Adoption of Safety Standards in the Japanese Automotive Industry: A Consortium Study

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Abstract. As the number of automotive safety standards increases, including ISO 26262, ISO 21448 (Safety of the Intended Functionality, SOTIF), and UL 4600, practitioners need evidence on how these standards are being adopted in industry. This practical experience report presents a questionnaire-based study conducted within JASPAR, a Japanese automotive consortium, through its Functional Safety Working Group, with 30 responses from 28 of 40 companies (70% company coverage). We compared adoption status across the three standards and analyzed adoption drivers and role allocation between original equipment manufacturers (OEMs) and suppliers for ISO 26262 and SOTIF using non-parametric tests with Holm correction. Adoption stages differ markedly: ISO 26262 is institutionalized (93%), SOTIF is emerging (10% active, 60% preparing), and UL 4600 is pre-adoption in this sample (0% active). Four findings remained significant after multiple-comparison correction: (1) contract requirements and (2) pressure to conform to industry practice are both perceived as stronger drivers of ISO 26262 adoption than of SOTIF; (3) suppliers perceive stronger ISO 26262 contract pressure than OEMs; and (4) despite similar V-model allocation patterns, respondents perceive SOTIF role boundaries as less clear. We derive practical recommendations for OEMs, suppliers, and industry consortia.

Keywords: ISO 26262 · ISO 21448 (SOTIF) · UL 4600 · automotive safety · practical experience report

1 Introduction

Assuring the safety of advanced driver assistance systems (ADAS) and automated driving functions has become more important than ever as vehicles increasingly rely on perception, decision-making, and control software. Three major standards address different aspects of automotive safety. ISO 26262 [9] provides a well-established framework for functional safety, focusing on risks arising from system failures or malfunctions. ISO 21448 (SOTIF) [10] addresses safety issues caused by functional insufficiencies or unforeseen environmental conditions, even when a function performs as intended. UL 4600 [23] (first published in 2020) provides safety-case guidance for autonomous systems, emphasizing evidential completeness and governance.

The importance of international safety standards became particularly evident after the 2009–2010 Toyota unintended-acceleration recalls [3, 24]. For the Japanese automotive industry, this incident highlighted the need for more systematic safety engineering and accountability for software-intensive automotive systems. ISO 26262 was first published in 2011 and has since become a de facto requirement in the global automotive supply chain.

While ISO 26262 is widely adopted, SOTIF (published in 2022) and UL 4600 are comparatively new. Adoption patterns, interactions with established processes, and the organizational challenges of operating multiple standards concurrently remain underexplored, especially in Japan. We examine the adoption of these three standards in collaboration with JASPAR (Japan Automotive Software Platform and Architecture)[3], whose more than 200 member companies include nearly all major Japanese vehicle manufacturers and leading suppliers. This consortium setting provided cross-organizational access that is rarely feasible through conventional academic channels. Although the data come from Japan, the tiered original equipment manufacturer (OEM)–supplier structure and contract-driven compliance that shape adoption have clear parallels in other regions, notably Germany [19] and South Korea [13]. Germany represents a core European automotive production network with tiered OEM–supplier relationships, while South Korea provides an example of OEM-centered parts-supply networks, illustrated by Hyundai Motor's quasi-vertical integration of internal and external supplier networks. These parallels suggest that the contract-pressure and boundary-clarity findings are most transferable to OEM-centered, tiered automotive supply chains; the UL 4600 adoption pattern and JASPAR's coordinating role are more Japan-specific.

Because UL 4600 emphasizes safety-case governance rather than component-oriented V-model activities, it cannot be directly compared with ISO 26262 and SOTIF on all analytical dimensions. Furthermore, no respondent reported active UL 4600 use, precluding meaningful analysis of drivers or role allocation. Accordingly, UL 4600 appears only in the adoption overview (Section 4.1) and the discussion of adoption stages (Section 5.1); all other analyses focus on ISO 26262 and SOTIF.

This work arose from a practical need within JASPAR to assess the readiness of its member companies for multi-standard operation. In particular, questions had emerged about how to allocate SOTIF responsibilities across the OEM–supplier interface; the analysis reported here allowed us to examine whether this concern was broadly shared across companies and how large the perceived boundary-clarity gap was.

This paper makes three contributions. First, it quantifies an asymmetry in contract pressure between OEMs and suppliers and shows how this asymmetry shapes adoption of safety standards. Second, it grounds the interpretation of multi-standard adoption in institutional theory. Third, it translates the findings

[3] https://www.jaspar.jp/en/about_us

Table 1. Positioning among related empirical and technical studies. • = addressed.

Study	Scope	Method	Standards	Cross-standard	OEM–supplier
Born et al. [1]	Auto (DE)	Exp. report	ISO 26262		
Nair et al. [16]	Cross-domain	Quest.	Multiple		
De la Vara et al. [25]	Cross-domain	Quest.	Safety std		
Huber et al. [8]	Automotive	Quest.	26262+security		Partial[a]
Nouri et al. [18]	Auto (SE)	Exp. report	26262+SOTIF		
Wang et al. [26]	AV/ADAS	Review	SOTIF		
Diemert et al. [5]	Cross-domain	Interv. + quest.	Assurance case		
Soleimani & Sari [21]	AV/ADAS	Framework	3 standards	•	
This study	**Auto (JP)**	**Quest.**	**3 standards**	•	•

[a]OEM/supplier roles collected but not comparatively analyzed. Quest. = questionnaire-based study.

into priorities for consortium-level action, including empirical support for JASPAR's ongoing work on SOTIF responsibility-assignment templates. These contributions connect the empirical results to safety-case practice, multi-standard governance, and the organizational dimension of safety engineering.

Section 2 reviews related work and introduces the institutional-theory lens used to interpret adoption stages. Section 3 describes the research questions, questionnaire design, and statistical methods. Section 4 presents the results, including adoption status, benefit–cost perceptions, driver profiles, and OEM–supplier role allocation. Section 5 discusses the findings and identifies practical priorities for industry consortia. Section 6 concludes with directions for future work.

2 Related Work

Several empirical and technical studies have examined safety-standard practice (Table 1); to the best of our knowledge, none directly compares the adoption of ISO 26262, SOTIF, and UL 4600 empirically.

Born et al. [1] reported early industrial experience with the ISO 26262 draft and noted supplier hesitance to commit before OEMs demonstrated acceptance, an observation consistent with the contract-pressure asymmetry we quantify here. Cross-domain questionnaire-based studies by Nair et al. [16] and De la Vara et al. [25] identified operational burden as a systemic issue, but neither compared adoption drivers across standards nor analyzed OEM–supplier role differences. Huber et al. [8] studied automotive safety and security practitioners using a questionnaire and reported coordination challenges, though without comparing adoption patterns across standards.

For SOTIF, Wang et al. [26] reviewed research and practice, focusing on the technical state of the art rather than organizational adoption. Soleimani and Sari [21] proposed a unified framework integrating ISO 26262, SOTIF, and UL 4600, addressing technical integration at the artifact level. Yet how organizations actually adopt and coordinate these standards remains an open question. Nouri et al. [18] reported friction between safety-process requirements and rapid development cycles, a concern related to the operational burden described by our respondents.

Assurance cases, which are central to UL 4600 and increasingly used for ISO 26262, have also been studied empirically [2, 4, 22]. Diemert et al. [5] found that barriers include additional workload and inadequate guidance, findings that complement our results. Recent work on automated-driving safety argumentation [7, 14, 15] addresses specific methodological aspects rather than cross-standard adoption patterns.

To characterize differing adoption stages of international standards, we draw on institutional theory [6], which distinguishes three mechanisms that drive organizational adoption: *coercive* pressure (adoption mandated through contracts or regulations), *mimetic* pressure (adoption driven by imitating industry peers), and *normative* pressure (adoption driven by professional recognition of technical necessity). In Section 5, we use these mechanisms to explain why ISO 26262, SOTIF, and UL 4600 are at different stages of adoption.

3 Research Design and Methodology

3.1 Research Questions

Drawing on prior literature on safety-standard practice and adoption [1, 8, 16, 18, 25] and practical concerns raised in JASPAR Functional Safety Working Group meetings, we formulated three research questions:

- **RQ1 (Benefits and Costs)**: Do perceptions of safety improvement, operational burden, and cost-effectiveness differ between ISO 26262 and SOTIF?
- **RQ2 (Adoption Drivers)**:
  - **RQ2a**: Do the relative weights of adoption drivers differ across standards?
  - **RQ2b**: Do OEMs and suppliers differ in their driver profiles?
- **RQ3 (Role Allocation)**:
  - **RQ3a**: How are V-model activities allocated between OEMs and suppliers for each standard?
  - **RQ3b**: Are role boundaries perceived as less clear for SOTIF than for ISO 26262?

3.2 Questionnaire Design and Data Collection

Data were collected through a web questionnaire administered to members of the JASPAR Functional Safety Working Group. Quantitative items used 5-point scales; anchors ranged from 1=Strongly disagree to 5=Strongly agree for driver and benefit/cost items, from 1=OEM only to 5=Supplier only for role allocation,

Table 2. Respondent characteristics ($n = 30$)

Category	Item	n	%
Company type	OEM	10	33%
	Tier 1 supplier	17	57%
	Tier 2 or below	2	7%
	Tier 1 & Tier 2	1	3%
Role	Safety assessor	11	37%
	Engineer	8	27%
	Quality assurance	4	13%
	Manager/Other	7	23%
Automotive SPICE status	Operating	15	50%
	Not operating	9	30%
	Preparing	5	17%
	No response	1	3%
ISO 26262 experience	5+ years	26	87%

and from 1=Much less clear to 5=Much clearer for boundary clarity. Open-ended items elicited qualitative comments. The questionnaire covered respondent characteristics, adoption status, standard-specific items (ISO 26262, SOTIF, UL 4600), assurance-case practice, and multi-standard challenges. Branching logic directed respondents only to questions for standards they were using or preparing to adopt.

The questionnaire was distributed in December 2025 to the 40 companies participating in the JASPAR Functional Safety Working Group, and we received 30 responses from 28 distinct companies (70% company coverage). Two companies contributed two respondents each. Because the questionnaire was anonymous, individual responses cannot be linked to specific companies. Participation was voluntary, informed consent was obtained on the entry page, and no personally identifiable information was collected. To reduce social-desirability bias, respondents were instructed to answer on the basis of their own practical experience rather than provide official company positions. Table 2 summarizes respondent characteristics. For the OEM–supplier comparisons in subsequent analyses, the 10 OEM respondents form the OEM group, and the remaining 20 respondents (Tier 1, Tier 2, and Tier 1 & 2) form the Supplier group.

To support reproducibility, the companion repository[4] provides questionnaire materials, analysis outputs, and analysis scripts.

3.3 Statistical Methods

Given the small sample size and the ordinal nature of the data, we used non-parametric tests throughout (all two-tailed). Specifically, the Wilcoxon signed-rank test was used for paired comparisons (e.g., ISO 26262 vs. SOTIF ratings

[4] `https://github.com/yutakaJssst/SafeComp2026SurveyQuestionnaire`

from the same respondent), the Mann–Whitney U test for independent-group comparisons (OEM vs. supplier), the Friedman test for comparing multiple drivers within a standard, and the one-sample Wilcoxon test for testing whether a rating differs from the neutral midpoint (3).

Effect sizes are reported as $r = |Z|/\sqrt{N}$ [20], where $r \geq 0.5$ indicates a large effect[5]. To guard against false positives from multiple comparisons, we applied Holm correction within each research-question family. When a planned test could not be computed (e.g., too few differing responses), it was still counted, making the correction more conservative. Results that are significant only before correction are treated as exploratory. We excluded "Not applicable" responses item-wise and used pairwise-complete data. Means and standard deviations are reported as descriptive summaries; Norman [17] provides justification for interpreting means of ordinal scales in this manner.

An AI assistant (Claude, Anthropic) assisted with initial scripting and preliminary coding of free-text comments; all results were independently verified by the authors using reproducible scripts. AI-generated initial codes for the 28 free-text comments were reviewed, revised, and consolidated into themes through author discussion on the original Japanese-language responses.

4 Results

Because branching logic skipped questions for standards a respondent was not using or preparing to adopt, sample sizes vary: ISO 26262 items typically have $n = 25$–28, whereas SOTIF items have $n = 12$–20.

4.1 Adoption Overview

ISO 26262 is nearly universally adopted, with 28 of 30 respondents (93%) reporting active use. In contrast, SOTIF is still in an early phase of adoption: only 3 respondents (10%) reported active use, whereas 18 (60%) reported that they were preparing to adopt it. No respondent reported active UL 4600 use. Only 2 respondents (7%) reported preparing for UL 4600 adoption, and 16 (53%) reported no plans to adopt it. UL 4600 is therefore included only in this adoption overview; it is excluded from the driver and role-allocation analyses that follow. Fig. 1 illustrates these adoption patterns.

Among ISO 26262 adopters, Part 4 (system-level product development) and Parts 7–9 (production, supporting processes, and Automotive Safety Integrity Level (ASIL)-oriented analysis) showed the highest adoption at 93%, followed by Part 2 (management of functional safety) at 89%. Part 3 (concept phase) was notably lower at 46%, likely because 67% of respondents are suppliers (Table 2) and concept-phase activities are typically performed by OEMs in the Japanese supply chain.

[5] For the Wilcoxon test, N is the number of respondents whose paired ratings differ ("non-zero differences"); for Mann–Whitney, $N = n_1 + n_2$ with tie-corrected variance.

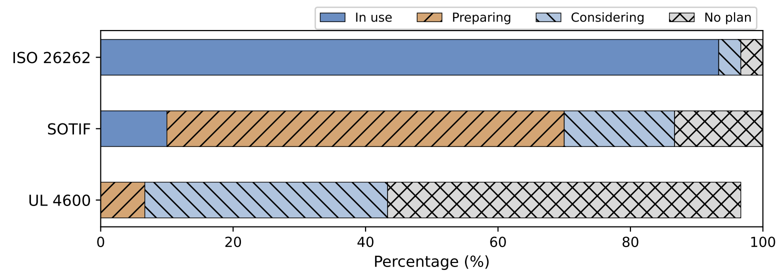

Fig. 1. Standard adoption status ($n = 30$). ISO 26262 shows near-universal adoption (93%), while SOTIF is in early adoption (10% active, 60% preparing). No respondent reported active UL 4600 use.

Table 3. Perceived benefits and costs (5-point scale; Holm correction within RQ1). † denotes uncorrected $p < 0.05$ only.

Item	ISO 26262		SOTIF		n_{pair}	p
	M (n)	SD	M (n)	SD		
Safety improvement	3.73 (26)	0.96	2.92 (13)	0.95	12	.039†
Operational burden	4.23 (26)	0.82	4.17 (12)	0.39	12	.844
Cost-effectiveness	3.20 (25)	1.00	2.92 (12)	1.00	11	.438

4.2 RQ1: Perceived Benefits and Costs

Table 3 presents perceptions of benefits and costs. The key pattern is an effort–benefit imbalance: both standards were rated as high burden ($M \geq 4.17$), but SOTIF's perceived safety improvement fell below the scale midpoint ($M = 2.92$), whereas ISO 26262 was rated moderately positively ($M = 3.73$). Respondents thus see SOTIF as nearly as burdensome as ISO 26262 but less beneficial, which may help explain why SOTIF is harder to promote internally (see also Section 5). The difference in perceived safety improvement was suggestive ($p = 0.039$) but did not survive Holm correction ($p_{\text{Holm}} = 0.117$). As a supplementary check, we compared companies operating Automotive SPICE ($n = 15$) with those not yet operating it ($n = 14$; Preparing or Not operating) to see whether process maturity influenced these perceptions, but found no significant differences (all $p > 0.2$).

4.3 RQ2: Adoption Drivers

Table 4 and Fig. 2 present perceptions of adoption drivers. For ISO 26262, respondents rated accountability to end users and certifiers ($M = 4.44$), contract requirements ($M = 4.44$), and conformity to industry practice ($M = 4.25$) as especially strong drivers. Within SOTIF, by contrast, the highest-rated drivers were accountability to end users and certifiers ($M = 4.37$), accountability to clients ($M = 3.78$), and technical safety ($M = 3.75$). Two between-standard differences remained significant after Holm correction: contract requirements scored

Table 4. Adoption drivers by standard (5-point scale). ** = significant after Holm correction. Effect size r is shown only when at least 10 respondents rated the two standards differently; otherwise omitted.

Driver	ISO 26262 M (n)	ISO 26262 SD	SOTIF M (n)	SOTIF SD	p	r
Technical safety	4.18 (28)	0.90	3.75 (20)	1.12	.049	.63
Accountability to clients	4.08 (26)	1.26	3.78 (18)	1.26	.109	—
Accountability to end users/certifiers	4.44 (27)	0.70	4.37 (19)	0.60	.109	—
Contract requirements	4.44 (25)	1.16	3.47 (17)	1.28	.002**	.89
Conformity to industry practice	4.25 (28)	0.80	3.58 (19)	0.84	.004**	—

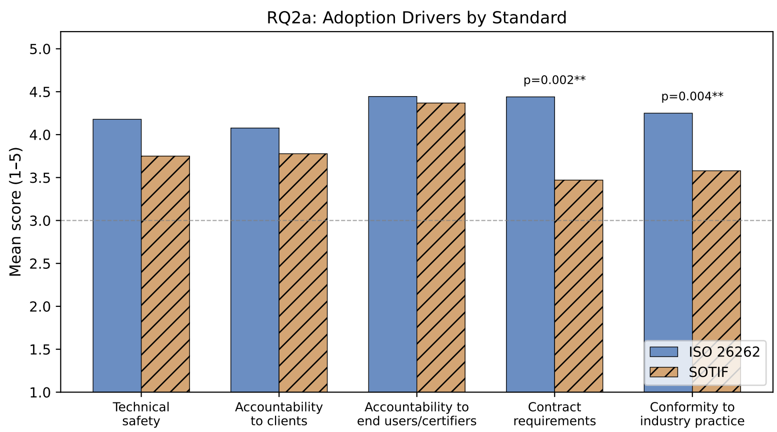

Fig. 2. Adoption drivers by standard. Contract requirements ($p = 0.002$) and conformity to industry practice ($p = 0.004$) are significantly stronger for ISO 26262 than SOTIF (Holm-corrected). The dashed line indicates the neutral midpoint (3).

higher for ISO 26262 than for SOTIF ($M = 4.44$ vs. 3.47; $p = 0.002$, $r = 0.89$, a large effect), and so did conformity to industry practice ($p = 0.004$). Technical safety showed a similar tendency ($p = 0.049$, $r = 0.63$) but did not survive correction.

A Friedman test, which assesses whether the five drivers are rated equally within a standard, indicated significant differences among drivers for SOTIF ($\chi^2 = 13.18$, $p = 0.010$, $n = 17$), confirming that certain drivers (notably accountability and technical safety) stand out more than others. For ISO 26262, the difference did not reach significance ($\chi^2 = 7.61$, $p = 0.107$, $n = 25$), consistent with all drivers being rated similarly high.

Table 5 shows OEM–supplier differences for contract requirements, the only driver that reached significance after correction (full results for all five items are in the companion repository). For ISO 26262, suppliers reported significantly stronger contract pressure ($M = 4.89$, $n = 18$) than OEMs ($M = 3.29$, $n = 7$; $p = 0.002$, $r = 0.63$). This asymmetry reflects the supply-chain structure: OEMs face expectations from end customers and certification bodies, whereas suppliers

Table 5. OEM vs. Supplier differences in contract requirements (Mann–Whitney U; Holm-corrected over all 5 drivers per standard; only contract requirements shown as the sole significant driver). Supplier = Tier 1 + Tier 2 + Tier 1 & 2.

Standard	OEM M (n)	Supplier M (n)	U	p	r	Holm
ISO 26262	3.29 (7)	4.89 (18)	22.0	.002	.63	Sig. **
SOTIF	2.50 (6)	4.00 (11)	12.5	.038	.52	n.s.

Table 6. V-model activity allocation (1 = OEM only, 5 = Supplier only). Paired tests are omitted because only 3–5 respondents per activity rated the two standards differently.

Activity	ISO 26262		SOTIF	
	M (n)	SD	M (n)	SD
Safety goals / upper req.	1.73 (26)	0.83	1.77 (13)	0.83
Requirements validation	1.85 (26)	0.67	1.83 (12)	1.11
Detailed design	3.69 (26)	0.79	3.25 (12)	1.22
Implementation / unit test	4.23 (26)	0.65	4.17 (12)	0.72
Integration / system test	3.08 (26)	0.93	2.92 (12)	1.24

face OEM-imposed contractual requirements. For SOTIF, a similar tendency was observed (OEM $M = 2.50$ vs. Supplier $M = 4.00$; $p = 0.038$, $r = 0.52$) but did not survive Holm correction, suggesting that a comparable asymmetry may be emerging.

4.4 RQ3: Role Allocation and Boundary Clarity

Table 6 presents the perceived allocation of V-model activities. On a scale where 1 = OEM only and 5 = Supplier only, the pattern is consistent for both standards: upstream activities (requirements definition and validation) are OEM-led ($M \approx 1.8$), midstream activities (detailed design) lean toward suppliers ($M \approx 3.5$), and downstream activities (implementation and unit testing) are supplier-led ($M \approx 4.2$). Integration testing shows mixed responsibility ($M \approx 3.0$).

Most respondents assigned identical allocations for both standards, choosing the same scale point for ISO 26262 and SOTIF on each activity. This left only 3–5 respondents per activity whose paired ratings differed, too few for a meaningful statistical test. The high proportion of identical responses is itself informative, however, and may reflect organizational inertia: once roles are established for ISO 26262, organizations apply them to SOTIF without renegotiation.

Despite similar role allocations, boundary clarity differs markedly. Respondents were asked to compare SOTIF boundary clarity with ISO 26262 on a scale from 1 = Much less clear through 3 = Same to 5 = Much clearer. Of the 15 respondents, 73% (11/15) rated SOTIF boundaries as “less clear” or “much less clear,” and none rated them clearer (Fig. 3). The mean rating was $M = 1.93$ ($SD = 0.80$), significantly below the neutral midpoint ($p = 0.001$, $r = 0.88$); this result remained significant after Holm correction ($p_{\mathrm{Holm}} = 0.006$).

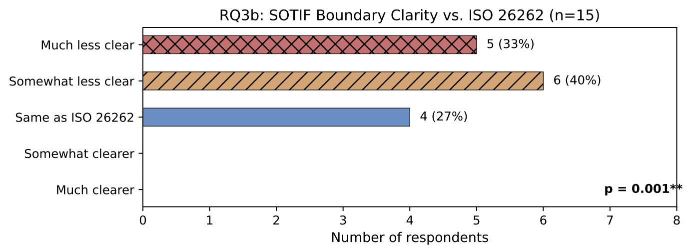

Fig. 3. SOTIF boundary clarity compared to ISO 26262 ($n = 15$). 73% of respondents rated SOTIF boundaries as less clear, with none rating them clearer ($p = 0.001$, $r = 0.88$).

Table 7. Challenges in multi-standard operation ($n = 30$, multiple selection)

Challenge	%
Requirement overlap	47%
Scope understanding	40%
Document integration	37%
Terminology confusion	33%
Cross-department coordination	33%
Priority judgment	27%
Customer requirement differences	27%
No challenges	13%

This pattern is notable because if organizations assign the same roles as for ISO 26262, one might expect comparable boundary clarity. The gap likely arises because SOTIF requires system-level scenario analysis whose scope depends on the OEM's operational design domain (ODD) definition. In contrast, ISO 26262 requirements can be decomposed per component, making responsibility boundaries easier to define. When OEM specifications are incomplete, it becomes unclear which party is accountable for a gap in scenario coverage.

4.5 Supplementary Findings

Table 7 shows the challenges in operating multiple standards; the most frequently cited were requirement overlap (47%), scope understanding (40%), and document integration (37%). Regarding integration approaches, 30% used ISO 26262 as a foundation, 20% operated standards independently, and 17% had no clear policy.

Assurance Case Practice. Only 11 of 30 respondents (37%) reported active use of assurance cases for ISO 26262; 10 (33%) had no plans. Plain documents were the most common format ($n = 14$), followed by Goal Structuring Notation (GSN) or Claims-Arguments-Evidence (CAE) ($n = 6$). Comments revealed mixed views: some saw long-term value but warned of "enormous effort," whereas others felt assurance cases are "still created mainly for accountability rather than genuine safety benefit."

Qualitative Themes. The free-text material was limited but useful for interpreting the quantitative results. Across the open-ended fields, we obtained 28 comments: ISO 26262 challenges (10), SOTIF challenges (4), multi-standard operation (7), assurance-case practice (4), and JASPAR activities (3). We therefore use these comments as contextual evidence rather than as a separate qualitative study.

Three themes were most relevant to the statistical findings. First, respondents repeatedly described *workload and organizational burden*, including work-product creation, resource shortages, and training difficulties; one respondent noted that "the workload doubles with each new standard" (all quotations translated from the original Japanese responses). Second, several comments pointed to *OEM–supplier coordination friction*, especially delayed or unclear upper-level requirements: "OEMs tell us to comply, but they are slow to issue upper-level safety requirements." Third, SOTIF comments reflected uncertainty about value and mandate. Respondents described SOTIF as documenting practices already performed, or noted that it is difficult to promote internally because it is "not clearly required by regulations." These comments are consistent with the quantitative findings that SOTIF has weaker contract pressure and less clear role boundaries than ISO 26262.

5 Discussion

The main practical message of this study is that the emerging challenge lies less in reallocating V-model activities than in negotiating clear SOTIF responsibilities across the OEM–supplier interface. Although the direction of the four significant findings (Section 4) may align with practitioner intuition, the effect magnitudes are large, particularly for contract pressure ($r = 0.89$, Table 4) and boundary ambiguity ($r = 0.88$). These magnitudes have not previously been quantified and are relevant for calibrating consortium-level interventions.

5.1 Interpretation

An important caveat applies: because ISO 26262 and SOTIF differ markedly in adoption maturity (93% vs. 10% active use), the observed differences may partly reflect maturity effects rather than inherent properties of the standards themselves. With this limitation in mind, the data suggest a three-stage picture.

ISO 26262 can be characterized as *institutionalized*: adoption is high (93%), and all drivers are rated highly ($M \geq 4.08$), although no single driver stood out as significantly stronger than the others. High operational burden ($M = 4.23$) combined with only moderate perceived safety improvement ($M = 3.73$) may indicate that compliance is seen as burdensome relative to its benefits.

SOTIF can be characterized as *emerging*: 70% of respondents are either using it or preparing to adopt it, but weaker contract pressure and less clear role boundaries make implementation more difficult. Qualitative comments (Section 4.5) also identify the lack of regulatory mandate as a practical obstacle.

UL 4600 remains in a *pre-adoption* stage in this sample (0 active users; 53% with no plans), likely reflecting both the Functional Safety Working Group sample composition and the absence of coercive pressure from regulatory references in Japan. Only 37% reported assurance-case use even for ISO 26262, with plain-document approaches being the most common.

These stages align with the institutional mechanisms introduced in Section 2. ISO 26262 is more strongly associated with *coercive* ($p = 0.002$) and *mimetic* pressure ($p = 0.004$) than SOTIF, for which *normative* drivers (accountability, technical safety) are more prominent. UL 4600 shows limited evidence of any pressure type in this sample.

Regarding RQ1, the effort–benefit imbalance noted in Section 4.2 is consistent with comments such as "SOTIF is mainly documenting what we already do." This comment and the boundary-clarity finding are complementary rather than contradictory: before SOTIF, the underlying activities (e.g., scenario analysis, sensor-performance evaluation) were likely performed without a dedicated standard, under ISO 26262 processes or OEM-specific requirements, without explicit responsibility allocation. SOTIF's formalization makes the previously hidden ambiguity visible, which explains why practitioners feel they are "just documenting" existing practice while simultaneously reporting unclear boundaries. With only 10% reporting active SOTIF use, many respondents may not yet have faced the challenges of situation-dependent safety reasoning for ADAS/AD functions that cannot be decomposed as in ISO 26262. This perception may change as adoption progresses. The effort–benefit imbalance nonetheless makes SOTIF harder to justify internally without the coercive pressure that drove ISO 26262.

Turning to the supply-chain perspective, qualitative responses echo the friction identified in RQ2b: suppliers are asked to comply before upper-level guidance has been fully specified, which may contribute to SOTIF boundary ambiguity.

5.2 Implications for Practice

For OEMs, timely provision of upper-level safety requirements and early clarification of SOTIF-specific role boundaries should precede demands for supplier compliance. For suppliers, building on established ISO 26262 processes when preparing for SOTIF and proactively seeking clarification of role boundaries may help reduce perceived overhead.

For industry consortia such as JASPAR, the findings point to five practical priorities:

1. *Artifact-mapping tables* that cross-reference ISO 26262, SOTIF, and UL 4600 work products (addressing requirement overlap, 47%).
2. *Terminology-harmonization guides* (terminology confusion, 33%).
3. *RACI (Responsible, Accountable, Consulted, Informed) templates for SOTIF* that define responsibility assignments at the OEM–supplier interface.
4. *Minimal safety-case templates* with reusable GSN/CAE patterns.

5. *Role-based training programs.*

Of these, responsibility-assignment templates are the most urgent given the large boundary-clarity effect ($r = 0.88$); a JASPAR working group is already developing such templates, and our results reinforce the urgency of this effort.

The JASPAR Functional Safety Working Group includes a dedicated UL 4600 study group; the pre-adoption findings reported here will serve as a baseline for its efforts to identify adoption barriers.

5.3 Threats to Validity

Internal validity Social-desirability bias was mitigated through anonymity and individual-level response instructions. Two companies contributed two respondents each (4 of 30), introducing minor non-independence. Small paired-sample sizes (SOTIF $n_{\text{pair}} = 11$–20) limit precision and may inflate effect sizes.

Construct validity Cross-standard comparisons are confounded with adoption maturity (see Section 5.1); longitudinal studies are needed to disentangle these factors. The questionnaire did not ask respondents to estimate the planned year of SOTIF adoption, so the timing gap relative to ISO 26262 may also confound the cross-standard comparison. The study scope is limited to functional and operational safety standards and does not cover adjacent standards such as ISO/SAE 21434 (cybersecurity engineering) [12] or ISO/PAS 8800 (safety and artificial intelligence) [11]; interactions with cybersecurity and AI/ML safety standards are important directions for future work.

External validity Twelve of the 40 companies did not respond and may differ systematically. Non-response bias could skew the results toward more favorable adoption perceptions. The 40 companies in the JASPAR Functional Safety Working Group include nearly all major Japanese vehicle manufacturers and leading Tier 1 suppliers active in functional-safety practice, so the 28 responding companies provide near-census coverage of the safety-engineering community within this consortium setting. However, the sample does not cover smaller suppliers, non-JASPAR firms, or regions without comparable OEM-centered supply chains. In particular, the UL 4600 findings should not be generalized to all Japanese companies.

Statistical validity Although $n = 30$ limits statistical power, the sample covers 70% of the target population. We address power limitations by reporting effect sizes, using non-parametric tests, applying Holm correction, and distinguishing robust findings from exploratory tendencies.

6 Conclusion

Using questionnaire responses from the JASPAR Functional Safety Working Group ($n = 30$, 70% company coverage), we examined how Japanese automotive safety practitioners perceive the adoption of ISO 26262, SOTIF, and UL 4600. Contract requirements and pressure to conform to industry practice appear to motivate ISO 26262 adoption more strongly than SOTIF adoption, and suppliers report stronger contract pressure than OEMs. SOTIF role boundaries are perceived as less clear than those of ISO 26262 despite similar allocation patterns. Adoption follows a three-stage pattern: ISO 26262 is institutionalized (93%), SOTIF is emerging (70% in use or preparing), and UL 4600 remains at a pre-adoption stage in this sample. High operational burden combined with uncertain benefit was a recurring concern.

Based on these findings, we identify five practical priorities for industry consortia, with SOTIF responsibility-assignment templates as the highest priority. Future work should evaluate such templates in OEM–supplier projects, track SOTIF/UL 4600 diffusion longitudinally, and replicate this study in other regions to assess transferability.

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References

1. Born, M., Favaro, J., Kath, O.: Application of ISO DIS 26262 in practice. In: Proceedings of the 1st Workshop on Critical Automotive Applications: Robustness & Safety (CARS). pp. 3–6. ACM (2010)
2. Cheng, J., Goodrum, M., Metoyer, R., Cleland-Huang, J.: How do practitioners perceive assurance cases in safety-critical software systems? In: Proceedings of the 11th International Workshop on Cooperative and Human Aspects of Software Engineering (CHASE). pp. 57–60 (2018)
3. Cusumano, M.A.: Reflections on the Toyota debacle. Communications of the ACM **54**(1), 33–35 (2011)
4. Dardar, R., Gallina, B., Johnsen, A., Lundqvist, K., Nyberg, M.: Industrial experiences of building a safety case in compliance with ISO 26262. In: 23rd IEEE International Symposium on Software Reliability Engineering Workshops, ISSRE Workshops, Dallas, TX, USA, November 27-30, 2012. pp. 349–354 (2012)
5. Diemert, S., Shortt, C., Weber, J.H.: How do practitioners gain confidence in assurance cases? Information and Software Technology **185**, 107767 (2025)
6. DiMaggio, P.J., Powell, W.W.: The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. American Sociological Review **48**(2), 147–160 (1983)
7. Fenn, J., Hawkins, R., Nicholson, M.: A new approach to creating clear operational safety arguments. In: SAFECOMP 2024 Workshops. LNCS, vol. 14989, pp. 227–238. Springer (2024)
8. Huber, M., Brunner, M., Sauerwein, C., Cârlan, C., Breu, R.: Roadblocks on the highway to secure cars: An exploratory survey on the current safety and security practice of the automotive industry. In: Computer Safety, Reliability, and Security (SAFECOMP). LNCS, vol. 11093, pp. 157–171 (2018)
9. ISO: ISO 26262:2018 Road vehicles – Functional safety (Parts 1–12) (2018)
10. ISO: ISO 21448:2022 Road vehicles — Safety of the intended functionality (2022)

11. ISO: ISO/PAS 8800:2024 Road vehicles – Safety and artificial intelligence (2024)
12. ISO/SAE: ISO/SAE 21434:2021 Road vehicles – Cybersecurity engineering (2021)
13. Kim, C., Jeong, J.H., Jo, H.J.: Detecting dynamic changes in Hyundai Motor's parts supply system as an industry latecomer: The quasi-vertical integration of internal and external networks. Journal of Asian Sociology **50**(1), 55–89 (2021). https://doi.org/10.21588/dns.2021.50.1.004
14. Kodama, H., Matsuno, Y., Takai, T., Ota, H., Okada, M., Tsuchiya, T.: A case study of continuous assurance argument for level 4 automated driving. In: SAFECOMP 2024. LNCS, vol. 14988, pp. 150–165. Springer (2024)
15. Matsuno, Y., Hayashi, M., Tsuchiya, T.: Consensus building in level 4 automated driving field trials through assurance cases. In: SAFECOMP 2025. LNCS, vol. 15954, pp. 33–47. Springer (2025)
16. Nair, S., de la Vara, J.L., Sabetzadeh, M., Falessi, D.: Evidence management for compliance of critical systems with safety standards: A survey on the state of practice. Information and Software Technology **60**, 1–15 (2015)
17. Norman, G.: Likert scales, levels of measurement and the "laws" of statistics. Advances in Health Sciences Education **15**(5), 625–632 (2010)
18. Nouri, A., Berger, C., Törner, F.: An industrial experience report about challenges from continuous monitoring, improvement, and deployment for autonomous driving features. In: Proceedings of the 48th Euromicro Conference on Software Engineering and Advanced Applications (SEAA). pp. 358–365 (2022)
19. Pavlínek, P.: Restructuring and internationalization of the European automotive industry. Journal of Economic Geography **20**(2), 509–541 (2020). https://doi.org/10.1093/jeg/lby070
20. Rosenthal, R.: Meta-Analytic Procedures for Social Research. SAGE Publications, Newbury Park, CA, 2nd edn. (1991)
21. Soleimani, M., Sari, A.A.: A unified safety framework for automated vehicle development: integrating ISO 26262, SOTIF, and UL 4600. Transportation Research Interdisciplinary Perspectives **36**, 101831 (2026)
22. Törner, F., Öhman, P.: Automotive safety case: A qualitative case study of drivers, usages, and issues. In: Proceedings of the 11th IEEE High Assurance Systems Engineering Symposium (HASE). pp. 313–322 (2008)
23. UL: UL 4600: Standard for Safety for the Evaluation of Autonomous Products (2023)
24. U.S. Department of Transportation: Toyota gas pedals: Is the public at risk? (2010), testimony before the House Committee on Oversight and Government Reform
25. de la Vara, J.L., Borg, M., Wnuk, K., Moonen, L.: An industrial survey of safety evidence change impact analysis practice. IEEE Transactions on Software Engineering **42**(12), 1095–1117 (2016)
26. Wang, H., Shao, W., Sun, C., Yang, K., Cao, D., Li, J.: A survey on an emerging safety challenge for autonomous vehicles: Safety of the intended functionality. Engineering **33**, 17–34 (2024)