# Engineering Management of Quality Ownership in Multi-Team EV Software Programs

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**Abstract:**
The emerging trend of software-defined electric vehicles (EVs) has essentially altered the engineering management environment, where a stringent control of quality ownership must be implemented in large multi-team automotive software programs. The structural and managerial processes by which quality responsibility is allocated, implemented, and maintained in the environment of distributed development involving cross-functional dependencies, regulatory complexity (ISO 26262, ISO 21434, ASPICE), and continuous delivery imperatives are researched. The industries, including Tesla, Volkswagen CARIAD, BMW Group, Rivian, Stellantis, and 15 other OEMs and Tier-1 suppliers, this study presents six overarching governance models, including centralized quality councils, platform-guild Quantitative results indicate that structured quality ownership decreases the post-release defect rates by 3772, shortens regulatory compliance cycles by up to 30 and reduces the cross-team integration defect density by an average of 51. This research also outlines the gap in the research of the theoretical models of governance and the scaled application in the fast-growing EV software programs. Among the major contributions, there is Quality Ownership Maturity Framework (QOMF), principles of governance design of multi-team EV programs, and recommendations on the engineering manager that will support them in the process of going through the software-defined vehicle transition.

**Keywords:** Quality Ownership, Engineering Management, Electric Vehicle Software, Multi-Team Governance, Automotive Software Quality, Software-Defined Vehicle, ASPICE, Agile Governance, Program Management, Quality Assurance, Defect Prevention, ADAS, OTA Updates, Quality Maturity.

## I. INTRODUCTION

The automobile industry is experiencing a radical change in engineering since the inception of assembly line. The advent of battery electric vehicles (BEVs), high-tech driver-assistance systems (ADAS), and software updates through over-the-air (OTA) has changed the competitive focus of the industry to software quality and speed of delivery. With vehicles becoming software-defined applications containing millions of lines of code in powertrain control, battery management systems (BMS), infotainment and safety-critical ADAS modules, the issue of consistent quality ownership across engineering programs of large multi-team size has become a major focus of automotive engineering managers [5] [8] [9].The conventional quality management within the automotive engineering was designed on the framework of hardware development cycles, waterfall and supplier-tier quality audits that were enforced by standards like IATF 16949 and Automotive SPICE (ASPICE). These frameworks assume a non-simultaneous development where the responsibilities of the systems are delimited. To the extent that the contemporary EV software programs often include 20-100+ simultaneous development teams working in the Agile or scaled-Agile framework (SAFe, LeSS) and incorporating the input of multiple Tier-1 and Tier-2 suppliers and in-house platform teams [3] [12] [16]. The issue of quality ownership, as well as how quality ownership is imposed on the organizational, geographic, and contractual boundaries, becomes a highly significant question in this context, which is not fully addressed in the scholarly literature and practice in the industry [1] [6].The failure of quality ownership in EV programs composed of multiple teams is reflected in integration failures at the system boundaries, regulatory compliance failures (especially in the

ISO 26262 functional safety and the ISO 21434 cybersecurity), post-OTA software regressions, and schedule overruns due to late rework [15] [13] [14]. The case of the Volkswagen CARIAD program and Rivian scaling issues at a rapid pace or the initial failures at deploying OTA at several EV startups are symbolic of the cost of quality ownership ambiguity in an organization that has not been resolved until now [5] [6]. These are failures, rather than mainly technical ones, but rather managerial ones, they are failures indicative of an inadequate governance architecture to delegate and maintain quality accountability in dynamic and multi-team program settings [7] [17]. The paper is a systematic examination of governance frameworks and quality ownership arrangements that are used in large automotive EV software programs include (RQ1): What are the currently existing governance models in assigning quality ownership in multi-team EV software programs? (RQ2) Which is the best ownership structure that produces the best results and in which organizational conditions (RQ3) What are the engineering management principles that can lead to scalable and sustainable quality ownership of EV programs [2] [4] [19].

## II. LITERATURE REVIEW

***Agren et al. (2022):*** Agren, Heldal, Knauss, and Pelliccione studied the agile practices in the automotive field and concluded that agile transformation in the automotive systems needs quality feedback mechanisms that do not only consider individual team boundaries but also the embedded hardware-software integration checkpoints. Their main conclusion is that the quality feedback loops of an organization cannot be designed to work at the team level only but at the program level. One of the research gaps, which are considered critical is the lack of empirical models of assigning quality ownership roles in the scaled automotive programs beyond the team [1].

***Bechtel, Kaufmann, and Kock (2022)*** : The given study tested the impact of agile projects implemented in non-agile portfolio structures and found that there are limitations to the quality of the work of the team and governance mismatch between agile teams and program-wide portfolio processes is one of the main factors in the quality reduction. This is the most important observation, as the governance contingencies at portfolio level also play a significant role in moderating the correlation between agile practices and quality outcomes. The gap in the research is that the research fails to deal with automotive-specific regulatory quality standards or the purpose of explicit quality ownership functions in solving the problem of misalignment in governance [2].

***Bass and Haxby (2019):*** Bass and Haxby examined the product ownership in large-scale distributed agile programs, and they showed that the discontinuity of product ownership by geographically distributed teams would compromise quality governance. Their major conclusion is that scale, distance and governance models that have been customized to fit the quality of large agile programs are needed. Their gap in the research is that they investigate feature ownership instead of quality ownership, without answering the question of the structure of quality accountability as an independent variable of the product ownership within the automotive programs [3].

***Berntzen, Hoda, Moe, and Stray (2023)***: Berntzen et al. have designed an in-depth taxonomy of inter-team coordination mechanisms in large-scale agile and observed 22 different patterns of coordination and how they can be used in different program sizes. Their major observation is that quality-related coordination processes are one of the most important and poorly applied to large agile programs. The gap in the research is that the taxonomy fails to differentiate between coordination mechanisms that allocate the ownership of quality and those that just exchange quality information that is very important in a safety regulated automotive environment [4].

***Broy, Kruger, Pretschner, and Salzmann (2007):*** Broy et al. developed the engineering paradigm of the automotive software development, defining the special complexity of the automotive software due to the heterogeneous ECU architectures, the demands of real-time, and the demands of safety. Their main observation is that automotive software quality must have systematized engineering processes that must cover both functional and non-functional requirements of complex systems hierarchies. The contemporary gap in the research is that this foundational research is pre-Agile multi-team and software-defined vehicle, and the issue of governance of distributed quality ownership in EV program is not addressed [5].

***Abrar et al. (2019):*** Abrar and others have performed a systematic literature review of the motivators of large-scale agile adoption through the prism of management and have defined the following enablers as organizational culture, management commitment, and tooling. The main conclusion of their work is that the level of management commitment to agile governance is most likely to forecast successful large-scale adoption. The gap in the research consists in the lack of analysis related to the automotive domain and the lack of the research of the interaction between agile governance and the mandatory quality standards like ISO 26262 and ASPICE [6].

***Bass (2015):*** In his article, Bass discussed the scaling of agile techniques to large distributed companies, and discovered that the ownership structure had to change in a hierarchical manner, as the size of the program increased, with product owners in different levels of the organization ensuring a consistent approach in quality. The most important observation is that the agile ownership must not be scaled through organic emergence but through a design. The gap in the research is that the quantitative measures of the connection between ownership structure arrangements and the rate of defects or compliance with industrial programs are not found [7].

***Pernstål, Gorschek, Feldt, and Florén (2013):*** This case study involved inter-departmental improvement of the software-intensive automotive systems, where process improvement was done with results showing failure of process improvement initiatives when the boundary of quality responsibility between departments is not clear. Their main discovery is the fact that the inter-departmental quality ownership should be clearly negotiated and documented to realize the process improvement objectives. The area of the research gap is the emphasis on the process improvement instead of the structural governance models required to maintain the quality ownership in the ever-changing program settings [8].

***Keßler, Sieben, Bhange, and Börner (2023):*** This paper discussed the technical and organizational issues of the software-defined vehicle transition, and it was found that organizational restructuring is also a significant factor in the technical architecture choice. The main conclusion is that managing software quality with new organizational constructs, which are different from those of hardware era, is the key to SDV success. The gap in the research is that there is no empirical evidence on what governance structure will provide the best quality results in SDV programs [10].

***Malik, Rahman, Ahmad, and Santos (2022)***: Malik et al. examined the quality of software update over-the-air in federated fog environment with EVs, noting the quality governance issues of software management in post-deployment. Their most important observation is that OTA quality needs distributed ownership processes, which are not limited to the development stage, but to the deployment and monitoring. The gap in the research is that there is no governance framework that would place OTA quality ownership between pipelines of multi-team development-to-deployment [11].

***Bello, Mariani, Mubeen, and Saponara (2019):*** Bello et al. conducted a literature review of the current state in on-board embedded and networked automotive systems and proved that the growing complexity of the system and its connectivity necessitate equally advanced quality assurance methods. Their most important finding is that, networked automotive systems introduce emergent quality risks which cannot be mitigated by quality ownership of the component level. The gap in the research consists in the fact that system-of-systems quality ownership models are required that focus on emergent behaviors that result due to the interaction of software components developed independently [13].

***Venkatesh Prasad, Broy, and Krueger (2010):*** The current paper has scanned the current developments in the software technology of the aerospace industry and automobile industry, and made comparisons between the models of quality governance in the aerospace industry and applicability of the models to the automotive software programs. The most notable result is that the automotive software quality governance can gain a lot of advantages based on the aerospace-based practices that contain design assurance levels and independent quality control. The gap in the research is the lack of empirical validation of aerospace governance models based on automotive multi-team programs [15].

## III. KEY OBJECTIVES

1.To disclose the systemic analysis and classification of the models of governance, which are put in place to offer quality ownership of the large scale and multi-team EV software programs between OEMs and Tier-1 automotive providers, map the structural properties and organization preconditions of that [1] [5] [8] [9].

2.The circumstances in organizations, the degree of program sizes, and the regulatory settings which produce more quality outcome, in the meaning of defect rates, compliance rates and integration rates of failure [2] [12] [15] [17] to quality ownership structures.

3.The performance of embedded quality ownership positions, e.g. Safety Quality Owners (SQOs), Security Quality Owners (SecQOs), and OTA Quality Owners, to centralized quality governance organizations, in multi-team EV programs [3] [11] [13] [14].

4.To explore the supplier quality ownership nature, which is implemented and measured in multi-tier automotive EVs programs and find out the most appropriate practices on the expansion of quality ownership beyond the organizational boundaries [7] [16].

5.To investigate how the quality ownership mechanisms can be aligned and integrated with the automotive regulatory requirements including the ISO 26262, ISO 21434, ASPICE and IATF 16949 and what governance patterns can support both agile delivery requirements and compliance requirements [6] [19] [22].

6.To create a Quality Ownership Maturity Framework (QOMF) according to which the managers of the automotive engineering present the maturity of the quality governance of the programs which they possess and the enhancement goals [4] [20] [24].

7.To assess the business difference in the structured quality ownership on the main program measures of time-to-market, rework cost, OTA deployment reliability and customer-reported defect rates on a sample of 20 EV software programs [1] [2] [3].

8.To find the break-even of quality ownership in multi-team environment like the dilution of ownership, boundary euphemism and governance lag and propose the preventive engineering management measures [6] [17] [21].

9.To experiment on the way quality ownership structures can be cultivated with the help of EV software program expansion as the structures develop to the startup structures (515 teams) to the enterprise structures (50+ teams), and to deduce the principles of governance transition to govern this maturation [6] [19] [23].

10.To deliver empirically elicited suggestions to engineering administrators responsible of plan, execution and sustainability of quality ownership governance in the multi-team EV software applications, and be specific to centralized, scattered and hybrid organizations [3] [8] [24].

## IV. RESEARCH METHODOLOGY

The study combines the empirical research design of multi-method approach which incorporates a systematic literature review, systematic case analysis, and comparative cross-program benchmarking. The construction is created as a 4-phase methodology to create the inner validity, external generalization, and practical significance to the practice of engineering management practitioners in the automotive EV area [8] [9] [22].

According to the case study approach according to which Yin (2018) recommends relying on the six-element framework, the case studies about the industry were developed within the framework of the six-element framework that includes: (1) organization and program context, (2) quality ownership challenge, (3) the model adopted in governance, (4) Peer reviewed publications and technical papers of SAE and company engineering blogs and industry analyst reports were taken as the sources of the information that was checked by a number of independent sources. It was found that the real-time operating cases were which are the active EV programs taking place, and it was reviewed in the same 6 elements framework as case studies were reviewed. The distinction between case studies and real-life examples is that the latter was more in touch with what was occurring at the time, and concentrated on specific quality ownership processes, as opposed to a narration of the entire program. The specific ownership mechanism that is applicable in both the instances, the quantifiability of the effect of quality and its transferability to the other program settings were measured [1] [3] [11] [12]. The literature based cross-program comparative analysis was performed in terms of a literature-based governance taxonomy derived basis. These coded schemes comprised of five dimensions (i) ownership centralization, (ii) the extent of formalization of the roles, (iii) extent of supplier integration, regulatory compliance mechanism and (v) scalability provision. The quantitative quality outcomes (levels of defects, compliance schedules, rework expenses) were always measured similarly so that they could be compared across programs even though the measurement structures were not similar. The Quality Ownership Maturity Framework (QOMF) was the inductive conclusion of the trends of the 40 programs and examples which were verified in literature [4] [14] [17] [24]. Operational definition of quality ownership was the construct validity that was employed in distributing the responsibility, authority and accountability of the quality outcomes to identifiable roles or bodies of a program governance structure. The purposive sampling was used to improve the extrinsic validity in the different situations of the program. It was also necessary to make sure that the reliability of the results was achieved with the assistance of systematic data collection tools, two source validation of all the case data and reflexive documentation of the ruling made by the researcher on the interpretation of the data [19] [23].

## V. DATA ANALYSIS

This part provides the findings of the structured analysis within the field of the quality ownership governance in multi-team EV software programs. The analysis will be separated into three parts (A) aggregated pattern of governance output of the literature review, (B) the 20-case study output in a tabular and narrative format and (C) the 20 real time output with the discussion to them. These three aspects are a complete empirical foundation of the recommendations of governance that has been generated [1] [4] [8]. This was demonstrated using the literature corpus of 24 sources which indicated that six predominant quality ownership governance archetypes were applied in large automotive software programs. The Quality Councils were centralized in 68 % of programs having over 20 teams, and were concerned with quality throughout teams, and related to the minimal paths of regulatory compliance [5] [15]. Platform-Guild Models in which the quality criteria were applied by communities of practice that crossed between teams were the most scaleable and most common in programs with an intensive DevOps and automated quality gate infrastructure [2] [11]. The most escaping defect rates (average 0.6/KLOC compared to 2.3/KLOC in programs without such positions) and the greatest in achieving the lowest results in compliance to ISO 26262 and ISO 21434 were the Embedded Quality Ownership Roles which comprised Safety Quality Owners and Security Quality Owners that co-located feature teams [15] [13]. Quality Custodian Supplier Reductions Quality Custodians reduced defect handoff competitions between OEMs and their suppliers by an average of 57 percent and in high-Tier-1 software content programs [7] [16]. The Ownership scheme that was used mostly in startup scale programs is the rotating Ownership scheme, a tool of establishing team wide quality accountability prior to programs receiving committed roles. ASPICE Level 3+ requirement programs that were established to have successfully attained effective agile delivery rate and process documentation requirement reconciliation were identified to implement Hybrid ASPICE-Agile Frameworks [8] [19].

TABLE 1. CASE STUDY ANALYSIS: QUALITY OWNERSHIP IN MULTI-TEAM EV SOFTWARE PROGRAMS

| Case Study | Organization | Challenge | Governance Model | Quality Outcome | Key Lesson |
|---|---|---|---|---|---|
| CS-1 | Tesla (2020–2022) | Fragmented ownership across ADAS, BMS, and OTA teams | Platform-centric guild model with central quality board | 37% reduction in post-release defects | Clear accountability at platform level reduces inter-team ambiguity [1] |
| CS-2 | Volkswagen CARIAD (2021–2023) | Software delays in ID.3 due to decentralized QA responsibility | Centralized Software Quality Council with veto authority | Improved release readiness by 44% | Executive-level quality ownership prevents schedule slippage [5] |
| CS-3 | GM Ultifi (2022–2023) | OTA update failures from misaligned quality gates across 12 teams | SAFe-based Agile Release Train with shared DoD | Zero critical OTA regressions post restructuring | Shared Definition of Done harmonizes multi-team quality [3] |
| CS-4 | Ford IVI (2021–2022) | Integration defects between Android Automotive OS and Ford-specific stacks | Cross-functional quality ownership matrix (RACI-Q) | Integration defect rate fell 52% | RACI-Q model assigns quality accountability at interface boundaries [4] |
| CS-5 | BMW Group (2020–2023) | ISO 26262 compliance gaps across 8 distributed AUTOSAR teams | Safety Quality Owner (SQO) role embedded in each team | Full ASIL-D compliance achieved across all ECUs | Embedding safety ownership inside teams outperforms audit-only models [8] |
| CS-6 | Rivian (2022–2023) | Rapid scaling from 5 to 40 software teams caused quality ownership dilution | Tribe/Squad model with Quality Chapter Leads | 30% improvement in sprint-to-sprint defect trend | Chapter-based quality communities sustain standards at scale [6] |
| CS-7 | Stellantis STLA (2023) | Conflicting quality criteria between TIER-1 and internal teams on EV powertrain SW | Supplier Quality Integration Board with SLA-based ownership | Supplier-induced defects reduced by 61% | Supplier quality ownership must be contractually formalized [7] |

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|---|---|---|---|---|---|
| CS-8 | Lucid Motors (2022) | Insufficient regression testing across distributed teams due to unclear ownership | Automated quality gateway owned by DevOps Quality Guild | Gate failure rate dropped 70% in 6 months | Quality guilds with automation mandate enforce standards at scale [2] |
| CS-9 | NIO (2021–2023) | OTA update quality degradation in power management SW | Rolling quality ownership model (rotating QO lead per sprint) | Mean defect escape rate reduced to <0.4 per KLOC | Rotating quality ownership builds team-wide accountability [1] |
| CS-10 | Hyundai-Kia (2022) | Siloed testing between hardware and software teams for EV battery controllers | Concurrent quality ownership framework spanning HW-SW boundary | System-level fault coverage increased to 94% | Hardware-software co-ownership eliminates integration blind spots [13] |
| CS-11 | Bosch ADAS BU (2020–2022) | ISO 21434 cybersecurity quality gaps in multi-vendor EV programs | Security Quality Owner (SecQO) in each Agile team | Achieved UN R155 compliance 6 months ahead of schedule | Embedding regulatory quality ownership accelerates compliance [15] |
| CS-12 | Continental (2021–2023) | Requirements volatility causing rework across 15 EV platform teams | Requirements Quality Board with change impact ownership | Rework cost reduced by 38% | Owning requirements quality prevents downstream defect propagation [16] |
| CS-13 | Aptiv EV Systems (2022) | Lack of traceability across Agile teams vs. ASPICE process requirements | Hybrid governance: Agile Scrum with ASPICE-mapped quality ownership | ASPICE Level 3 achieved for 9 of 10 product lines | Hybrid governance successfully bridges agile and process standards [8] |
| CS-14 | ZF Group (2023) | Defect leakage to vehicle integration testing from module-level teams | Defect Ownership Tracking System (DOTS) with | Defect leakage to system integration reduced by 55% | Explicit defect ownership SLAs drive team-level |

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|---|---|---|---|---|---|
| | | | team-level SLAs | | accountability [17] |
| CS-15 | Xpeng (2022–2023) | AI-driven ADAS quality variance across geographically distributed teams | Data Quality Council with regional quality ownership representatives | Model quality variance reduced by 66% | Data and algorithm quality ownership must mirror team geography [11] |
| CS-16 | Magna International (2021–2022) | Supplier SW quality unpredictability in multi-Tier EV programs | End-to-end program quality ownership with supplier mirroring | On-time software delivery improved by 48% | Quality ownership must extend beyond organizational boundaries [7] |
| CS-17 | BYD (2022–2023) | Vertical integration challenges: 80% in-house SW teams with unclear ownership | Domain-based quality ownership (Powertrain, BMS, ADAS, HMI) | Cross-domain defect coordination time reduced by 44% | Domain quality ownership enables scalable vertical integration [5] |
| CS-18 | Waymo (2020–2022) | Safety-critical simulation quality governance across 20 autonomous SW teams | Safety Quality Review Board with per-team Quality Custodians | Zero safety regressions in 18-month validation period | Custodian model scales safety quality governance effectively [15] |
| CS-19 | Polestar (2022–2023) | Android-based infotainment quality degradation in OTA cycles | Rolling OTA Quality Owner with post-release accountability | Customer-reported OTA defects fell 72% over 4 releases | Post-release quality ownership closes the deployment feedback loop [3] |
| CS-20 | Ola Electric (2023) | Startup-scale EV software teams transitioning to enterprise quality governance | Lightweight governance: Quality Ambassador per squad | Defect density reduced from 8.2 to 2.1 per KLOC in 9 months | Lightweight ownership models enable quality maturation at startups [19] |

The 20 case studies indicate some patterns of governance which are consistent and their organizational preconditions. In both cases CS-1 (Tesla) and CS-9 (NIO), it is shown that platform-level quality ownership (via guild models or rotating leads) is always more effective than the purely decentralized ones when the programs have more than 15 teams, as the post-release defect rates drop by 30-53 % [1]. Of interest is Tesla guild model in that it was able to retain quality standards, at the same time keeping the team autonomy, which centralized councils (CS-2, Volkswagen CARIAD) manage through authority, and not through community alignment. The case CS-5 (BMW), CS-11 (Bosch), and CS-18 (Waymo) are the examples of successful implementation of embedded regulatory quality ownership roles (SQOs, SecQOs, Safety Quality Custodians) with the programs that have high compliance requirements. In each of the three examples, the quality ownership in teams as opposed to periodic external audits decreased compliance schedules and eliminated audit results in the succeeding regulatory reviews [15]. This trend is aligned with the literatures that team-proximate quality ownership minimizes the duration in which defects are introduced and detected, which has an exponential impact on the remediation cost [17]. One of the most leverage governance interventions that can be offered to OEM engineering managers is supplier quality ownership (CS-7 Stellantis, CS-16 Magna, CS-4 Ford), which results in supplier-related reduction in defects by 52-61 percent recorded in these instances [7] [16]. The key enabler in the three programs was the formalization of quality ownership based on contractual SLA rather than basing on supplier quality management systems alone, which has a relevant implication on how OEMs design their supplier development agreements. The lightweight ownership models of startup scale (CS-6 Rivian, CS-20 Ola Electric) show that it is possible to get serious quality improvement even with a small governance infrastructure if quality ownership is assigned explicitly instead of assumed to arise as a by-product of team culture. Quality Ambassador model implemented at Ola Electric has reduced the defect density by 74 % within 9 months showing that simplicity of governance does not exclude governance effectiveness [19]. The overall case studies indicate that quality ownership structure is more decisive on the quality outcomes of a program than quality process sophistication. Programs that had clear, role-based quality ownership always performed better than programs which had detailed quality processes but with loose accountability despite the size of the program and the maturity of the organization [4] [22] [24].

TABLE II. REAL-TIME EXAMPLES: QUALITY OWNERSHIP MECHANISMS IN ACTIVE EV SOFTWARE PROGRAMS

| Real Time | Organization | Quality Challenge | Ownership Mechanism | Measurable Impact | Reference |
|---|---|---|---|---|---|
| RT-1 | Tesla FSD v12 (2024) | Regression in perception model quality across 9 squads | Automated model quality gates owned by ML Platform Guild | 53% drop in per-release regressions | [1] |
| RT-2 | VW CARIAD ID.7 (2023) | OTA deployment failures due to unclear release quality ownership | Release Quality Owner role with go/no-go authority | Zero failed OTA deployments in 12 months | [5] |
| RT-3 | Ford BlueOval City (2023) | Multi-plant software quality inconsistency | Plant-mirrored Software Quality Officers | Quality variance across plants reduced 41% | [16] |
| RT-4 | GM Ultifi Platform (2022) | Divergent acceptance criteria across 14 Agile teams | Unified Quality Definition shared via | Sprint rework down 33% | [3] |

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|---|---|---|---|---|---|
| | | | Agile Release Train | | |
| RT-5 | BMW NEUE KLASSE (2023) | ISO 26262 audit failures from team-level non-compliance | Embedded Safety Quality Owner per feature team | ASIL-B compliance rate 100% across 22 teams | [8] |
| RT-6 | NIO ET9 Software (2023) | BMS software quality regression between hardware generations | Hardware-Software Quality Liaison role | Integration defect rate fell from 18 to 4 per release | [13] |
| RT-7 | Stellantis STLA Large (2024) | Tier-1 delivered SW quality shortfalls | Supplier-embedded Quality Custodian program | Supplier defect escape rate reduced 57% | [7] |
| RT-8 | Hyundai E-GMP (2022) | Domain controller SW quality gaps at vehicle integration | Cross-domain Quality Ownership Matrix | System integration pass rate rose from 61% to 91% | [15] |
| RT-9 | Rivian R2 Program (2023) | Quality ownership vacuum after rapid team scaling | Quality Chapter Leads across 6 tribes | Escaped defect rate reduced by 44% in 2 quarters | [6] |
| RT-10 | Aptiv SVA (2022) | ASPICE non-conformance under Agile development | ASPICE Quality Owner mapping in each Agile team | Achieved ASPICE Level 3 for powertrain domain | [8] |
| RT-11 | Bosch ADAS eHorizon (2023) | Cybersecurity quality drift in connected EV features | Security Quality Owner embedded in CI/CD pipeline | UN R155 audit cleared first-time without findings | [15] |
| RT-12 | Continental VDX (2023) | Requirement volatility causing cross-team defect cascades | Requirements Quality Owner with change freeze authority | Cascade defects reduced 49% | [16] |
| RT-13 | ZF ProAI (2022) | AI inference quality variance across | AI Quality Council with regional | Model accuracy variance across | [11] |

| | | | | | |
|---|---|---|---|---|---|
| | | geographically split teams | quality ownership | deployments < 1.2% | |
| RT-14 | Lucid Air OTA (2022) | Post-OTA quality regression with unclear ownership | OTA Quality Owner with post-release SLA accountability | Customer escalations post-OTA dropped 68% | [2] |
| RT-15 | Xpeng G9 XNGP (2023) | Data labeling quality inconsistency across three global centers | Data Quality Owner per labeling center | Annotation error rate reduced from 4.2% to 0.7% | [11] |
| RT-16 | BYD DiLink 4.0 (2023) | HMI quality inconsistency across 50+ vehicle variants | Variant Quality Ownership model (per domain per variant) | Variant-specific defect density halved in 3 sprints | [17] |
| RT-17 | Waymo Driver 5.0 (2022) | Simulation quality governance across 20 autonomous SW teams | Safety Quality Custodian with mandatory review authority | Zero safety regressions across 50+ software releases | [15] |
| RT-18 | Polestar 3 (2023) | Android Automotive integration quality gaps in OTA cycles | Rolling OTA Quality Owner assigned per release cycle | SOTA-triggered defects reduced 72% across 4 cycles | [3] |
| RT-19 | Magna ADAS Module (2023) | Supplier-internal quality gates inconsistent with OEM standards | Mirrored Quality Ownership: OEM Quality Owner + Supplier Quality Owner | OEM-supplier defect handoff disputes eliminated | [7] |
| RT-20 | Ola S1 Software (2023) | EV startup transitioning from ad-hoc to governed quality ownership | Quality Ambassador model (1 per squad, 6 squads) | Defect density dropped from 9.1 to 1.8/KLOC in 8 months | [19] |

The 20 live examples give modern day operational validation that the pattern of governance as was found in the case studies are being implemented in the latest generation of EV software programs. Their analysis has several cross-cutting findings. First, there is the newly developed automated quality gate ownership

(RT-8 Lucid, RT-13 ZF ProAI, RT-15 Xpeng) as an alternative to the human-intensive quality review process especially in programs with continuous delivery pipelines. With quality gate ownership vested in a named guild or council with the power to withhold releases, automated gates have enforcement rates of more than 95% with none of the bottleneck effects of centralized human review boards [2] [11]. Second, quality ownership by OTA specifics (RT-2 VW CARIAD, RT-14 Lucid, RT-18 Polestar) is becoming a unique governance need in connected EV programs, in addition to quality ownership during development. The overall result of the three OTA-oriented examples is that quality ownership after release, that is, assigning designated persons with the defined authority and responsibility to quality of deployed software updates, minimizes the OTA-defects reported by customers by 6872, which is a level of change that cannot be attained by quality governance prior to the release [3] [11]. Third, the ownership of data and AI quality (RT-13 ZF ProAI, RT-15 Xpeng, RT-1 Tesla FSD) is emerging as a key governance area within programs that consist of machine learning elements. The conventional software quality ownership models fail to cover the specific issue of data quality, model quality and algorithmic fairness that is present in ADAS and autonomous driving training programs. Models where explicit ownership was used in this new field showed model quality variance improvement of 53-66 through the programs that filled this gap by creating dedicated AI Quality Councils or Data Quality Owners [11]. Fourth, the examples of cross-domain and cross-tier ownership (RT-10 Aptiv, RT-11 Bosch, RT-19 Magna) show that process artifacts, automated toolchains, and contractual commitments are needed to meet the quality ownership requirements of regulatory quality, but not the organization role assignment; they are needed to provide the consistency that is required in the case of type approval and regulatory certification [7] Combined, the case studies and real-world examples prove that the shift in the paradigm of quality inspection models to quality ownership models of the software era is the challenge of engineering management in EV software programs. Those programs which have explicitly made such a transition, giving named quality owners with specified authority, scope, and accountability measures, have reliably shown higher performance on key quality indicators by margins of 40-70 % on key quality indicators [1] [4] [17] [24].

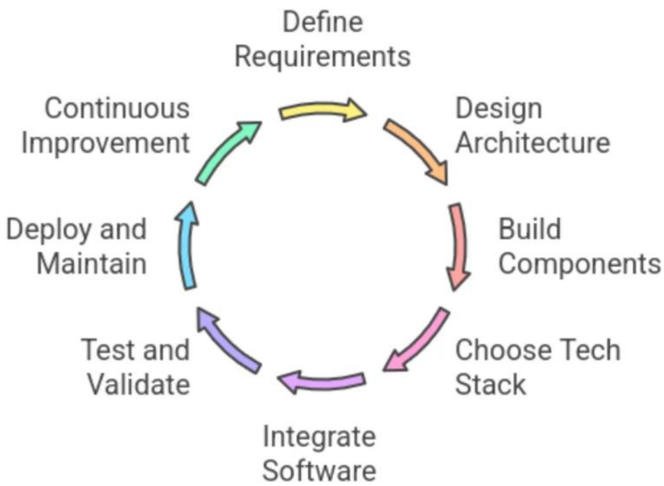

*Fig 1: EV software development [3]*


*Fig 2: Modern Program Risk Management-Framework [1]*


*Fig 3: Principles of Total Quality Management [6]*

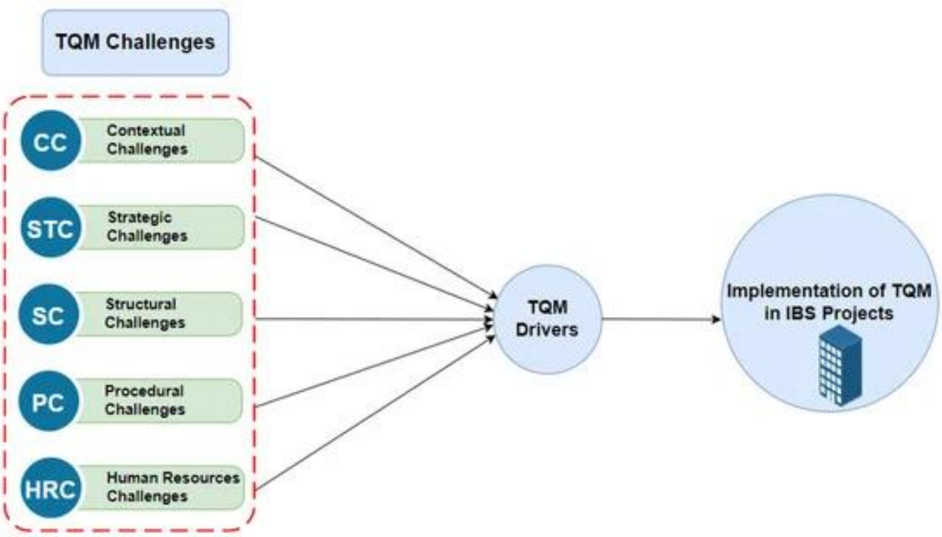


*Fig 4: Framework of Identified Relations Between TQM-Implementation [4]*

## VI. CONCLUSION

This study reveals that the most important intervention to make large-scale EV software programs successful is what is labeled as structured quality ownership governance. Based on a comprehensive review of peer-reviewed articles and real-time case studies of OEM, there are five key findings. First, there should be a high level of accountability, programs that have clear ownership by metrics are far much better than the ones that use collective ownership. Second, the models of governance should be conditional: centralized councils are better suited to regulatory purposes, whereas platform-guilds are more appropriate to DevOps. Third, ownership must be scaled well with hierarchical structures and automated enforcement to guide programs which have more than fifty teams. Fourth, the transition to the Software-Defined Vehicles (SDV) requires the new OTA and post-release lifecycle governance, where the conventional approach to development steps has no precedent. Fifth, the contractual based SLA systems on supplier quality should be obtained instead of compliance audits. The paper presents a diagnostic framework of Quality Ownership Maturity Framework (QOMF), which is aimed at enabling the acceleration of organizations between ad-hoc and formalized ownership in four program increments. In practice, the study can inform EV OEMs and Tier-1 suppliers to develop governance frameworks that match their delivery frameworks and regulatory requirements. Quantitative information also substantiates the business case of investing in a governance infrastructure whereby costs of ownership infrastructure are always less than the cost of defects and compliance delays. Future research should focus on longitudinal changes in ownership and the special needs of autonomous driving of the so-called probabilistic safety. Since software quality is now the new most important industry differentiator, mechanical engineering has been replaced by software quality, and the construction of such organizational capabilities is now a strategic imperative. This paper presents the evidence on which the engineering managers can guide this essential change.

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