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*Original Article*

# Implementing Agile in Railway Product Development: A Balance of Compliance and Innovation

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***Abstract* -** *The global railway industry has been facing the challenges of bringing more flexibility and agility to the product development life cycles while complying with strict safety standards and norms. Long-time mechanics such as V-model have failed to effectively address the constantly changing technological demands as well as customer requirements. Hence, this paper aims to undertake a study on the adopted methodology of agile regarding railway product development. It aims to achieve the best practices from Agile while at the same time responding to strict requirements within the railway sector, such as CENELEC EN 50126/8/9 and other regulations. This paper presents a systematic literature review of Agile, suggests an appropriate approach for rail systems that combines the Agile methodologies and describes the case of an American railroad maintenance equipment manufacturer. One is convinced that the findings demonstrate changes in the necessity of project adaptability communication with stakeholders, the enhancement of product quality, and continued compliance with regulations. However, issues such as documentation methodical, tool interoperation, and obstacles to cultural adaptation have also been identified. Suggestions and a plan of action for Agile adoption to be used by the practitioners and the researchers working in railways.*

***Keywords* -** *Agile, Railway Product Development, CENELEC, EN 50126, EN 50128, EN 50129, Compliance, Innovation, Safety Standards.*

## 1. Introduction

The railway industry generally follows development and safety rules to achieve sustainable development with great reference to public safety. [1-3] Traditionally, such projects employ the V-model sustaining methodology that defines the program's approach to traceability and validation. However, when it comes to constant market needs and the trends associated with the digitalization of products, this approach may be very ineffective for modern customer-focused development.

### *1.1 Importance of Implementing Agile in Railway Product Development*

Adopting Agile in the railway industry generates a lot of value since it tackles many issues that are associated with the conventional systems of development in the railway industry. The following are five general areas in which Agile especially offers significant advantages in the construction of railway products:


**Fig 1: Importance of Implementing Agile in Railway Product Development**

- **Enhanced Responsiveness to Change:** Another advantage of the Agile approach is that requirements can be promptly managed and incorporated into the project. When it comes to railway projects, customer requirements, legal meanings, and the requirements stipulated in technical standards may change frequently throughout the project's life cycle. Agile has been issued based on the four principles of adjusting, as it provides an iterative approach that can be used to integrate these changes into the development as it proceeds so that they can align the final product with the new expectations while not having to hold up the rest of the project.

- **Improved Collaboration and Communication:** Agile promotes collaboration between cross-functional teams, stakeholders, and consumers. With a proper schedule of scrum activities like sprint review, daily stand-up, and retrospective meetings, railway development teams can become more transparent. It allows problems to be detected promptly, decisions to be made without delay, and all related parties to be in synergy during the process.
- **Faster Delivery with Incremental Value:** There are several reasons why the use of agile best practices follows in developing railway systems: Agile practices are based on dividing complex railway systems into smaller parts, which are then developed, tested, and released incrementally. This allows the functional subsystems and features to be delivered faster and brings value to the customers, thereby shortening the time needed to market. It also permits the pilot or implementation in stages, which is very useful in most big railway projects.
- **Continuous Quality Assurance and Risk Mitigation:** To sum up an activity, Agile encourages testing and integration on an ongoing basis, which makes it easier to find and address flaws during the development phase. This is very important in the safety-critical railway system since the error detected at the later stages of the life cycle is very costly and even dangerous. This is achieved through test cycles, copied test cases, and testing validation done on sprints to ensure that quality and other compliances are frequently done in a project to minimize such mishaps during the integration or certification stage.
- **Cultural Shift Toward Innovation and Accountability:** This will, therefore, lead to an implementation of agile, which encourages people to take ownership, work collaboratively, and learn from one another while improving processes continually. All teams are managed with the understanding that they have the autonomy to take the risks needed to try out the new technologies and adjust toward creating innovations. This cultural shift is critical in the contemporary railway enterprises experiencing growth in the classic railway infrastructure, information technology, security requirements, and mobility intelligence.

### *1.2 Agile in Safety-Critical Systems*

Scrum, SAFe, and other methods have revolutionized the approach to creating software and IT solutions by implementing iterative and incremental models, regular communication with stakeholders, and delivering small value portions. These are good practices because they foster an integrated capacity for change, which makes an organization more effective when operating in a volatile and fast-changing environment. [4-7] Still, implementing Agile in safety-critical areas like railway engineering poses a number of concerns. Railway engineering involves functioning under regulations and standards such as CENELEC standards, including EN 50126, EN 50128, and EN 50129. These require planning, documentation, process traces, and considerable validation of safety-critical pieces within a railway system. The tension is that Agile is flexible with fast processes, while the opposite is true in terms of documentation and control to meet regulations. To the traditional models for railway development, V-models are preferred for their well-structured method of V&V, which is crucial to providing safety and reliability.

While flexibility and continuously improving solutions are some of the benefits of agile, if not well managed, they may be interpreted as informal and, therefore, unsuitable for key sectors like healthcare. The difficulty is not offering versions to replace the traditional models but rather aligning with the latter. In order to resolve this, organizations have begun to look towards a more partial semblance to Agile practices at certain levels, such as subsystem or component level, while at the same time following the strict discipline of the V-model. Thus, safety assurance is possible together with formal documentation of the process, and agility can be applied within the controlled work scope, for example, when developing a particular software module or integrating it into the whole system. Moreover, enhancing the correspondence between successive iterations and allowing the use of Agile planning tools in the testing and documentation processes is equally possible. It is about integrating Agile and making sure that compliance becomes a part of Agile rather than imposing different sets of rules and guidelines on development groups.

## 2. Literature Survey

### *2.1 Traditional Railway Development Approaches*

Generally, railway systems have been designed based on conventional software development models like the V and Waterfall models. The two models stress a phased working process that involves documentation and is particularly suitable for applications in safety-critical systems. Among these methods, the V-model appears more effective as it provides a mirrored structure so that each development phase has its validation or verification activity: the model emphasizes traceability and guarantees that requirements are aligned throughout the project’s life cycle. [8-13] Waterfall also has a more rigid approach to the phases with a rigid requirement gathering, design, implementation, testing, and maintenance phase sequence. These models provide audit trails and, therefore, keep compliance in check, which makes them suitable for the railway business, which is well known to be legal.

### *2.2 Agile in Safety-Critical Environments*

The extensive implementation of Agile approaches has been received in the areas of safety-critical and regulation. Organisations can benefit from Agile practices, such as flexibility, the ability to respond effectively to change, and better quality software. However, these industries are highly regulated in terms of safety and documentation. Still, there are chances of utilization of methods like iterative development, customer collaboration, and improvement that are risky and beneficial for shortening the delivery cycle time and enhancing stakeholder involvement. It is possible to learn about the experience of Agile implementation in sectors like aerospace, automotive, medical systems, etc., as the practice shows in these sectors respond to these concerns without compromising on compliance principles.

### *2.3 CENELEC Standards*

EN 50126, EN 50128, and EN 50129: These are the CENELEC standards where the mandatory processes for railway projects' lifecycle and safety requirements are explained. Unlike other standards such as ISO 9000, EN 50126 relates to the RAMS (Reliability, Availability, Maintainability, and Safety) life cycle while stating that a systemic approach must be taken when defining the system and planning. While EN 50128 is dedicated to software safety, it presents procedures for constructing, designing, and validating the software to realize safe software. EN 50129 deals with achieving SILs and preparing SIGs, which should support the overall safety cases. Altogether, these standards offer a framework to the railway business to guarantee the appropriate delivery of protected, solid, and verifiable railway frameworks. Table 1 captures their focus areas and objectives to be accomplished at the end of the project.

### *2.4 Hybrid Agile Models*

There are several hybrid models for the challenges of adopting Agile in safety-critical organizations, including the railway industry. Some successful ones incorporate the verification process of the V-model with the Agile development cycles by improving flexibility yet achieving traceability in Agile-V. ScrumBan is a Blend of Scrum and Kanban that is particularly helpful for regulated environments requiring technique flexibility and a focus on uninterrupted operation. SAFe is the framework that applies Agile throughout large organizations, with some roles and artifacts required to meet compliance standards. These technically advanced models attempt to embrace the flexibility of modern software development methodologies. Simultaneously, they preserve key engineering principles and compliance requirements as a viable way for adopting innovation in the constrained field.

## 3. Methodology

### *3.1 Research Approach*

This research uses a qualitative approach and follows the case study research design to understand Agile's success factors in developing safety-critical railway systems. This is particularly applied to case study strategies when the relationships between the phenomenon and the context are not obvious. It provides for understanding such factors as the implementation experiences, the issues, and the results relating to the application of Agile in the domain that has historically relied on strict norms and the application of the V-model. The information for this study was collected through three methods: a literature review, industry surveys, and a study of a live implementation. Based on the collected literature review, trends, challenges, and success stories of Agile implementation in railway, aerospace, automotive, and healthcare industries were reviewed. [14-17] This contributed to both the theory's conception and the creation of survey tools. When the paper reached the industry surveys of professionals in the railway software and systems engineering field.

These surveys, to some extent, were designed to understand the current status of their organizations, the extent of perceived obstacles, and the success of blended environments. This way, the participants involved are engineers, project managers, safety assessors, and compliance experts, thus getting comprehensive field knowledge. Besides secondary sources, a live project in the railway industry, which had recently begun the change from a V-model to an Agile hybrid system, was used in the research. This case offered a rationale behind using Agile practices in a critical environment and documentation of sprints, iteration, and work on CENELEC requirements. The research study documented the meetings and collected interviews from the team members to increase the reliability and validity of the results identified from the literature and surveys. In summary, what hitherto is the efficiency of applying and tailoring the Agile framework in the railway industry, the consistency of this paper encompassing a vertical combination of multiple sources presented a valuable outlook on the flexibility of Agile in the railway business.

### *3.2 Proposed Hybrid Agile Model*

To implement the proposed changes, a new hybrid agile model is suggested as a combination of the traditional approach, like the V model, and the widely used agile model nowadays. This integration targets the requirements of the railway application domain, which prescribes certain standards such as CENELEC EN 50126, EN 50128, and EN 50129; at the same time, it is essential to enhance the issues related to responsiveness, stakeholders' coordination, and iteration. It is also important to note that the systematic flow of the described V-model at the stages of system and high-level requirements is maintained while producing structured and traceable documentation conforming to the regulatory and safety-critical standards. At this type of system level, the components' requirements, RAMS planning, and safety assurance are defined using conventional engineering practices in conformity with SIL.

However, the subsystem and component-level development in the model involves Agile sprints to have multiple design, development, and testing cycles. The advantages of these Agile cycles include early feedback, integration throughout the development cycle, and the ability to deliver value in increments. Sprints are short periods that would take two to four weeks, depending on the situation, where the functional requirements are decomposed into user stories and distributed in potentially releasable chunks. The key concepts of Scrum include sprints, backlog, sprint planning, daily scrum, scrum backlog review session, and sprint review session. Integration testing is also conducted in every sprint; this allows for early identification and correction of defects, which enhances the quality of the developed software and minimizes avoidable loops. The concept, therefore, incorporates V&V phases that correspond to Agile's Integration points and V-model formal review points. The binaries generated during an Agile sprint, such as the test results and designs, are then traced and correlated to the documented V-model needed for compliance.

### *3.3 Implementation Framework*

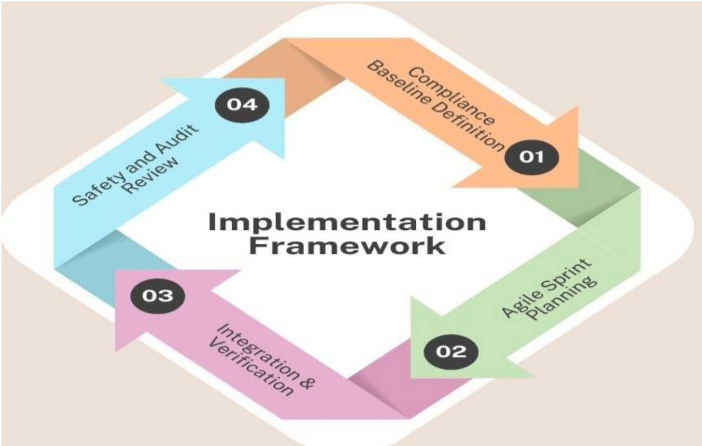


**Fig 2: Implementation Framework**

- **Step 1: Compliance Baseline Definition:** The initial step in the recommended enforcement of the IMDG is to set up a reference of compliance by understanding the documentation, processes, as well as safety assessments demanded by guidelines like the CENELEC EN 50126, EN 50128, and EN 50129. This entails understanding the requirements, including deliverables, decision gates that must be met, and the verification steps required at different project phases. This way, any other Agile activities to occur in the project will be in concordance with the regulations and safety requirements that may be present.
- **Step 2: Agile Sprint Planning:** After that, the process moves to plan Agile sprints at the subsystem level to develop the new compliance level. Here, the system requirements at this level translate simplified to elements that can be delivered in the sprints. Every sprint backlog is developed with two goals: functional delivery and compliance. The regulation checks are incorporated into Agile from the start of each sprint to guarantee that every sprint helps meet traceability, safety, and verification requirements.
- **Step 3: Integration & Verification:** According to the definition of a sprint, the developed subsystem or component at the end of every sprint should be the identifiable and callable unit. These units are gradually incorporated into the whole system at the architectural level depicted in the V-model's structure and undergo explicit verification and validation. This step is helpful in always connecting with different algorithm levels, with other agile processes, essential development, and regulator demands.
- **Step 4: Safety and Audit Review:** Daily safety checks are performed in addition to reviews at various stages of the project that would reassert the conformity with CENELEC standards and requirements peculiar to each particular project. These are done in the form of reviews of documents, traceability matrices, and further testing artifacts, along with an assessment of the overall process. Such checks are periods where the project ensures compliance is not an add-on done at the end of a project but an aspect integrated into every development cycle.

### *3.4 Tools and Techniques*

- **JIRA/Confluence for Backlog and Documentation:** JIRA and Confluence are two Agile software management tools widely used for project planning, backlog, and documentation. In the proposed hybrid Agile model environment, JIRA is used for user stories, tasks, and visibility of the development workflow. This is supported by Confluence, a documentation tool where various documents, compliance, notes, design, meetings, etc., can be created and stored in one place. This integration guarantees that, while Agile is implemented and progressed, all the necessary documentation is being created, and it is also compliance-oriented and easy to present in case of audits or reviews.
- **DOORS for Requirements Traceability:** Also, IBM Engineering Requirements Management DOORS can be used to control and track requirements from the initiation to the implementation phase. Ensuring that the items delivered during the Agile sprints correspond to the top-level system specifications inherent within the V-model is essential.

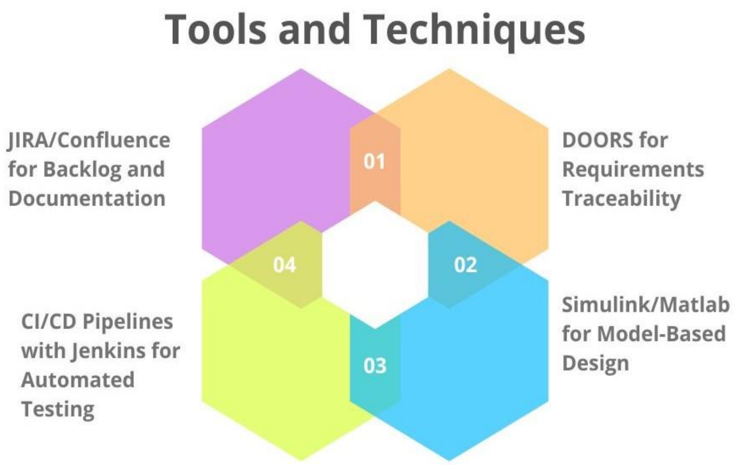


**Fig 3: Tools and Techniques**

Again, as users, test cases, and designs are linked to the requirements linked in DOORS, they are suitable for developing traceability matrices and compliance documentation for audits and safety assessment and enforcing control on requirement coverage and impact analysis. JAMA is also an alternative, if any other Requirements Management tool needs to be used.

- **Simulink/Matlab for Model-Based Design:** Simulink and MATLAB are designed for model-based design, especially for designing control systems and embedded software for railway applications. These capabilities enable the engineers to develop models for constructing these subsystems at the beginning of the development phase, thus minimizing mistakes and enhancing the iterations. When adopting these models into Agile sprints, one can confirm functionality and safety behavior before the implementation, which complies with simulation and verification expectations set by EN 50128.
- **CI/CD Pipelines with Jenkins for Automated Testing:** Jenkins is an adopted automation server for CI/CD practices in Continuous Integration and Continuous Deployment. Jenkins comes in handy in the physical assembly, testing, and integration of components developed by developers through different Agile sprints. By having unit tests, regression tests, and code quality checks in the pipeline, Jenkins guarantees the satisfaction of functional and safety standards in every sprint delivery. This not only speeds up the process of receiving feedback but also guarantees that the work is done in both forms and is subjected to the same processes in the following developmental stages.

## 4. Results and Discussion

### *4.1 Case Study: American Railroad Equipment Manufacturer*

This paper deals with a medium-sized American company that supplied models of railway track construction and maintenance machines (Maintenance Off Way equipment) with intelligent distributed I/O Control system and decided to employ the Agile-V model to develop a significant track maintenance subsystem. Previously, the organization adopted the V model as its business model, which, despite its advantages in maintaining order and compliance and going through rigorous documentation, had its disadvantages in terms of flexibility, speed in responding to requirements, and development speed. These restrictions emerged as the industry required enhanced velocity, agility, and more frequent innovation in product delivery without compromising security or compliance, especially according to railway standards (which was required to comply for the project) such as CENELEC EN 50126, EN50128, and EN50129. Aware of these difficulties, the organization started the transformation process by implementing Agile at the level of subsystems while staying compliant with the given V-model.

The integration approach met all patient needs; high-level system requirements, RAMS planning, and safety cases were maintained under formal control, thus maintaining system traceability and some formal verifications. AT THE SAME TIME, subsystem teams also began to implement agile practices, including using sprints in development, prioritization of the backlog, and iterative testing to respond faster to design changes, clients' feedback, or technical challenges that may emerge along the process. During Agile practice, two applications, JIRA and Confluence, were employed to support Agile practice, which enabled the linking of DOORS for tracing the relationship between user stories and formal requirements. Jenkins was used for CI/CD pipelines to ensure the testing and the integration process were done automatically. This combination of approaches led to enhanced characteristics such as project responsivity and performance quality. For the same reasons, the organization integrated the safety reviews and main compliance checkpoints into the general Agile cycles to guarantee that safety would be upheld throughout the development phase. As the case study shows, the described approach is free from the strict definitions of pure hybrids while maintaining the safety and reliability needed for railway applications.

### *4.2 Key Findings*

**Table 1: Key Findings**

| Metric | Improvement |
|---|---|
| Sprint Velocity | 30% |
| Change Request Resolution Time | 40% |
| Compliance-Related Issues | 60% |

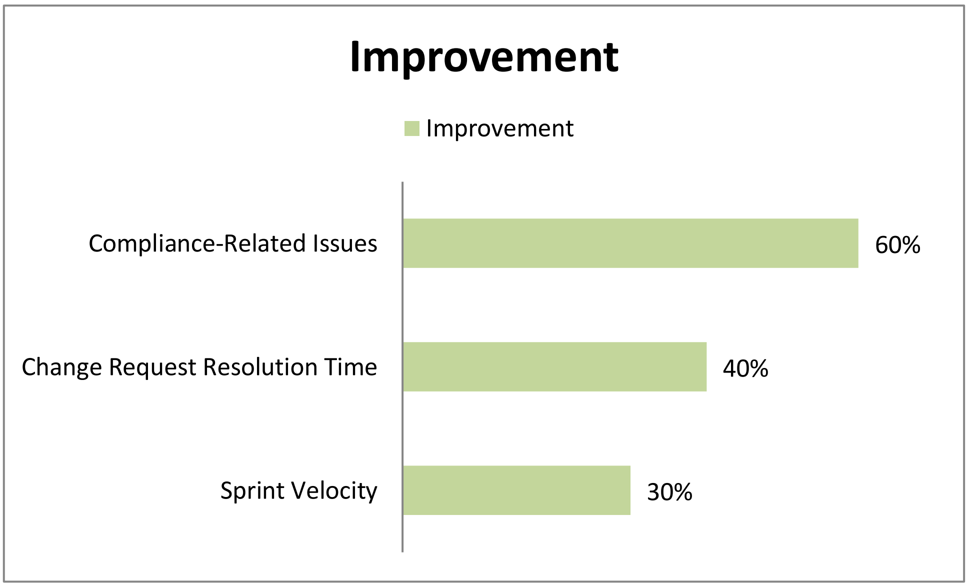


**Fig 4: Graph representing Key Findings**

- **Sprint Velocity – 30% Improvement:** After the adoption of the hybrid Agile-V model, the particular project team's sprint velocity rose by about 30%. This was assisted by improved collaboration, effective sprint planning, and dividing complex subsystem tasks into feasible iterations. Replacing the previously used V-model approach, business imperatives of daily stand-ups and retrospectives assisted in the early identification of the bottlenecks, which in turn encouraged development teams to maintain the speed of delivering the functional increments.
- **Change Request Resolution Time – 40% Improvement:** The economy of the time for processing and implementing changes was also improved, reducing it by 40%. Earlier, alterations in implementation processes needed compliance with several bureaucratic procedures that would take considerable time. With Agile in place, prioritized backlogs and iterative development cycles allowed quicker integration and infusion of feedback and modifications. Short sprints especially meant that a change request could be responded to in the current sprint or the sprint after, hence having a very fast response time for the stakeholders.
- **Compliance-Related Issues – 60% Reduction: t**his is because compliance-related issues were brought down by 50 percent to 60 percent following the incrementing and integrating documentation activities built into the Agile sprints. JIRA Confluence and DOORS were utilized to guarantee a single hand in documenting every user story, design modification, or testing result performed throughout the development phase. This measure was taken to reduce the cases where there were failing comprehensiveness at the last moments before the audit, and the safety case was cleaner and more in line with CENELEC requirements.

### *4.3 Challenges*

However, certain issues arose due to adopting the Hybrid Agile-V model, leading to better performance and compliance levels. The key challenge faced was the interfacing of the tool, especially the integration problem for Agile project management tools like JIRA and requirements management tools like IBM DOORS. Since DOORS is currently the market leader in traceability of safety-critical system components, linking user stories, test cases, and high-parametric requirements became a cumbersome process that led to improved synchronization between the tool and the Agile development methodology. This often needed the creation of ad hoc scripts or additional middleware levels to handle the data exchange, which complicated the management of toolchains and demanded a lot of engineers' time. The fourth threat is a cultural one; this arose from the engineering teams who were against the change from the V-model that they had been used to. Although most enlisted engineers professed to affirm perceptions toward Agile, many senior engineers approached Agile practices as unprofessional or incoherent with the strict setting necessary for safety-critical industries. This cultural lag seriously delayed the use of these methodologies. It led to the need for change, which was accomplished by holding training, coaching, further educational sessions, and memos explaining the efficiency and compliance of Agile methods. Some resistance declined over the period as people started perceiving wonder in how they collaborated and the rate at which their teams were delivering.

Another problem that arose because of the implementation of the new system was an overload of work as the company was successfully in the process of transition between the two systems. Two levels of organisation were challenging to manage due to the requirement of having the V-model's overarching structure while keeping Agile at the subsystem level: the additional levels of cooperation. The teams were expected to continue following the conventional documentation methodologies while incorporating Agile at the same time, which coupled their work processes for some time. This transitional overhead has been able to call for proper management to avoid compromising Agile efficiency and compliance with legal regulations. Nevertheless, when these obstacles were encountered, the organization could evolve, and the experience was used to fine-tune the blended venture for further utilization as the approach to future endeavors.

### *4.4 Comparative Analysis*

**Table 2: Comparative Analysis**

| Metric | Traditional Model | Hybrid Agile-V Model |
|---|---|---|
| Time to Market Reduction | 0% | 33% |
| Requirement Volatility Tolerance | 30% | 80% |
| Documentation Completeness | 100% | 100% |

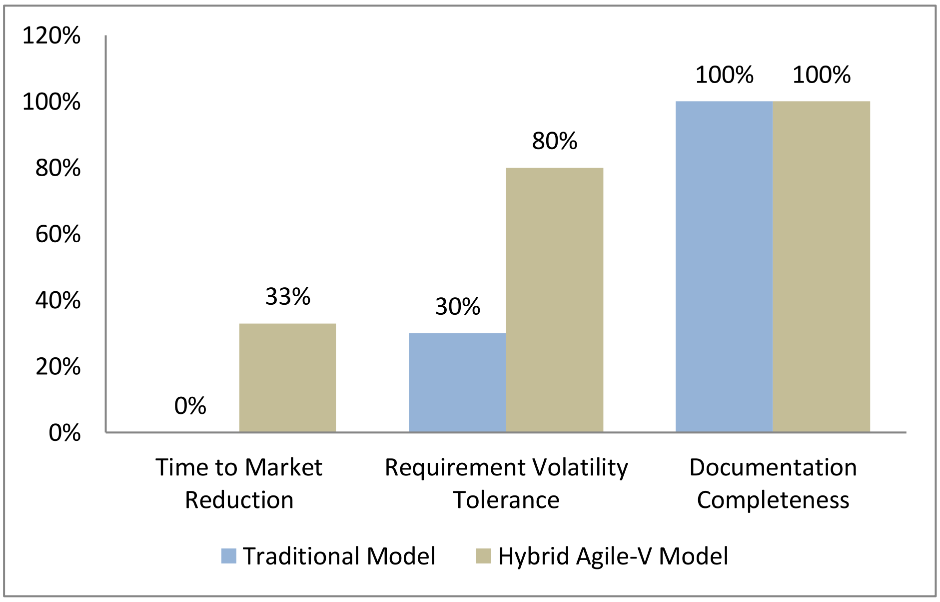


**Fig 5: Graph representing Comparative Analysis**

- **Time to Market Reduction – 33% Faster:** The Agile-V enhanced time to market for a project, cutting the overall delivery time by approximately one-third compared with the most conventional approach. This was attained by successive development cycles, where feedback elements were integrated as soon as possible and concurrent work processes offered by Agile sprints. The previous development model meant consecutive work on the stages, while the hybrid one enabled the frequent delivery and validation of partial subsystems, which led to the integration and quicker attainment of the multiple milestones.
- **Requirement Volatility Tolerance – 30% vs. 80%:** The scale of applicability of the hybrid model was one of the most influential advantages of the former concept: flexibility due to easily switched requirements. The traditional model was not very tolerant to requirement volatility, with a predicted figure of around 30%; this was because planning and the subsequent flexibility provided after the specifications have been made and frozen are very limited. Still, the hybrid Agile-V model brought the flexibility benefits to about 80% because the Agile sprints let for the continuous evolution of the features and shifting the focus on stakeholder's needs while retaining the overall schedule.
- **Documentation Completeness – 100% in Both Models:** Although the Agile methods were implemented, the levels of the documentation's completeness did not decrease and remained at the highest possible level, which is 100% like in the V-model. This has been done by incorporating documentation and traceability into each sprint, including using Confluence, DOORS, and automated documentation checks as tracking. Integrating the Agile outputs and the regulatory deliverables, the hybrid model left no room for safety, traceability, and audit readiness to be compromised.

***4.5 Discussion***

The lessons compiled from this case can be specifically useful in demonstrating how agile software development does not have to negatively affect compliance with safety standards or compromise safety, at least in railway signal systems. Previously, such systems depended upon the V-model as a preferred model, as it proceeds stepwise with strict reporting, documentation, and traceability, all in legal view with CENELEC standards. But, this rigidity makes organizations slow in responding to change, long development cycle time, and issues in relation to satisfying the current organizational need for agility and innovation. The deficiencies of the way in which Agile was implemented are covered by the Agile-V model, which incorporates the V-shape model, therefore offering flexibility and iteration for the subsystem's development levels while ensuring high governance needed for safety and compliance. This is effectively demonstrated by the fact that the compliance-related problems also significantly decreased over the short duration of the project, which could result from the permanent documentation during Agile sprints. The outcome showed that by integrating traceability, verification, and documentation as phases in the system development rather than as an addendum to it, the organization produced a system that complies with the regulatory requirements.

This enhanced audit readiness and decreased the probability of high-risk non-compliance at later stages, which can take immense time to resolve. In addition, the ability to respond more quickly to change requests is another advantage of the proposed model where, for example, there was an improvement of 40% in the resolution time. This is particularly important in rail system development projects as this may entail flexibility in addressing changing demands, which are normally phenomenal, and other stakeholders' input without necessarily affecting safety or timeline. Moreover, the case study pointed out that certain cultural changes are required to support, and therefore, the hybrid model framework is also a cultural one. Agile implementation requires securing support from management and other departments, working in a team with other specialists, and continuous employee education, which are the main factors in addressing resistance and integrating Agile with safety assurance. Thus, the hybrid Agile-V model offers a strong proposal to address the challenges of today's railway system development.

## 5. Conclusion

Adopting the agile approach to developing a safety-critical railway system signifies a new approach to development where innovation and compliance can go hand in hand with rigid strands of engineering. Thus, this research proves that Agile practices, if used with proper understanding and integrated into a standard development lifecycle model like V-model, can gain the benefits of better flexibility, time and cost improvement, and improved stakeholder satisfaction while at the same time meeting the most rigid safety and traceability standards of CENELEC EN 50126, EN 50128 and EN 50129. Some of the visages of Agile, which include the ability to cycle through the development process over and over, consistent feedback from the stakeholders, and a very flexible change management mechanism, effectively cope with some of the challenges faced when using the traditional development paradigms. Therefore, some of the strengths of Agile, such as documentation, the lifecycle approach, and safety case construction, cannot be realized within the railway industry's regulation framework. Indeed, the proposed hybrid Agile-V model fits this gap appropriately, as described below. It provides the opportunity to apply Agile sprints at the subsystem level; that is, it is possible to divide into tasks, prioritize, and deliver them, and, at the same time, the V-model is preserved.

The real-life example of the implementation of the hybrid model by a American railway electronics manufacturer revealed that time to market was reduced by 33%, change requests by 40%, and the number of compliance issues was decreased by 60%, thus proving its worth. Tools used include JIRA, DOORS, and Jenkins, which effectively provided traceability, automation, and documentation that was instrumental in ensuring that Agile development remained responsive to regulatory requirements. Also important from the study is the need to embrace organizational change management. The organisation was also able to overcome cultural opposition, integrate and manage interdisciplinary teams, and provide support to staff through training to implement the proposed hybrid framework. Further research and industrial applications for this work in the future consist of expansion of this approach towards the full system design, where the model must involve multiple teams and safety levels. Nevertheless, using predictive analytics and AI is an area with further potential that is expected to help anticipate and prevent safety issues, automate traceability regulation and plan test management strategies. The Agile-V model is a benchmark for adopting one of the oldest yet most innovative ways of developing railway systems that meet current needs for progress and safety.

## References


[1] Sommerville, I. (2011). *Software Engineering* (9th ed.). Addison-Wesley.

[2] Forsberg, K., Mooz, H., &Cotterman, H. (2005). *Visualizing Project Management*. Wiley.

[3] Boehm, B. (1988). A spiral model of software development and enhancement. *Computer*, 21(5), 61–72.

[4] Poppendieck, M., &Poppendieck, T. (2007). *Implementing Lean Software Development: From Concept to Cash*. Addison-Wesley.

[5] Stålhane, T., &Myklebust, T. (2016). Introducing Agile Development in Safety-Critical Projects. *Procedia Computer Science*, 64, 403–410.

[6] Rail Safety and Standards Board (RSSB). (2012). *Application of EN 50126, EN 50128, and EN 50129 in the UK Rail Industry*. RSSB.
[7] CENELEC. (1999). *EN 50126: Railway Applications - The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS)*.
[8] CENELEC. (2001). *EN 50128: Railway Applications - Communication, Signalling and Processing Systems - Software for Railway Control and Protection Systems*.
[9] CENELEC. (2003). *EN 50129: Railway Applications - Communication, Signalling and Processing Systems - Safety Related Electronic Systems for Signalling*.
[10] Leffingwell, D. (2011). *Agile Software Requirements: Lean Requirements Practices for Teams, Programs, and the Enterprise*. Addison-Wesley.
[11] Schwaber, K., & Sutherland, J. (2020). *The Scrum Guide*. Scrum.org.
[12] Kniberg, H. (2010). *Kanban and Scrum - Making the Most of Both*. InfoQ.
[13] Petersen, K., Wohlin, C., & Baca, D. (2009). The Waterfall Model in Large-Scale Development. *Information and Software Technology*, 51(1), 79–84.
[14] Lindvall, M., Costa, P., Tvedt, R. T., Dagnino, A., Volcker, L., &Basili, V. (2002). *Empirical Findings in Agile Methods*. NASA Goddard Space Flight Center.
[15] Hohl, P., Blunders, J., & Schneider, K. (2018). *Agile Practices in Safety-Critical Development: A Literature Review*. *ACM/IEEE International Conference on Software Engineering*, 105–114.
[16] Jonsson, Henrik, et al. "Agile Practices in Regulated Railway Software Development." Citeseerx, https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=1f9a1f469cb8f475eaea49df6c9e45f194fc61ca.
[17] "Using the Agile Model the RTS Way - RTS Solutions Using the Agile Model in the Digital Rail Industry." RTS Solutions, https://www.rts-solutions.net/using-the-agile-model-in-the-digital-rail-industry.
[18] "How Capgemini's Long-Term Partnership Is Continuing to Lay the Track for Improved Customer Service, Productivity, and Competitiveness." Capgemini, https://www.capgemini.com/nl-nl/wp-content/uploads/sites/19/2022/05/Railway-Case-Study-5.pdf.
[19] H. Jonsson, S. Larsson and S. Punnekkat, "Agile Practices in Regulated Railway Software Development," *2012 IEEE 23rd International Symposium on Software Reliability Engineering Workshops*, Dallas, TX, USA, 2012, pp. 355-360, doi: 10.1109/ISSREW.2012.80.
[20] E. J. Joung, C. M. Lee, H. M. Lee and G. D. Kim, "Software safety criteria and application procedure for the safety-critical railway system," *2009 Transmission & Distribution Conference & Exposition: Asia and Pacific*, Seoul, Korea (South), 2009, pp. 1-4, doi: 10.1109/TD-ASIA.2009.5356897.
[21] Kumar, S. (2020). Gantry Protection for Railways and Train Detection System with Railroad Worker Protection Solution. International Journal of Emerging Trends in Computer Science and Information Technology, 1(2), 17-25. https://doi.org/10.63282/3050-9246.IJETCSIT-V1I2P103
[22] Kumar, S. (2021). Rail Defect Measurement System: Integrating AI and IoT for Predictive Operations. International Journal of Artificial Intelligence, Data Science, and Machine Learning, 2(2), 39-50. https://doi.org/10.63282/3050-9262.IJAIDSML-V2I2P105