotal element in modelling the intricate temporal dimensions of the Digital Feed Water Control System (DFWCS). This sophisticated tool played a crucial role in injecting time-related dynamics into the Petri net representation, providing a formalized framework for the in-depth analysis and understanding of temporal influences on system behaviour.

**Precision-Enhanced Findings:**

- The precision achieved through the integration of the Time-Net tool markedly heightened the accuracy of our findings, fostering a more nuanced examination of the reliability of the DFWCS.

**Methodical Analysis with Time-Net Tool:**

- We successfully created a graph to determine reachability calculated the values, for transition throughput and conducted an analysis of games using the Time Net tool.

**Critical Insights and Comprehensive Understanding:**

- These findings led to discoveries that gave us an understanding of how the DFWCS operates.

**Integrated Approach Impact:**

- In essence, our integrated approach using the Time Net tool has enhanced the analysis of system behavior providing us with a profound comprehension of the intricacies involved in the Digital Feed Water Control System.

# 4. Discussion

**1. Learning Petri Nets:**

To ensure we were well prepared for our analysis we initiated our project by examining Petri nets. It was essential for us to have a grasp of the principles of Petri nets to accurately model the complex dynamics of the Digital Feed Water Control System.

**2. Time-Net Tool Application:**

Once we became familiar, with Petri nets we effortlessly utilised the Time Net tool. This allowed us to determine the transition throughput values, for each state in our Petri model giving us a grasp of the operational states of the digital feed water control system.

**3. Token Game Analysis:**

We delved into the intricacies of the game, which plays a role, in our approach. By comparing the graph displaying the distribution of tokens with the values indicating transition throughput we were able to establish the connection, between throughput values and corresponding system states.

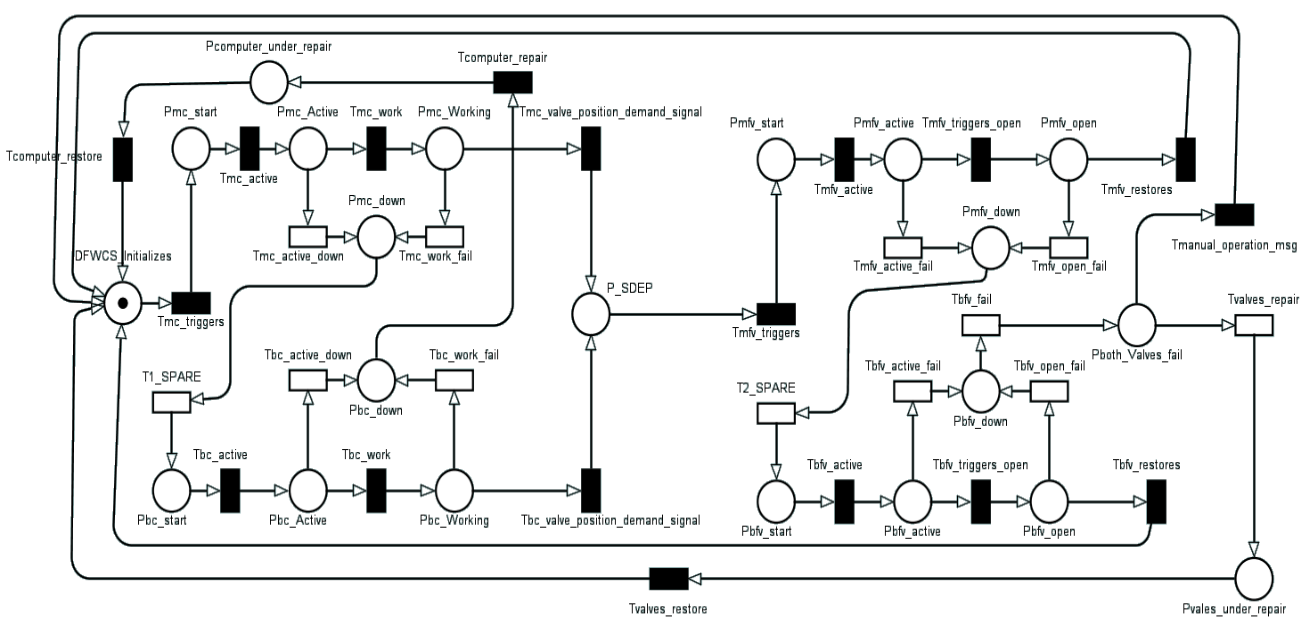


Figure 2: PN model for DFWCS

## 4. Reachability Graph Construction:

Creating a reachability graph is a part of modelling the Digital Feed Water Control System (DFWCS). This graph provides a view of how the system behaves by illustrating the various states it can transition to from its initial state. We construct the reachability graph through analysis to better understand how the DFWCS evolves dynamically over time.

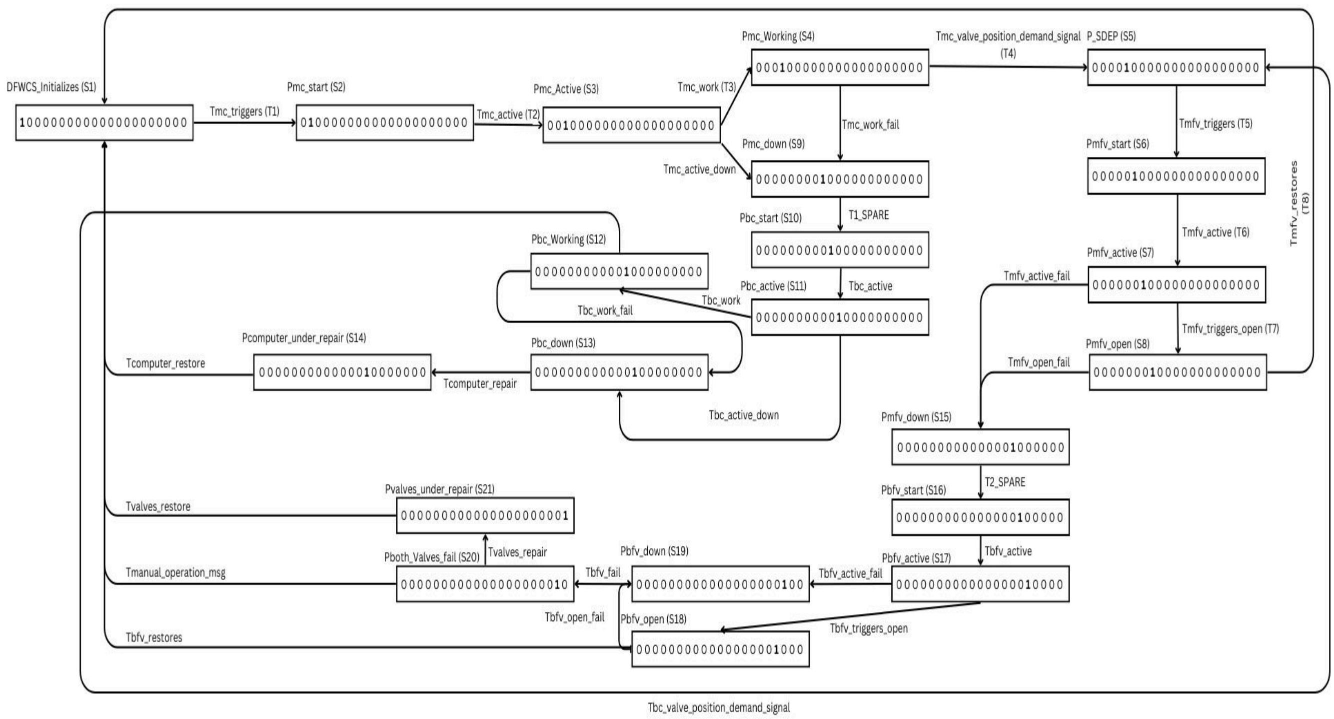


Figure 3: Reachability Graph for the PN model for DFWCS

**5. Markov Model Translation:**

To transform our representation into a framework we convert the system into a Markov model using the Petri net model as a foundation. This translation is a step, in capturing the transitions between different states within the system. By employing the Markov model we can quantitatively analyze the behavior of the system. This translation process establishes a connection between modelling and graphical representation bridging the gap from the Petri net, to the Markov model.

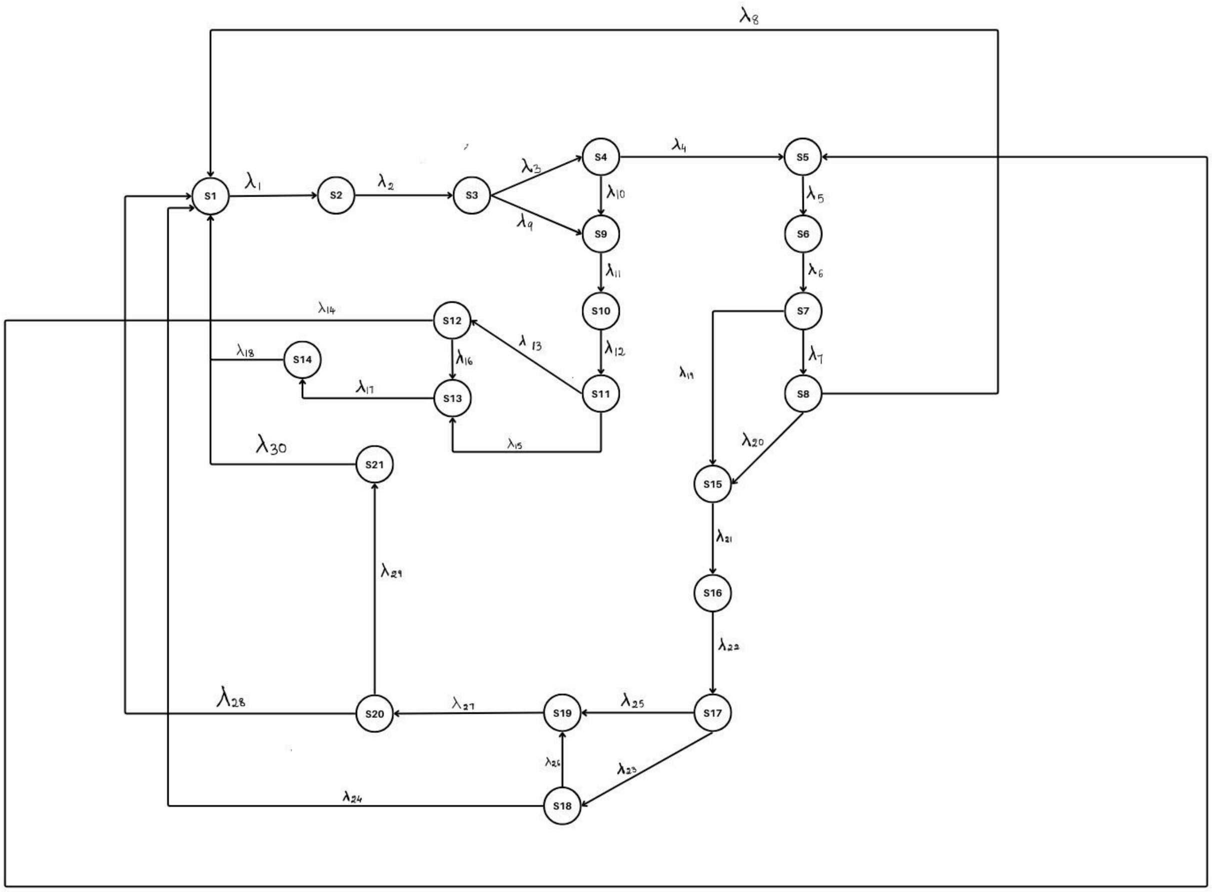


Figure 4: Markov model for the DFWCS

**5. Transition Throughput Values:**

In our analysis of the Digital Feed Water Control System (DFWCS), one crucial aspect to consider is the transition throughput values. These values indicate the speed at which the system switches between states. They form the foundation, for all calculations and assessments.

Table 1: Transition Throughput rate

| Throughput | Value |
|---|---|
| $\lambda 1$ | 0.12 |
| $\lambda 2$ | 0.12 |
| $\lambda 3$ | 0.07 |
| $\lambda 4$ | 0.03 |
| $\lambda 5$ | 0.03 |
| $\lambda 6$ | 0.03 |
| $\lambda 7$ | 0.02 |
| $\lambda 8$ | 0.01 |
| $\lambda 9$ | 0.07 |
| $\lambda 10$ | 0.03 |
| $\lambda 11$ | 0.10 |
| $\lambda 12$ | 0.10 |
| $\lambda 13$ | 0.06 |
| $\lambda 14$ | 0.02 |
| $\lambda 15$ | 0.06 |
| $\lambda 16$ | 0.02 |
| $\lambda 17$ | 0.09 |
| $\lambda 18$ | 0.09 |
| $\lambda 19$ | 0.02 |
| $\lambda 20$ | 0.01 |
| $\lambda 21$ | 0.03 |
| $\lambda 22$ | 0.03 |
| $\lambda 23$ | 0.02 |
| $\lambda 24$ | 0.01 |
| $\lambda 25$ | 0.02 |
| $\lambda 26$ | 0.01 |
| $\lambda 27$ | 0.02 |
| $\lambda 28$ | 0.01 |
| $\lambda 29$ | 0.01 |
| $\lambda 30$ | 0.01 |

### 6. Transition Rate Matrix Calculation:

We calculated the matrix, for transition rates by utilizing the values of transition throughput. The values, for transition throughput were inserted into the remaining elements of the matrix while the diagonal elements were filled with the values of their corresponding transition throughput (lambda).

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 | S13 | S14 | S15 | S16 | S17 | S18 | S19 | S20 | S21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | -0.12 | 0.12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S2 | 0 | -0.12 | 0.12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S3 | 0 | 0 | -0.14 | 0.07 | 0 | 0 | 0 | 0 | 0.07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S4 | 0 | 0 | 0 | -0.06 | 0.03 | 0 | 0 | 0 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S5 | 0 | 0 | 0 | 0 | -0.03 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S6 | 0 | 0 | 0 | 0 | 0 | -0.03 | 0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S7 | 0 | 0 | 0 | 0 | 0 | 0 | -0.04 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 |
| S8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 |
| S9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.1 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.1 | 0.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.12 | 0.06 | 0.06 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S12 | 0 | 0 | 0 | 0 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 | -0.04 | 0.02 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.09 | 0.09 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S14 | 0.09 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.09 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.03 | 0.03 | 0 | 0 | 0 | 0 | 0 |
| S16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.03 | 0.03 | 0 | 0 | 0 | 0 |
| S17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.04 | 0.02 | 0.02 | 0 | 0 |
| S18 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.02 | 0.01 | 0 | 0 |
| S19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.02 | 0.02 | 0 |
| S20 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.02 | 0.01 |
| S21 | 0.01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -0.01 |

Figure 5: Transition Rate Matrix

### 7. Transition Probability Matrix Derivation:

We employed a specific probability formula to calculate the transition probability matrix based on the rate of transitions. This matrix resulted in a representation of the likelihood of transitioning, between states.

| | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 | S13 | S14 | S15 | S16 | S17 | S18 | S19 | S20 | S21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S3 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S4 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S5 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S6 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 |
| S8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| S9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S12 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S14 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| S16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| S17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0.5 | 0 | 0 |
| S18 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0 | 0 |
| S19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| S20 | 0.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 |
| S21 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 6: Transition  Probability Matrix

**8. Equation Formulation:**

To formalize our findings, we translated the transition probability matrix into equations. These equations encapsulated the dynamic relationships between states, offering a quantitative framework for understanding the system's behaviour.

$s_1 = s_{14} + 0.5(s_{18}) + 0.5(s_{20}) + s_{21}$
$s_2 = s_1$
$s_3 = s_2$
$s_4 = 0.5(s_3)$
$s_5 = 0.5(s_4) + 0.5(s_{12})$
$s_6 = s_5$
$s_7 = s_6$
$s_8 = 0.5(s_7)$
$s_9 = 0.5(s_3) + 0.5(s_4)$
$s_{10} = s_9$
$s_{11} = s_{10}$
$s_{12} = 0.5(s_{11})$
$s_{13} = 0.5(s_{11}) + 0.5(s_{12})$
$s_{14} = s_{13}$
$s_{15} = 0.5(s_7) + s_8$
$s_{16} = s_{15}$
$s_{17} = s_{16}$
$s_{18} = 0.5(s_{17})$
$s_{19} = 0.5(s_{17}) + 0.5(s_{18})$
$s_{20} = s_{19}$
$s_{21} = 0.5(s_{20})$

$$\sum_{i=1}^{i=21} s = 1$$

This sequential process from learning Petri nets to the formulation of equations signifies a methodical approach in our quantitative analysis of the Digital Feed Water Control System.

## 9. Code Implementation

```
from scipy.optimize import fsolve
import numpy as np

# Define the equations as a system of functions
def equations(vars):
    s1, s2, s3, s4, s5, s6, s7, s8, s9, s10, s11, s12, s13, s14, s15, s16, s17, s18, s19, s20, s21 = vars
    eq1 = s14 + 0.5 * s18 + 0.5 * s20 + s21 - s1
    eq2 = s1 - s2
    eq3 = s2 - s3
    eq4 = 0.5 * s3 - s4
    eq5 = 0.5 * s4 + 0.5 * s12 - s5
    eq6 = s5 - s6
    eq7 = s6 - s7
    eq8 = 0.5 * s7 - s8
    eq9 = 0.5 * s3 + 0.5 * s4 - s9
    eq10 = s9 - s10
    eq11 = s10 - s11
    eq12 = 0.5 * s11 - s12
    eq13 = 0.5 * s11 + 0.5 * s12 - s13
    eq14 = s13 - s14
    eq15 = 0.5 * s7 + s8 - s15
    eq16 = s15 - s16
    eq17 = s16 - s17
    eq18 = 0.5 * s17 - s18
    eq19 = 0.5 * s17 + 0.5 * s18 - s19
    eq20 = s19 - s20
    eq21 = 0.5 * s20 - s21

    return [eq1, eq2, eq3, eq4, eq5, eq6, eq7, eq8, eq9, eq10, eq11, eq12,
            eq13, eq14, eq15, eq16, eq17, eq18, eq19, eq20, eq21]
```

```
# Initial guess
initial_guess = np.ones(21)

# Solve the system numerically
solution = fsolve(equations, initial_guess)

# Normalize the values to ensure the sum is 1
normalized_solution = solution / sum(solution)

# Display the normalized solution
for state, value in zip(['s1', 's2', 's3', 's4', 's5', 's6', 's7', 's8', 's9', 's10', 's11',
                         's12', 's13', 's14', 's15', 's16', 's17', 's18', 's19', 's20', 's21'],
                        normalized_solution):
    print(f"{state}: {value}")

# Ensure the sum is 1 and round to 10 decimal places
rounded_sum = round(sum(normalized_solution), 10)
print(f"Sum of all states: {rounded_sum}")
```

**Predicted Reliability**

```
s13= 0.050526315789473676
s19= 0.02947368421052631

r=1-(s13+s19)
print("Reliability: ",r)
print("Reliability Percentage: ",r*100,'%')
```

Figure 7: Code Implementation

## 10. Final Findings

Table 2: Steady State Probability

| State | Probability Value |
|---|---|
| $\pi 1$ | 0.08982456140350877 |
| $\pi 2$ | 0.08982456140350877 |
| $\pi 3$ | 0.08982456140350877 |
| $\pi 4$ | 0.04491228070175438 |
| $\pi 5$ | 0.03929824561403508 |
| $\pi 6$ | 0.03929824561403508 |
| $\pi 7$ | 0.03929824561403508 |
| $\pi 8$ | 0.01964912280701754 |
| $\pi 9$ | 0.06736842105263158 |
| $\pi 10$ | 0.06736842105263158 |
| $\pi 11$ | 0.06736842105263158 |
| $\pi 12$ | 0.03368421052631579 |
| $\pi 13$ | 0.050526315789473676 |
| $\pi 14$ | 0.050526315789473676 |
| $\pi 15$ | 0.03929824561403508 |
| $\pi 16$ | 0.03929824561403508 |
| $\pi 17$ | 0.03929824561403508 |
| $\pi 18$ | 0.01964912280701754 |
| $\pi 19$ | 0.02947368421052631 |
| $\pi 20$ | 0.02947368421052631 |
| $\pi 21$ | 0.014736842105263156 |

```
Reliability:  0.92
Reliability Percentage:  92.0 %
```

# 5. Concluding Remarks

In conclusion, this UROP project systematically examined the software quality attributes of the Digital Feed Water Control System (DFWCS) within nuclear power plants. Employing Petri nets for modelling revealed nuanced insights, including transition throughput values, transition rate matrix, and transition probability matrix.

After computing the reliability of 21 states we obtained an average accuracy prediction accuracy of **92.0%**

During the architecture phase our approach, to forecasting software reliability surpasses the constraints faced by methods relying on the Markov chain model. We have confidence, in the robustness of our validation results enabling software designers to make decisions based on our software reliability predictions.

Through rigorous analysis, we have assessed the reliability of the DFWCS, shedding light on its performance characteristics and identifying key insights that contribute to the system's dependability. This research not only enhances our understanding of software quality in safety-critical industrial processes but also underscores the significance of leveraging advanced modelling techniques for system analysis.

The proposed modifications, rooted in the findings of our reliability assessment, offer actionable strategies for refining the DFWCS, ensuring a more robust and resilient operation within the challenging context of nuclear power plants. As we reflect on this UROP journey, the acquired knowledge not only contributes to the broader field of software engineering but also serves as a testament to the efficacy of interdisciplinary approaches in addressing complex challenges at the intersection of technology and industrial processes.

# 6. Future Work

The trajectory of this research sets the stage for future endeavours aimed at refining and advancing the Digital Feed Water Control System (DFWCS). The following pragmatic directions outline potential areas for further exploration:

**Precision in Modeling Techniques:**

Investigate advanced modelling techniques beyond Petri nets to enhance the precision and granularity of the DFWCS representation, aiming for a more accurate portrayal of its dynamic behaviour.

**Real-Time Data Integration:**

Explore methodologies for the seamless integration of real-time data streams into the modelling process. This approach aims to bolster the authenticity and applicability of the system's representation, aligning it more closely with real-world operational conditions.

**Robust Stress Testing:**

Implement a comprehensive stress testing regimen, encompassing diverse operational conditions and scenarios. This initiative seeks to fortify the reliability evaluation, ensuring the robustness of the DFWCS across a spectrum of operational challenges.

**Empirical Validation through Rigorous Testing:**

Execute systematic simulation and practical testing protocols based on the proposed modifications. Real-world testing will provide empirical validation, offering insights into the feasibility and impact of these enhancements.

**Integration of Human Factors:**

Undertake a comprehensive study of the human-machine interface and the role of operators within the context of the DFWCS. Recognizing the critical impact of human factors on the reliability and safety of the system is paramount.

**Interdisciplinary Collaborative Frameworks:**

Establish collaborative frameworks with experts in nuclear engineering, control systems, and human factors. Interdisciplinary collaboration will enrich the research by integrating diverse perspectives and expertise.

**Continuous Adaptive Strategies:**

Develop and implement strategies for continuous system monitoring and adaptation. This initiative ensures that the DFWCS remains resilient to evolving technological landscapes and emerging threats over the long term.

# References


1. Pramod Kumar , Lalit Kumar Singh , Nilesh Chaudhari , Chiranjeev Kumar, 2020. "Availability analysis of safety-critical and control systems of NPP using stochastic modeling". Annals of Nuclear Energy
2. Lalit Kumar Singh, Gopika Vinod, A.K. Tripathi, 2016. Early Prediction of Software Reliability: A Case Study with a Nuclear Power Plant System.Volume: 49. Early Prediction of Software Reliability
3. T. Murata, "Petri Nets: Properties, Analysis and Applications," Proc.IEEE, 1989, pp. 541–580.
4. R.H. Reussner, H.W. Schmidt, and I.H.Poernomo, "Reliability Prediction for Component-Based Software," J. Systems and Software, vol. 66, no. 3, 2003, pp. 241–252.
5. Haitao Guo and Xianhui Yang. A simple reliability block diagram method for safety integrity verification. Reliability Engineering & System Safety, 92(9):1267–1273, 2007.
6. Vinay Kumar, Lalit Kumar Singh, and Anil Kumar Tripathi. Transformation of deterministic models into state space models for safety analysis of safety-critical systems: A case study of NPP. Annals of Nuclear Energy, 105:133–143, 2017.
7. Vinay Kumar, Lalit Kumar Singh, Anil Kumar Tripathi, and Pooja Singh. Safety analysis of safety-critical systems using state-space models. IEEE Software, 34(4):38–47, 2017.
8. Nand Kumar Jyotish, Lalit Kumar Singh, Chiranjeev Kumar, and Pooja Singh. Reliability and performance measurement of safety-critical systems based on Petri nets: A case study of nuclear power plant. IEEE Transactions on Reliability, 2023.
9. Pramod Kumar, Lalit Kumar Singh, and Chiranjeev Kumar. Software reliability analysis for safety-critical and control systems. Quality and Reliability Engineering International, 36(1):340–353, 2020.
10. Vinay Kumar, Lalit Kumar Singh, Pooja Singh, Karm Veer Singh, Ashish Kumar Maurya, and Anil Kumar Tripathi. Parameter estimation for quantitative dependability analysis of safety-critical and control systems of NPP. IEEE Transactions on Nuclear Science, 65(5):1080 1090, 2018.