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INTEGRATION OF IATF 16949 IN SOFTWARE DEVELOPMENT LIFECYCLE FOR AUTOMOTIVE INDUSTRY

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Abstract: *The paper aims to present a framework designed to simplify the complex challenges of software development in the automotive industry. By focusing on visualization and key concepts, the framework enhances understanding and makes the development process easier to implement. It integrates the IATF 16949 standard to ensure compliance and quality, offering an adaptable software development lifecycle (SDLC) tailored to industry needs. A distinctive feature is the use of visual maps and clear checklists, which guide teams through SDLC phases and ensure efficient process management. This approach helps companies achieve innovation while maintaining strict quality and safety standards.*
Keywords: *SDLC, IATF 16949, visualization, framework, automotive industry, implementation, standard, checklist.*

1. INTRODUCTION

The automotive industry is undergoing a rapid transformation, driven by technological advancements, particularly in electric and autonomous vehicles. Leading companies are at the forefront of this innovation, pushing the boundaries of battery technology and artificial intelligence. The global automotive software and electronics market is expected to grow significantly in the coming years, with substantial expansion in both the supplier and consumer segments [1].

The automotive sector significantly enhances mobility and accessibility, connecting individuals to essential services such as jobs, education, and healthcare. Intelligent transportation systems contribute to urban development, promoting a better quality of life through improved infrastructure [2].

As organizations navigate these transformations, they face increasing pressure to innovate, manage risks, and meet legal and regulatory requirements. International management system standards, such as IATF 16949, play a critical role in helping these organizations enhance performance, ensure compliance, and facilitate global collaboration [3 – 5].

However, as the complexity of software development in the automotive industry increases, so does the need for clear frameworks that align with both industry standards and quality management systems. Several studies have investigated the incorporation of SDLC within quality management systems and the implementation of IATF 16949 in industry. For instance, Bakhtiar Ostadi, Mohammad Aghdasi, Reza Kazemzadeh analyzed the impact of ISO/TS 16949 on the automotive industry and the organizational capabilities created through its implementation [6]. In a similar vein, Manohar Nayak conducted a comparative study of SDLC models, emphasizing the selection of the most suitable models for various types of software projects [7]. However, there has been little research that directly maps the phases of the SDLC in relation to the specific requirements of IATF 16949.

This article addresses this gap by proposing a structured, visual framework for software development, specifically designed for the automotive sector. “Velocidra” integrates IATF 16949 standards directly into the software development lifecycle, presenting a model that combines simplicity with rigor. By visualizing key phases and interdependent quality checks, this model provides the automotive industry

with a manageable approach to meet strict quality standards while improving operational efficiency. This approach is in line with Mohammad Ikbal discussion on the importance of clear and structured SDLC methodologies in project management [8].

2. MATERIALS AND METHODS

2.1. Materials

In this research, a range of materials and tools, presented in Table 1, were used to analyze and apply the requirements of the IATF 16949 standard in the software development process within the automotive industry [6].

Table 1

Materials used

Bibliographic sources	Software tools
IATF 16949, the automotive quality standard, was analyzed to identify compliance requirements, with a focus on software development for modern vehicles. Relevant studies and academic articles from platforms like Research Gate and MDPI were analyzed to understand automotive trends, including the rise of electric and autonomous vehicles. These insights helped clarify how IATF 16949 requirements can be effectively integrated into software development.	Microsoft PowerPoint/ Word: were used to create visual maps (process diagrams) illustrating the phases of the SDLC and how the requirements of IATF 16949 are integrated into each phase of the process. These diagrams were important for providing a clear visual representation of the software development process and highlighting the connections between the standard's requirements and each SDLC phase. Microsoft Excel: Used to create the "Velocidra" framework through a detailed checklist that allows tracking the progress of requirement implementation in each phase.

2.2. Methods

To achieve the objectives for this research, qualitative and quantitative methods analyzed IATF 16949 and its integration into automotive software development. Key quality requirements, including risk and change management, were identified. The study outlines general SDLC phases without selecting a specific model [7, 9].

Visual maps were created to represent SDLC phases and how IATF 16949 requirements are integrated. Using PowerPoint and Word, these maps highlight each phase, showing connections between SDLC activities and standard requirements, and illustrating workflows, control points, and team interactions. A detailed analysis aligned IATF 16949 requirements with evidence needed for software development projects, presented in a table to show the necessary actions to prove implementation.

A framework for implementing IATF 16949 within the SDLC of automotive software was created based on document analysis and visual maps. It identified key development phases and how to integrate the standard's requirements into each. The framework ensures compliance with automotive quality and safety standards. A compliance checklist, forming the "Velocidra" framework, tracks IATF 16949 requirements at each SDLC phase, ensuring the final product meets quality and safety standards.

3. RESULTS

The results presented below were achieved through the application and analysis of a rigorous case study, which will be detailed in the following section, providing a solid foundation for validating the conclusions and the proposed approach.

Case Study – Implementing Quality Processes in the Automotive Software Companies

Context and Problem

According to an article written by Deloitte Insights, companies specializing in software development for the automotive industry have faced numerous challenges related to compliance with industry-specific safety and quality requirements, as well as the need to improve internal development processes. The increasing regulatory demands, especially due to the growing complexity of vehicles, have necessitated the adoption of stringent quality standards to ensure functional safety and minimize software bugs [10].

Key problem

How can companies implement effective quality standards to improve software performance while maintaining innovation and efficiency throughout its lifecycle, using accessible and easy-to-apply methods?

Analysis of solutions

1. Implementation of industry-specific quality standard framework: IATF 16949;
2. Adopting a well-defined, flexible and adaptable software life cycle model (SDLC);
3. Integrating risk management into the software lifecycle;
4. The testing and validation processes automation.

After evaluating the proposed solutions, a combination was chosen as the best approach. This will create a clear framework, applying IATF 16949 and a flexible SDLC model to ensure software safety, security, performance, efficiency, and innovation, leading to effective results.

A well-structured SDLC model provides an adaptable framework to meet the specific needs of projects and ensures clear direction for each phase of the software development process in automotive companies [8]. Adopting IATF 16949 establishes a strict quality and safety framework throughout the SDLC. Each phase follows well-defined requirements to ensure compliance with industry standards. Risk management, including DFMEA, helps identify and prevent defects, while automated testing enhances validation and efficiency in software development.

In this chapter, it is proposed to apply the SDLC model adapted to the proposed solution to highlight the requirements of the quality standards in each phase of the software product development.

Starting from the classic SDLC model, a framework will be created, from planning to defining requirements, design, development, testing and maintenance. This framework will be represented in the form of a visual map that will illustrate the proposed solution. The map thus created will provide clarity on the role of quality standards throughout the product life cycle, which will integrate risk management and the automation of the testing and validation process [7 – 8].

To clearly illustrate the main phases of software development, the classic SDLC model was transformed into an intuitive and dynamic visual map. This visualization is more than a simple graphic; it effectively captures the process, showing key phases, their relationships, hierarchical structures, and interactions [11-12].

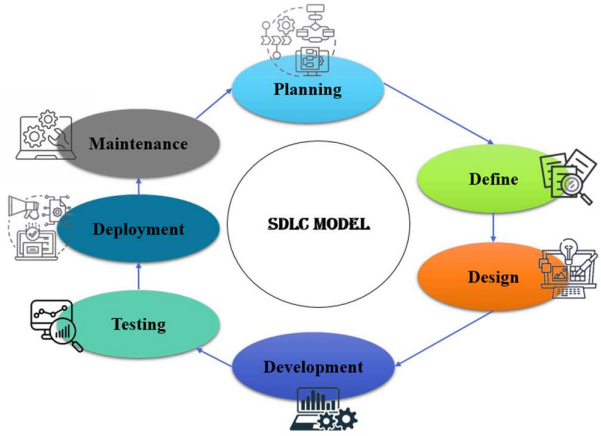


Fig. 1. SDLC model

The process of creating this visual map includes the following steps:

- Identifying and selecting SDLC phases: Filtered and transformed for the visual format.
- Defining nodes for each SDLC phase: Differentiated by size, shape, color, or other attributes.

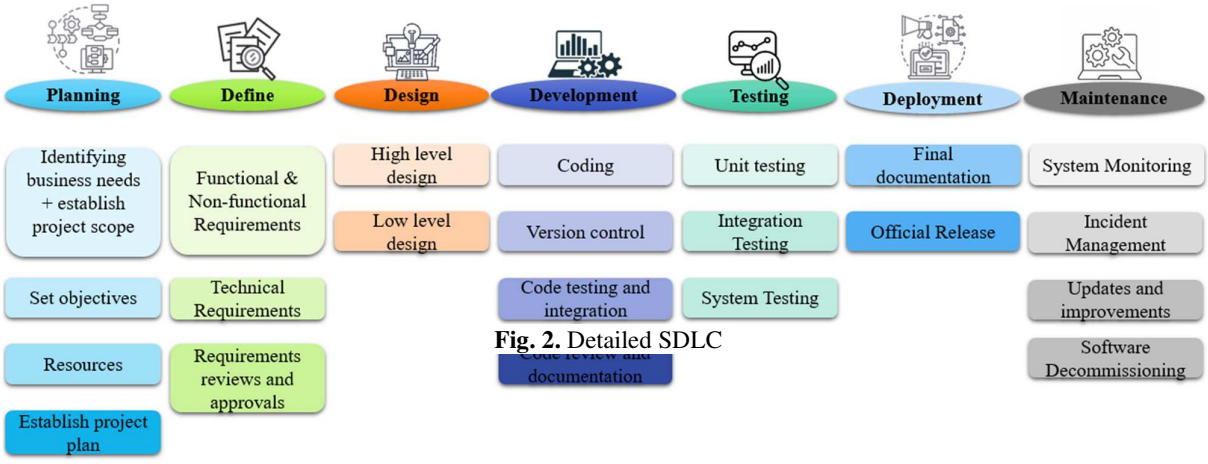


Fig. 2. Detailed SDLC

- Establishing phase connections: Represented with arrows or boxes, varying in thickness, style, and color.
- Verifying interactions: Ensuring accurate representation of phase interactions.

This approach provides a much more accessible and user-friendly perspective on the SDLC model, facilitating its understanding, implementation, and application in software development projects. In the Fig. 1. is illustrated the SDLC model.

Building on this model, has been created a visual map that incorporates each sub-phase of the SDLC model which is presented in Fig. 2.

Table 2 provides an analysis of the IATF 16949 requirements and demonstrates how each software development process in the automotive sector complies with these requirements and provides the necessary evidence to demonstrate compliance.

Table 2

Alignment of IATF 16949 Requirements with SW Development Processes in Automotive [13-14]

4.0 Context of the organization
☑ Automotive SW Company Quality Policy; ☑ Automotive SW Company Quality Management System;
5.0 Leadership
☑ Automotive SW Company policies; ☑ Automotive SW Company Quality Strategy; ☑ Quality Management Reviews, Process owners; ☑ Requirements management & customer requirements traceability;
6.1 Planning - Actions to address risks and opportunities
☑ Quality improvement plan - considering customer requirements & industry standards; ☑ Learning Outcomes, Risk Management, DFMEA process, 5Why analysis for defects and issues; ☑ Project Risk Register Reports, product DFMEA reports; ☑ Mitigation/contingency plans, actions items;
6.2 Planning - Quality objectives and planning to achieve them
☑ Quality Goals; ☑ Metrics Dashboards; ☑ Quality Management Reviews; ☑ Automotive SW Quality Criteria, deliverables and metrics; ☑ Quality Assurance Procedure and project specific plans defining quality objectives, project organization, processes and documents;
6.3 Planning - Planning Of Changes
☑ Quality process Improvement Plan; ☑ SDLC Integration;
7.1 Support - Resources
☑ For employee competencies/skills defined; ☑ Infrastructure and work environment: ☑ Equipment Verification and Calibration process; ☑ Metrics, Learning Outcomes, Root Cause analysis, DFMEA reports, Risk Management with input from other projects; ☑ Technical workshops, trainings, external events; ☑ Competency matrix and training plan;
7.2 Competence
☑ Organization Training Process; ☑ Competency matrix and training plan; ☑ Training feedback;
7.3 Awareness, 7.4 Communication
☑ Quality policy, quality objectives; ☑ IATF standard training; ☑ SDLC process training; ☑ All-Hands meeting;
7.5 Documented information
☑ Documentation Management Procedure;
8.1 Operational planning and control
☑ Product realization; ☑ Program Management; ☑ Roadmaps;
8.2 Requirements for products and services
☑ Marketing material, customer complaints, software defects reported by customer; ☑ Customer Satisfaction Survey about customer satisfaction at Automotive SW Company level ☑ Scope of Work, SW requirements, reviews;
8.3 Design and development of products and services
☑ Software Procedures; ☑ Schedule/Gantt including project phases and detailed activities; ☑ Internal audits; ☑ Software requirements; ☑ Design and coding standards, MISRA compliance; ☑ DFMEA reports; ☑ Review of product design, SDLC phases reviews; ☑ Project management, critical path, Risk Register Report; ☑ Quality goals, Release Criteria, Metrics, Peer reviews; ☑ Unit, Integration, System testing; ☑ Quality package; ☑ Quality Compliance Checklist and Action Report;
8.4 Control of externally provided processes, products and services
☑ Supplier List; ☑ Legal Agreements; ☑ Request for Information, Request for Quotation; ☑ Supplier Performance Evaluation Report;
8.5 Production and service provision
☑ Equipment Verification and Calibration process; ☑ Production and Service Provision Procedure; ☑ Maintenance Procedure; ☑ Traceability of Changes; ☑ Inventory Asset Management;

8.6 Release of products and services
☑ Quality Goals, Release Criteria; ☑ Quality Compliance Checklist and Action Report & Waiver process;
8.7 Control of nonconforming outputs
☑ Configuration and Change Management Procedure; ☑ Release candidates testing; ☑ Change control of customer requirements & traceability; ☑ Issues reporting and analysis, impact analysis; ☑ Release Notes with known issues;
9.1 Monitoring, measurement, analysis and evaluation
☑ Metrics Program & Dashboards; ☑ Quality Management Review and results; ☑ Customer Satisfaction Survey; ☑ Direct feedback, Emails, presentation slides; ☑ Six Sigma training;
9.2 Internal audit
☑ Automotive SW Company internal audit program (IATF 16949) – Audit plans, Nonconformities & corrective action plans; ☑ SDLC phases reviews;
9.3 Management review
☑ Dashboards; ☑ Quality Management Reviews;
10 Improvement
☑ Process improvement documented in the Software Quality Assurance Procedure; ☑ Defect Management process; ☑ Nonconformities & corrective action plans;

Mini-maps were created (**Error! Reference source not found.**., Fig. 4., Fig. 5., **Error! Reference source not found.**., **Error! Reference source not found.**., **Error! Reference source not found.**., Fig. 9.) for each SDLC phase, showing how IATF 16949 integrates into the process based on the main map and standard analysis.

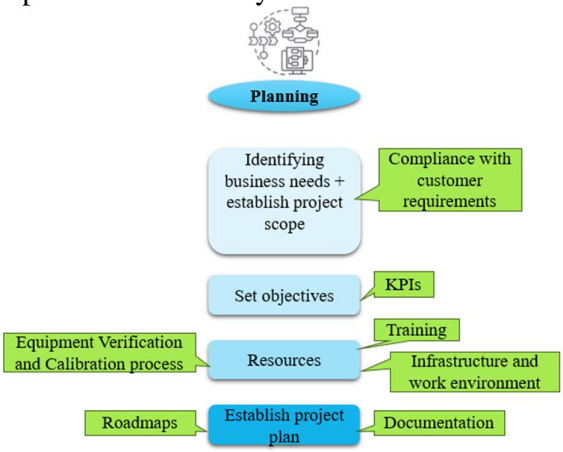


Fig. 3. Planning phase

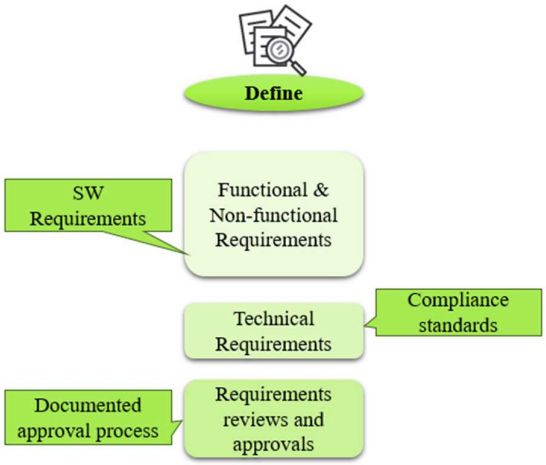


Fig. 4. Define phase

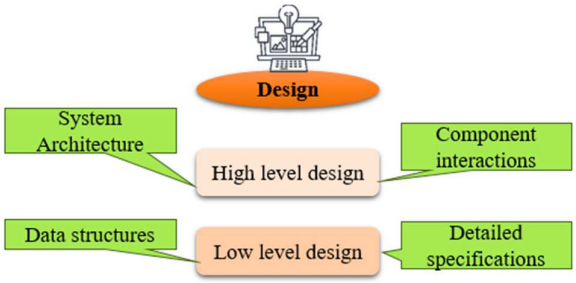


Fig. 5. Design phase

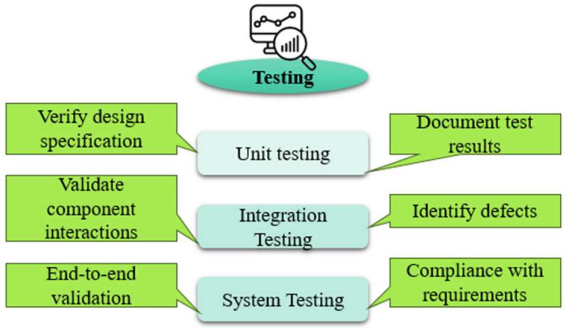


Fig. 6. Development phase

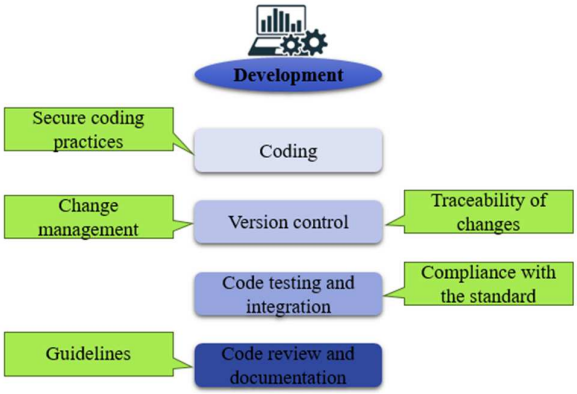


Fig. 7. Testing phase

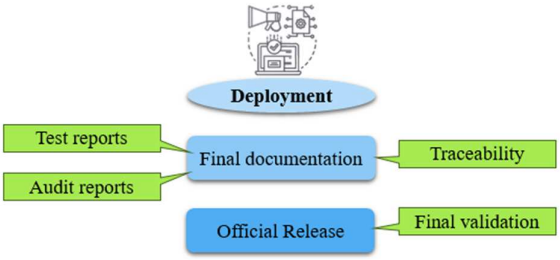


Fig. 8. Deployment phase

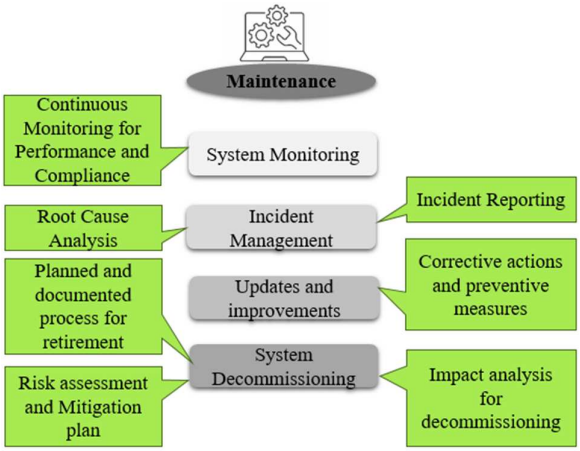


Fig. 9. Maintenance phase

Based on the table and the mini-maps presented above, a map was created outlining the key documents required by the IATF standard for each phase of the SDLC model.

Following the detailed analysis of the requirements imposed by the standard and the documentation necessary to demonstrate the organization's compliance, correlated with the SDLC phases, it was concluded that there is a need to create a clear and easily applicable framework to ensure the correct application of the standard at each phase.

This framework will henceforth be referred to as "Velocidra" and it is designed to address these needs. The framework is a process-oriented platform focused on product development, aimed at harmonizing and optimizing processes to ensure the successful launch of innovative solutions, including cutting-edge technologies or software applications. Built on industry best practices, the framework serves as a cornerstone for continuous improvement, fostering efficient and productive collaboration among software teams. The name "Velocidra" represents two key concepts:

Velocity: Symbolizing speed, agility, and adaptability, reflecting the efficient integration of SDLC processes with IATF requirements and the dynamic nature of the automotive industry.

Hourglass: Representing balance and time management, emphasizing resource management and alignment between development phases and compliance.

"Velocidra" is a framework that blends speed and precision, aligning SDLC and IATF best practices into a structured process.

The framework's application starts with a checklist that aligns SDLC and IATF requirements, ensuring compliance at each phase. The checklist, created in Excel, consists of multiple worksheets, each focusing on different quality areas, and must be used in full to assess overall compliance. Table 3 explain the actions required to create and use the checklist effectively [15].

Table 3

Quality Compliance Checklist and Action Report

1. First Page in Excel – Document Changes Overview
This page contains a detailed table with the following essential information about the document: *Document Name, Author, Date, Version, Changes Made, Approver, Document Status.*
2. Second Page – Project Overview
This page provides an overview of the project's progress and includes the following essential details: *Project Name*, *SDLC Phase*: Indicates the phase of the Software Development Life Cycle (SDLC) for which the verification is conducted, *Target Date*: The deadline for completing the verification and associated activities, *Verification Responsible*: The names of the individuals assigned to perform the verifications for the respective phase, *Score Achieved*: A global evaluation of performance during the verification phase, *Required Actions*: A list of steps to be followed if the score achieved is below 100%, including any corrections or improvements that need to be implemented to ensure full compliance (see Fig. 10.).
3. Third Page – Document Status Overview
This page provides detailed monitoring of the status of each SDLC (Software Development Life Cycle) phase and the required documents for each phase. The structure of this page is as follows: *SDLC Phase*: Each phase of the Software Development Life Cycle is listed, from planning to maintenance, *Required Documents*: For each phase, the documents that need to be completed and reviewed are listed, *Document Status*: Each document in the respective phase is assigned a status, which can be one of the following: green – the document is complete and meets the requirements, yellow – the document is partially complete or requires improvements, red – the document is incomplete or

does not meet the minimum requirements, *Score*: Based on the document's status (green, yellow, red), a score is assigned to evaluate progress, *Comments*: For providing additional details, suggestions for improvements, or explanations regarding the document's status (see Fig. 11.)

4. Fourth Page – Verification Checklist per Phase

The purpose of this page is to provide a clear and concise list of necessary checks to ensure the document compliance with IATF standards as the project progresses through various SDLC phases. The structure of this page may include: *SDLC Phase*: Each phase of the Software Development Life Cycle is listed (planning, defining, design, development, testing, implementation, maintenance), *Document*: For each phase, the documents to be created, completed, or updated are listed, *Required Verifications*: For each document, the verifications required to validate its compliance and quality are detailed. Verifications may include, but are not limited to: compliance with technical requirements and standards, validation of information and data, review of document clarity and completeness, confirmation of approval signatures, if necessary, *Responsible*: The role of the person responsible for keeping the document up to date.

5. Fifth Page – Project Status Overview

This page contains generic questions specific to each SDLC phase, related to resources, methods, and other aspects relevant to ensuring compliance with IATF standards.
The questions are organized for each phase of the software development process, aiming to verify adherence to the standard and best practices.
The page structure is based on SDLC phases and their specific questions. Similarly, a status is assigned to each question, and based on the status, a score is associated, which will be displayed on the second page in Excel.

6. Sixth Page – KPIs

This page monitors KPIs for each SDLC phase to evaluate quality against IATF standards. It includes status updates for each metric and corrective action comments, ensuring continuous quality monitoring and compliance with IATF requirements.

7. Seventh Page – Out of Bounds (OOB) Overview

This page is dedicated to identifying and monitoring elements that fall outside the established limits (Out of Bounds - OOB) during the software development process to ensure adherence to IATF standards and requirements. It serves as a monitoring tool for significant deviations, helping the team manage situations that may affect the project's compliance or performance.

8. Eighth Page – Template Version History

This page tracks the evolution of the template, providing clear transparency on its versions and the changes made during implementation.
It contains a table with the following information: *Document Name, Author, Date*, *Version*, *Changes Made*, *Approver*, *Document Status*.

4. CONCLUSION

Adapting the SDLC model to IATF 16949 establishes a framework that guarantees compliance with automotive standards, enhancing product quality and minimizing risks. Each phase is driven by specific requirements, helping teams make informed decisions and avoid errors that could affect safety. The flexibility of the framework allows for the integration of new technologies, adapting to changes in the automotive industry, such as the transition to electric and autonomous vehicles.

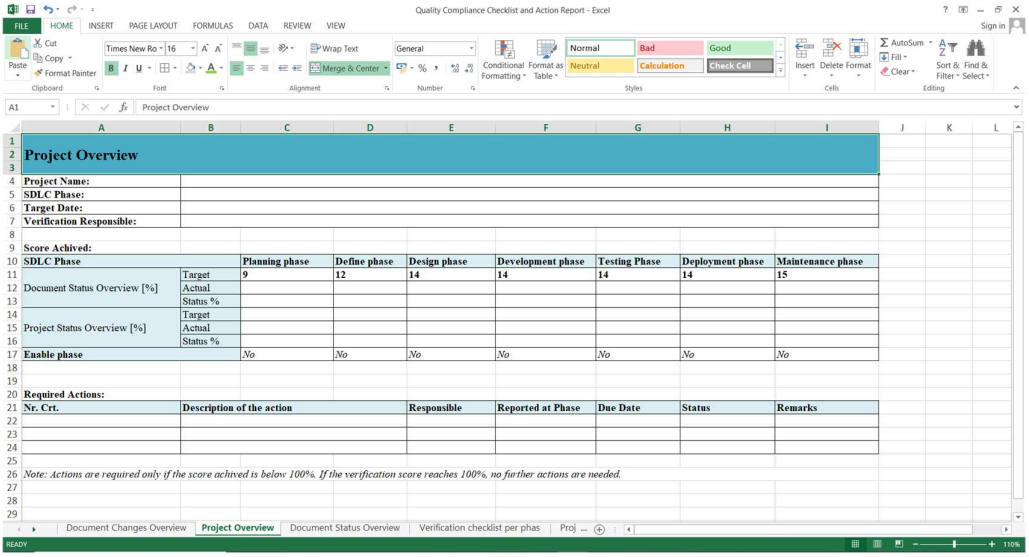
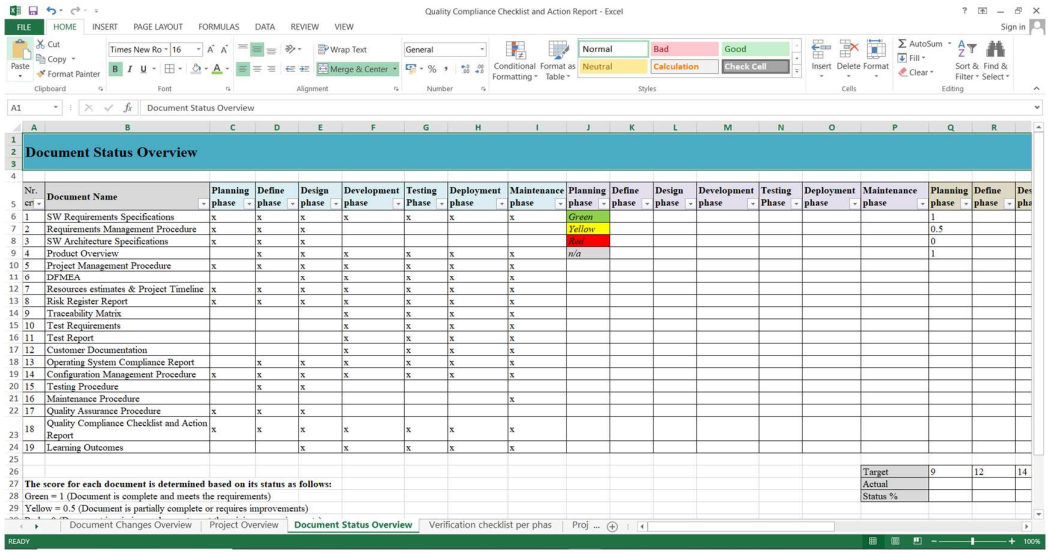


Fig. 10. Second Page in Excel – Project Overview



Document Status Overview

Nr. ctrl	Document Name	Planning phase	Define phase	Design phase	Development phase	Testing Phase	Deployment phase	Maintenance phase	Planning phase	Define phase	Design phase	Development phase	Testing Phase	Deployment phase	Maintenance phase	Planning phase	Define phase	Des pha
1	SW Requirements Specifications	x	x	x	x	x	x	x	Green							1		
2	Requirements Management Procedure	x	x	x					Yellow							0.5		
3	SW Architecture Specifications	x	x	x					Red							0		
4	Product Overview		x	x	x	x	x	x	n/a							1		
5	Project Management Procedure	x	x	x	x	x	x	x										
6	DFMEA			x	x	x	x	x										
7	Resources estimates & Project Timeline	x	x	x	x	x	x	x										
8	Risk Register Report	x	x	x	x	x	x	x										
9	Traceability Matrix				x	x	x	x										
10	Test Requirements				x	x	x	x										
11	Test Report				x	x	x	x										
12	Customer Documentation				x	x	x	x										
13	Operating System Compliance Report		x	x	x	x	x	x										
14	Configuration Management Procedure	x	x	x	x	x	x	x										
15	Testing Procedure		x	x														
16	Maintenance Procedure							x										
17	Quality Assurance Procedure	x	x	x														
18	Quality Compliance Checklist and Action Report	x	x	x	x	x	x	x										
19	Learning Outcomes			x	x	x	x	x										

Target	9	12	14
Actual			
Status %			

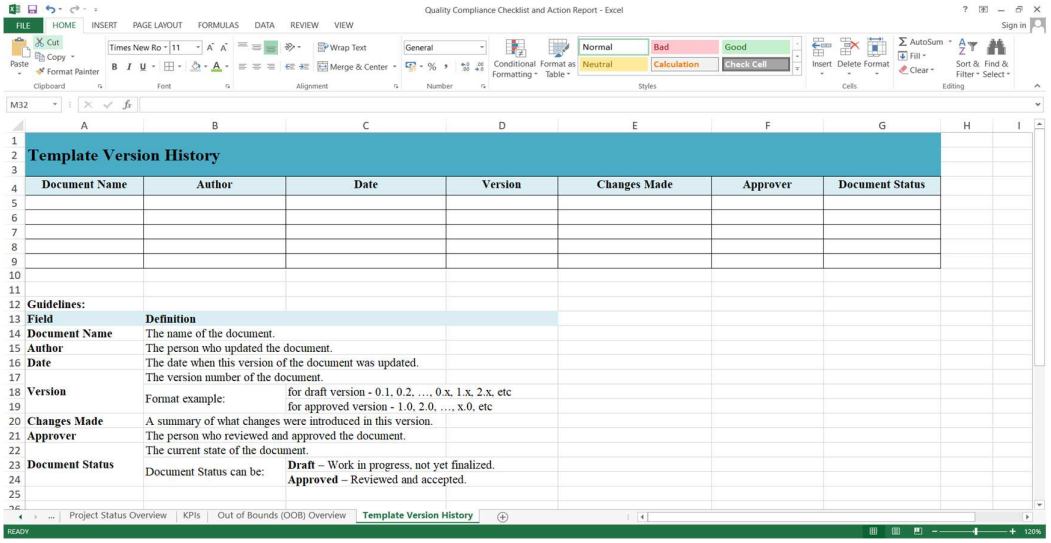
The score for each document is determined based on its status as follows:
Green = 1 (Document is complete and meets the requirements)
Yellow = 0.5 (Document is partially complete or requires improvements)

Document Changes Overview | Project Overview | Document Status Overview | Verification checklist per phas | Proj ...

Fig. 11. Third Page in Excel – Document Status Overview

In terms of efficiency, implementing this framework can accelerate software development processes, shortening the time needed for product implementation and testing. As a result, companies can achieve faster and more efficient development while still meeting stringent quality requirements. On the other hand, for companies with limited resources or experience, the adoption of this framework may pose challenges, and differences between software projects may require additional adjustments to the proposed model [9]. Along with the checklist, other quality documents play an essential role in ensuring compliance and enhancing the development process.

A survey for the quality team can be conducted to collect their insights on the practical benefits, challenges, and overall impact of quality documents, such as checklists, in facilitating the development lifecycle and to verify the extent of these time savings. The survey will provide valuable insights by confirming or refuting the speed improvements associated with the framework, helping to validate the claims regarding accelerated development times and enhanced efficiency.



Template Version History

Document Name	Author	Date	Version	Changes Made	Approver	Document Status

Guidelines:

Field	Definition	
Document Name	The name of the document.	
Author	The person who updated the document.	
Date	The date when this version of the document was updated.	
Version	The version number of the document.	
	Format example:	for draft version - 0.1, 0.2, …, 0.x, 1.x, 2.x, etc
		for approved version - 1.0, 2.0, …, x.0, etc
Changes Made	A summary of what changes were introduced in this version.	
Approver	The person who reviewed and approved the document.	
Document Status	The current state of the document.	
	Document Status can be:	**Draft** – Work in progress, not yet finalized.
		Approved – Reviewed and accepted.

Project Status Overview | KPIs | Out of Bounds (OOB) Overview | Template Version History

Fig. 12. Eighth Page in Excel – Template Version History

Future developments: Additional studies can improve the framework and associated quality documents, including checklists, for greater clarity, efficiency, and applicability in automotive software development. These improvements will enhance decision-making, support compliance with international standards, and contribute to the creation of safer products for end-users.

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Integrarea standardului IATF 16949 în ciclul de viață al dezvoltării software-ului pentru industria auto

Lucrarea își propune să prezinte un cadru conceput pentru a simplifica provocările complexe ale dezvoltării software-ului în industria auto. Focalizându-se pe vizualizare și concepte cheie, cadrul îmbunătățește înțelegerea și face procesul de dezvoltare mai ușor de implementat. Integrează standardul IATF 16949 pentru a asigura conformitatea și calitatea, oferind un ciclu de viață al dezvoltării software-ului (SDLC) adaptabil la nevoile industriei. O caracteristică distinctivă este utilizarea hartilor vizuale și a checklist-urilor clare, care ghidează echipele prin etapele SDLC și asigură un management eficient al proceselor. Această abordare ajută companiile să obțină inovație, menținând în același timp standarde stricte de calitate și siguranță.

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