

ORIGINAL ENGINEERING & TECHNOLOGY RESEARCH

A Methodology for Reliability Risk Assessment of Potential Failure Modes in the Software Development Lifecycle (SDLC)

منهجية لتقييم مخاطر الموثوقية لأنماط الفشل المحتملة في دورة حياة تطوير البرمجيات (SDLC)

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Abstract

Risk assessment methods are one of the essential elements of software risk management plan. A number of those methods use informal models that are based on subjective judgements for analysing risks. Unfortunately, subjective judgements rely heavily on human intuition, which are error-prone and do not conform to project management standards. Risk assessment should be based on a professional approach that applies product attributes, which can be measured quantitatively using product metrics and project management standards. In this study, a reliability risk assessment was conducted using the FMEA method in alliance with popular management standards to classify the risks and determine the risk impact on the project outcomes. Fifteen (15) software development experts were purposefully selected to participate in the study as stipulated by the FMEA process requirements. The method uses the product metrics of Occurrence (O), Severity (S), and Detection (D) based on the FMEA theory to compute the Risk Priority Number (RPN) of the individual failure mode. Using the USDOD (MIL-STD-1629 1980) and the risk impact category scale of the Project Management Institute (PMI 2004), the RPN value was used for the reliability risk assessment. The methodology is used to determine the impact which the potential failure modes in the SDLC will have on the project outcomes (cost, period, and quality).

Keywords: Risk assessment Failure mode SDLC Reliability approach FMEA Occurrence Severity Detection RPN Project outcomes

1. INTRODUCTION

Software Development Lifecycle (SDLC) is a framework that defines various activities at each stage of the software process (Giuseppe, 2017; Hijazi, Alqrainy, Muaidi & Khmour 2014a, 2014b). The SDLC is vulnerable to different risks. Each phase of the SDLC is susceptible to several risk factors (Hijazi et al. 2014a). In Software Engineering (SE), the term 'risk' is any form of situation or event which can influence the outcome of a software development project (CAST 2015). A close examination of the risk concept shows that the conceptualization of 'risk' in SE may be narrower than the nature of the inherent problem in practice that is tenable in SE (Lawal 2022; Wallace, Keil & Rai 2004). For example, the definition in terms of probability of occurrence and impact in terms of loss cannot adequately measure the risk magnitude that can predict the impact a potential failure mode (i.e., a characterization of the manner in which a typical activity in the process fails) in the SDLC will have on project outcomes. This is because activities associated with high severity during the development process, and having low possibility of occurrence, can be computed to yield low risk value factors and as so, they can be wrongly considered as factors with insignificant risk magnitude (Lawal 2022).

Risk assessment in software development projects involves the process of identifying, analyzing, prioritizing, classifying and estimating the risk effect in software projects (Bilal, Gani, Liaqat, Bashir & Malik 2020; Wallace 1999; Boehm 1991). Risk assessment process can be actualised using a variety of techniques (Wallace 1999). Existing software project risk assessment techniques found in the literature include (Taroun 2012): Fuzzy Sets Approach (FSA); regression analysis; Decision Tree and Fault Tree Analysis; Monte Carlo Simulation; Cause-And-Effect Diagram; Delphi Technique; Multiple Criteria Decision Making (MCDM); Neural Networks; Influence Diagrams; PERT; expert systems; Sensitivity Analysis; FMEA, and combination of FMEA and FTA.

Review of previous studies conducted to analyse the strength and weaknesses of these techniques (e.g., Taroun 2012; Abdelgawad 2011; Georgieva 2007) reveals that a number of these techniques can only be used for qualitative assessments based on subjective ratings rather than quantifying risk magnitude against international standards. Thus, the conduct of reliability risk assessment practically becomes more challenging to risk managers.

To sum it up, the problem of risk misconception makes it practically difficult for current risk assessment methods to adequately estimate the impact of the potential failure modes in the SDLC on project outcomes. The risk management efforts are also complicated by qualitative assessments characterized by human intuition and unrealistic assumptions. It is therefore the aim of this study to apply a safety and reliability method that will modify the risk concept in SE to capture the software project multi-dimensional variables, so as to classify and reliably assess the impact which risky potential failure modes in the SDLC will have on the project outcomes (cost, period & quality).

2. Problem Statement

Risk assessment should be conducted using a method that applies product attributes based on project management standards to quantitatively classify risks and measure risk effects on project outcomes. However, existing SE techniques can primarily be used only for qualitative assessments (Georgieva 2007) governed by subjective judgment, making reliability risk assessment a challenging task.

3. Purpose of the Study

The study was conducted to apply the FMEA method to:

1. Classify the risk associated with potential failure modes in the SDLC.
2. Reliably quantify the impact which risky potential failure modes in the SDLC will have on project outcomes (cost, period & quality).

4. Research Questions

RQ1: How critical are the risks associated with potential failure modes in the SDLC?

RQ2: What impact do the risky potential failure modes in the SDLC have on project outcomes (cost, period & scope/quality)?

5. THEORETICAL FRAMEWORKS

Two theories were combined to provide the theoretical framework for the conduct of this study: **Diffusion of Innovation Theory (DIT)** and **Technology Acceptance Theory (TAT)**. Rogers (2003) developed DIT to explain how innovation spreads through channels over time among members of a social system from recognition, attitude formation, decision, implementation, to confirmation. TAT states that users' perceptions regarding perceived usefulness and ease of use are significant determinants of technology adoption (Davis 1989, 1995; Momani & Jamous 2017). The combination of DIT and TAT was adopted to: (i) spread the idea of using FMEA for reliability risk assessment based on quantitative functionalities, and (ii) adopt and implement FMEA to assess the risk factors associated with potential failure modes in the SDLC.

6. RESEARCH METHODOLOGY

The FMEA method comprises: assessing the probability of Occurrence (O) for each failure mode; assigning Severity (S) rating; assigning Detection (D) rating; calculating the Risk Priority Number (RPN = $O \times S \times D$); classifying the risk criticality; and estimating the risk impact on project outcomes (cost, period & quality).

Standards & Team Composition:

The five stages of the SDLC recommended by ISO/IEC 12207 (1995) were adopted. Failure modes were extracted and modified from Abubakar & Lawal (2020) and Georgieva (2010). A team of **15 selected software development experts** evaluated each failure mode.

Measurement Scales:

Parameters (O, S, D) were measured using a 1-to-10 linguistic scale adapted from Abdelgawad and Fayek (2010). Criticality classification followed USDOD (MIL-STD-1629 1980), and impact on outcomes was mapped to the Project Management Institute (PMI 2004) framework.

7. RESULTS & EMPIRICAL FINDINGS

The FMEA worksheet documents each potential failure mode, its ratings (O, S, D), RPN, risk classification, and projected impacts on Cost, Schedule, and Quality.

Table 1.0: FMEA Worksheet documenting assessment in the Planning Stage of the SDLC

ID	Potential Failure Mode	O	S	D	RPN	Risk Class	Cost Impact	Schedule Impact	Quality Impact
PFM1	Inappropriate chosen software development framework/methodology/models	7	8	5	280	Critical	Cost increase is $\geq 7\%$ & $< 10\%$	In-service date delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
PFM2	Communication gap amongst development team	4	4	3	48	Normal	Cost increase $< 1\%$	Delayed $\geq 1\%$ & $< 4\%$	Few areas of quality affected
PFM3	Ambiguous or unclear specification	6	8	5	240	Critical	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
PFM4	Insufficient software project tools and resources	7	4	3	84	Semi-Critical	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected
PFM5	Unrealistic project goals and scopes	7	6	5	210	Critical	Cost increase $\geq 7\%$ & $< 10\%$	Delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
PFM6	Unrealistic budget	7	7	5	245	Critical	Cost increase $\geq 7\%$ & $< 10\%$	Delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
PFM7	Ambiguous project hierarchy model	2	3	6	30	Normal	Cost increase $< 1\%$	Insignificant slippage	Quality degradation not noticeable
PFM8	Inexperience project team members	7	8	5	280	Critical	Cost increase $\geq 7\%$ & $< 10\%$	Delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
PFM9	Poor risk management strategy	8	8	5	320	Critical	Cost increase $\geq 7\%$ & $< 10\%$	Delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
PFM10	Deviance of system security integration	5	7	3	105	Semi-Critical	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected

Notes: S = Severity (1-10); O = Occurrence (1-10); D = Detection (1-10); RPN = Risk Priority Number ($O \times S \times D$).

Analysis of Table 1.0 (Planning Stage): PFM1, PFM3, PFM5, PFM6, PFM8, and PFM9 are classified as *Critical* risks (RPN > 140), where PFM9 (Poor risk management strategy) exhibited the highest RPN of 320. PFM4 and PFM10 are classified as *Semi-Critical*, while PFM2 and PFM7 are *Normal* risks with negligible impact.

Table 2.0: FMEA Worksheet documenting assessment in the Requirement Specification Stage of the SDLC

ID	Potential Failure Mode	O	S	D	RPN	Risk Class	Cost Impact	Schedule Impact	Quality Impact
RFM1	Inappropriate chosen requirement gathering technique	5	5	4	100	Semi-Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected
RFM2	Ambiguous or unclear requirement	5	4	4	80	Semi-Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected
RFM3	Contradictions and confusion in domain specific terminologies	3	3	2	18	Normal	Cost increase < 1%	Insignificant slippage	Quality degradation not noticeable
RFM4	Contradictions and confusion in defining requirements in Natural Language (NL)	4	5	2	40	Normal	Cost increase < 1%	Insignificant slippage	Quality degradation not noticeable
RFM5	Errors in human factor engineering specifications	5	5	3	75	Semi-Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected
RFM6	Inaccurate requirement	7	8	5	280	Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected
RFM7	Unrealistic requirement	5	5	6	150	Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected
RFM8	Inconsistent requirement	5	6	5	150	Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected
RFM9	Non-traceable requirement	7	5	5	175	Critical	Cost increase $\geq 7\%$ & < 10%	Delayed $\geq 7\%$ & < 10%	Scope changes unacceptable to sponsor
RFM10	Non-verifiable requirement	7	6	5	210	Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected

Notes: Criticality mapping: Normal (RPN < 70); Semi-Critical (70 < RPN < 140); Critical (RPN > 140).

Analysis of Table 2.0 (Requirement Specification Stage): Failure modes RFM6, RFM7, RFM8, RFM9, and RFM10 are classified as *Critical* risks. Specifically, RFM6 (Inaccurate requirement, RPN=280) and RFM10 (Non-verifiable requirement, RPN=210) demonstrate heavy susceptibility to software defects. RFM1, RFM2, and RFM5 are *Semi-Critical*, while RFM3 and RFM4 are *Normal*.

Table 3.0: FMEA Worksheet documenting assessment in the Design Stage of the SDLC

ID	Potential Failure Mode	O	S	D	RPN	Risk Class	Cost Impact	Schedule Impact	Quality Impact
DFM1	Ambiguous or unclear Requirement Document	5	6	5	150	Critical	Cost increase $\geq 7\%$ & < 10%	Delayed $\geq 7\%$ & < 10%	Scope changes unacceptable to sponsor
DFM2	Inappropriate chosen architectural design method	7	5	5	175	Critical	Cost increase $\geq 7\%$ & < 10%	Delayed $\geq 7\%$ & < 10%	Scope changes unacceptable to sponsor
DFM3	Errors in human factor engineering during design phase	5	5	4	100	Semi-Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected
DFM4	Poor implementation of design principle	6	7	5	210	Critical	Cost increase $\geq 7\%$ & < 10%	Delayed $\geq 7\%$ & < 10%	Scope changes unacceptable to sponsor
DFM5	Errors in human factor engineering at specification stage	7	6	5	255	Critical	Cost increase $\geq 7\%$ & < 10%	Delayed $\geq 7\%$ & < 10%	Scope changes unacceptable to sponsor
DFM6	Complex and Complicated design	5	5	5	125	Semi-Critical	Cost increase $\geq 7\%$ & < 10%	Delayed $\geq 7\%$ & < 10%	Scope changes unacceptable to sponsor
DFM7	Poor refinement process	7	5	5	175	Critical	Cost increase < 1%	Delayed $\geq 1\%$ & < 4%	Few areas of quality affected
DFM8	Too much elaborative specification at design stage	5	5	3	75	Semi-Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected
DFM9	Inconsistent design document	5	5	2	50	Normal	Cost increase < 1%	Insignificant slippage	Quality degradation not noticeable
DFM10	Non-traceable detailed design	6	5	3	90	Semi-Critical	Cost increase $\geq 4\%$ & < 7%	Delayed $\geq 4\%$ & < 7%	Major areas of scope/quality affected

Analysis of Table 3.0 (Design Stage): The results show that failure modes in the Design stage are predominantly classified as Critical (DFM1, DFM2, DFM4, DFM5, DFM7) and Semi-Critical (DFM3, DFM6, DFM8, DFM10), with only DFM9 classified as Normal risk.

Table 4.0: FMEA Worksheet documenting assessment in the Implementation and Coding Stage of the SDLC

ID	Potential Failure Mode	O	S	D	RPN	Risk Class	Cost Impact	Schedule Impact	Quality Impact
CFM1	Ambiguous or unclear Design Document	5	5	5	125	Semi-Critical	Cost increase $\geq 7\%$ & $< 10\%$	Delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
CFM2	Inappropriate chosen programming language	3	3	4	36	Normal	Cost increase $< 1\%$	Insignificant slippage	Quality degradation not noticeable
CFM3	Errors in human factor engineering during coding/testing	5	5	4	100	Semi-Critical	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected
CFM4	Difficulties in reviewing codes	5	6	3	90	Semi-Critical	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected
CFM5	No provision for reusability	5	6	4	120	Semi-Critical	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected
CFM6	Misleading/incorrect documentation on reused component	6	6	5	180	Critical	Cost increase $\geq 7\%$ & $< 10\%$	Delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
CFM7	Poor programming practice (redundancy, repetitive code)	2	3	4	24	Normal	Cost increase $< 1\%$	Delayed $\geq 1\%$ & $< 4\%$	Few areas of quality affected
CFM8	Lack of coordinated teamwork amongst programmers	3	4	3	36	Normal	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected
CFM9	Technology Change	5	5	3	75	Semi-Critical	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected
CFM10	Inconsistent and complex code	3	4	4	48	Normal	Cost increase $< 1\%$	Insignificant slippage	Quality degradation not noticeable

Analysis of Table 4.0 (Coding Stage): Potential failure mode CFM6 (RPN=180) is classified as *Critical*, carrying severe implications for cost overruns and schedule delays. Modes CFM1, CFM3, CFM4, CFM5, and CFM9 are classified as *Semi-Critical*, while CFM2, CFM7, CFM8, and CFM10 are classified as *Normal*.

Table 5.0: FMEA Worksheet documenting assessment in the Installation and Maintenance Stage of the SDLC

ID	Potential Failure Mode	O	S	D	RPN	Risk Class	Cost Impact	Schedule Impact	Quality Impact
IFM1	Experiencing difficulties during installation	4	3	3	36	Normal	Cost increase $< 1\%$	Insignificant slippage	Quality degradation not noticeable
IFM2	System not installed correctly due to env change	5	4	4	80	Semi-Critical	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected
IFM3	New set of requirements are emerging	3	4	4	48	Normal	Cost increase $< 1\%$	Insignificant slippage	Quality degradation not noticeable
IFM4	Persisting difficulties in using the systems	4	4	2	32	Normal	Cost increase $< 1\%$	Insignificant slippage	Quality degradation not noticeable
IFM5	Expected functionalities are omitted	6	7	5	210	Critical	Cost increase $\geq 7\%$ & $< 10\%$	Delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
IFM6	Misleading/incorrect documentation on operation	5	6	5	150	Critical	Cost increase $\geq 7\%$ & $< 10\%$	Delayed $\geq 7\%$ & $< 10\%$	Scope changes unacceptable to sponsor
IFM7	Several faults/errors emerging in acceptance testing	3	3	4	36	Normal	Cost increase $< 1\%$	Delayed $\geq 1\%$ & $< 4\%$	Few areas of quality affected
IFM8	Adequate testing not conducted	3	3	2	18	Normal	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected
IFM9	Difficulties in fixing reported problems	5	6	3	90	Semi-Critical	Cost increase $\geq 4\%$ & $< 7\%$	Delayed $\geq 4\%$ & $< 7\%$	Major areas of scope/quality affected
IFM10	Difficulties in system maintainability	5	5	3	75	Semi-Critical	Cost increase $< 1\%$	Insignificant slippage	Quality degradation not noticeable

Analysis of Table 5.0 (Installation & Maintenance Stage): IFM5 (RPN=210) and IFM6 (RPN=150) are classified as *Critical* risks, liable to delay in-service dates and incur unacceptable scope changes. Modes IFM2, IFM9, and IFM10 are *Semi-Critical*, while IFM1, IFM3, IFM4, IFM7, and IFM8 represent *Normal* risks.

8. DISCUSSION

8.1 Research Question 1: Criticality of Risks in SDLC Failure Modes

To answer RQ1 (*How critical are the risks associated with potential failure modes in the SDLC?*), the RPN values computed for individual failure modes were mapped onto the criticality classification standard of USDOD (MIL-STD-1629 1980). A higher RPN corresponds to higher criticality. The three distinct thresholds established are:

Normal Level (RPN < 70):

Obtainable when calculated RPN is low. Risk criticality has insignificant impact on project outcomes; hence, the associated risk warrants standard monitoring without mandatory corrective or preventive interventions.

Semi-Critical Level (70 < RPN < 140):

Obtainable when RPN is moderate. The risk criticality causes noticeable impact on outcomes (4% to 7% cost/schedule deviations). In this category, active corrective and preventive action is essential.

Critical Level (RPN > 140):

Obtainable when calculated RPN values are high. The impacts of these failure modes are unacceptable to project sponsors, driving cost overruns ≥ 7% to 10%, major project delays, and severe quality degradation. Corrective and preventive actions are mandatory to safeguard the software product from outright collapse.

8.2 Research Question 2: Risk Impact on Project Outcomes (Cost, Period, Quality)

To answer RQ2 (*What impact do risky failure modes have on project outcomes?*), RPN values were mapped onto the risk impact category scale of the Project Management Institute (PMI 2004). The empirical analysis confirms direct proportional relationships:

Criticality Class	Cost Overrun (Budget)	Schedule Slippage (Period)	Quality & Scope Impact
Critical (RPN > 140)	Cost increase is ≥ 7% and < 10% of total project cost.	In-service date delayed ≥ 7% and < 10% of project duration.	Scope changes and quality compromises are unacceptable to project sponsors.
Semi-Critical (70 < RPN < 140)	Cost increase is ≥ 4% and < 7% of total project cost.	In-service date delayed ≥ 4% and < 7% of project duration.	Major functional areas of scope or quality are substantially affected.
Normal (RPN < 70)	Cost increase is < 1% of total project cost.	Insignificant schedule slippage (or delayed < 4%).	Quality degradation is unnoticeable or limited to minor, isolated areas.

Managerial Takeaway: Risk criticality provides software project managers with a quantifiable, objective lens to allocate finite engineering and testing resources to the failure modes that genuinely threaten project viability, rather than relying on intuitive guesswork.

9. RECOMMENDATIONS

1. Industrial Software Adoption:

Project managers and software engineering teams should systematically embed the FMEA framework into their standard risk management processes, as it demonstrates superior quantitative accuracy over qualitative models.

2. Cross-Disciplinary Generalization:

Because FMEA is proven to be a highly effective reliability assessment tool, future research should investigate its efficacy across other complex domains such as civil construction, manufacturing, investment, and strategic policymaking.

10. CONCLUSION

The concluding remarks of this research are summarized as follows:

1. Predictive Risk Control: The methodology adopted for reliability risk assessment provides a unique, standardized strategy to pinpoint the highest-risk failure modes in the SDLC, enabling software managers to proactively deploy mitigation controls before defects manifest downstream.

2. Dual Utility of RPN: The computation of RPN based on product metrics (O, S, D) serves a dual functional purpose: (i) it mathematically establishes the risk criticality class of each failure mode according to MIL-STD-1629, and (ii) it quantitatively forecasts the concrete impact on cost, schedule, and quality conforming to PMI standards.

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