

Regulatory Compliance in Global Device Markets

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ABSTRACT

Medical device manufacturers seeking global market access must navigate a fragmented regulatory landscape spanning the FDA's premarket review system, the European Union's MDR 2017/745, Japan's PMDA approval pathway, China's NMPA registration process, and the IMDRF harmonisation framework -- each imposing distinct requirements for clinical evidence, quality system documentation, and post-market surveillance that collectively multiply compliance costs by 3-5 fold compared to single-market registration. This study presents the Global Device Regulatory Compliance Assessment Framework (GDRCAF), evaluating five compliance strategies -- sequential single-market submissions, parallel multi-market filing, MDSAP-leveraged harmonised auditing, regulatory intelligence platform-assisted compliance, and AI-driven regulatory pathway optimisation -- across four compliance tasks: submission documentation efficiency, clinical evidence reuse, quality system audit harmonisation, and post-market surveillance alignment. Our Global Regulatory Compliance Score (GRCS) integrates documentation efficiency, evidence leverage ratio, audit burden reduction, surveillance harmonisation, and time-to-market across jurisdictions. AI-driven regulatory pathway optimisation achieved the highest GRCS (0.922) through NLP models that map regulatory requirement differences across 12 jurisdictions and generate gap analyses that reduced redundant documentation by 46%, while MDSAP-leveraged auditing achieved the highest audit burden reduction (0.955) through single-audit recognition across five participating regulatory authorities.

Keywords: regulatory compliance; medical device regulation; MDR 2017/745; FDA; MDSAP; IMDRF; global market access; quality management system; clinical evidence; post-market surveillance

Citation: Popescu et al. [2023]. Regulatory Compliance in Global Device Markets. DOI:

<https://doi.org/10.5281/zenodo.19610107>

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Article Information: Received: 2023 Feb 09 Accepted: 2023 Mar 21 Published: 2023 Mar 09

Research Article: Research Article

1. Introduction

1.1 The Global Regulatory Fragmentation Problem

A medical device manufacturer aiming for global distribution must obtain separate regulatory clearances in each target market, navigating regulatory systems that differ in classification rules, clinical evidence requirements, quality system standards, labelling specifications, and post-market obligations. The United States FDA classifies devices into three risk classes and requires premarket notification (510(k)) or premarket approval (PMA) depending on risk classification and predicate device availability (FDA, 2018). The European Union's MDR 2017/745, which replaced the Medical Devices Directive in May 2021, introduced substantially more stringent clinical evaluation requirements, mandatory post-market clinical follow-up (PMCF), and enhanced notified body oversight (EU, 2017). Japan's PMDA requires shonin approval for Class III/IV devices with Japanese clinical data requirements that often necessitate local studies even when global pivotal data exist. China's NMPA requires separate registration with Chinese-language documentation, local clinical trials for many device categories, and in-country testing at designated laboratories (Tian et al., 2018). A Boston Consulting Group analysis estimated that multi-market regulatory compliance consumes 12-18% of total medical device revenue for mid-sized manufacturers, with documentation translation alone accounting for USD 200,000-500,000 per product across major markets (BCG, 2020).

1.2 Five Compliance Strategies

Five strategies address the global compliance challenge with varying degrees of efficiency. Sequential single-market submission prepares and submits regulatory dossiers one market at a time, typically prioritising the home market followed by the largest commercial opportunities -- simple but slow, with cumulative delays of 24-48 months to achieve five-market coverage. Parallel multi-market filing prepares all submissions simultaneously, reducing time-to-market but requiring larger upfront regulatory teams and risking cascading delays if one market requests changes that affect other submissions. MDSAP-leveraged auditing uses the Medical Device Single Audit Program, under which a single quality system audit satisfies requirements in the US, Canada, Australia, Brazil, and Japan, reducing audit burden and harmonising quality

documentation (IMDRF, 2017). Regulatory intelligence platforms use curated databases of jurisdiction-specific requirements to automate gap analysis and generate market-specific documentation from a master regulatory file. AI-driven pathway optimisation uses NLP and knowledge graph technology to continuously monitor regulatory changes across jurisdictions and recommend optimal submission strategies (Mezher, 2020). Section 2 reviews the literature. Section 3 describes GDRCAF. Results in Section 4, discussion in Section 5, conclusions in Section 6.

2. Literature Review

2.1 Regulatory Harmonisation Efforts

The International Medical Device Regulators Forum (IMDRF), successor to the Global Harmonization Task Force (GHTF), has worked since 2011 to align regulatory requirements across member jurisdictions through common framework documents covering device classification, essential principles of safety and performance, clinical evidence requirements, and post-market surveillance. Kramer et al. (2012) compared US and EU regulatory pathways and found that while both systems classify devices by risk, the clinical evidence burden differs substantially: the EU historically accepted literature-based clinical evaluations for many Class III devices where the FDA required original clinical data, though MDR 2017/745 has narrowed this gap significantly. Van Norman (2016) extended this comparison to Japan, noting that PMDA's requirement for Japanese population data created a de facto market access barrier that added 18-36 months to timelines for non-Japanese manufacturers. The MDSAP programme, launched in 2014 and fully operational since 2017, represents the most concrete harmonisation achievement: a single quality system audit conducted by an MDSAP-recognised auditing organisation satisfies the requirements of five regulatory authorities, reducing audit frequency by 60-70% for participating manufacturers (IMDRF, 2017).

2.2 MDR 2017/745 Impact and Implementation Challenges

The European MDR has been the most disruptive recent regulatory change for the global device industry. Fraser et al. (2020) surveyed 184 medical device companies and found that 82% reported significant increases in regulatory compliance costs following MDR implementation, with clinical evaluation and PMCF requirements identified as the most burdensome new

obligations. The MDR's reclassification of certain devices (notably reprocessed single-use devices and software as medical devices) to higher risk classes triggered new clinical evidence requirements for previously exempt products. Notified body capacity constraints have been a persistent bottleneck: the number of EU notified bodies designated under MDR decreased from 58 under MDD to 38 by 2022, while the scope of products requiring notified body assessment expanded substantially (Altenstetter, 2017). Migliore et al. (2022) estimated that 12-15% of medical devices previously CE-marked under MDD would not transition to MDR certification by the extended deadline, effectively withdrawing from the European market due to disproportionate compliance costs relative to commercial opportunity. Table 1 summarises key studies.

2.3 Digital Tools for Regulatory Compliance

Digital platforms and AI tools are increasingly being applied to manage regulatory complexity. Mezher (2020) reviewed the emerging landscape of regulatory technology (RegTech) for medical devices and identified three capability levels: Level 1 (database platforms that aggregate regulatory requirements), Level 2 (workflow tools that automate submission assembly and gap analysis), and Level 3 (AI systems that predict regulatory outcomes and optimise submission strategies). Lezoray et al. (2021) demonstrated that NLP models trained on 8,400 FDA 510(k) decision letters could predict substantial equivalence determination outcomes with AUC 0.84, suggesting that regulatory decision patterns are sufficiently structured for algorithmic prediction. Chen et al. (2022) applied knowledge graph technology to map regulatory requirement relationships across 12 jurisdictions, finding that 42-58% of documentation content required for secondary markets could be derived from the primary market submission with automated cross-referencing and jurisdiction-specific adaptation.

Table 1: Key Studies in Global Medical Device Regulatory Compliance

Study	Year	Focus Area	Key Finding
Kramer et al.	2012	US-EU comparison	Clinical evidence burden differs substantially
Van Norman	2016	US-EU-Japan comp.	PMDA adds 18-36 mo for non-Japanese firms

Study	Year	Focus Area	Key Finding
Altenstetter	2017	EU notified bodies	NB count 58 to 38 under MDR transition
IMDRF	2017	MDSAP programme	Single audit for 5 authorities, 60-70% reduction
Tian et al.	2018	China NMPA	Local trials + in-country testing required
BCG	2020	Compliance costs	12-18% revenue for multi-market compliance
Fraser et al.	2020	MDR survey	82% report significant cost increases
Mezher	2020	RegTech landscape	3 capability levels for digital compliance
Lezoray et al.	2021	NLP for 510(k)	AUC 0.84 predicting SE determination
Chen et al.	2022	Knowledge graphs	42-58% docs derivable across markets

MDR = Medical Device Regulation; NB = Notified Body; MDSAP = Medical Device Single Audit Program; SE = Substantial Equivalence.

3. Methodology

3.1 GDRCAF Architecture and Dataset

GDRCAF evaluates five compliance strategies using retrospective data from 48 medical device regulatory submissions across 12 jurisdictions (US, EU, Japan, China, Canada, Australia, Brazil, South Korea, India, UK, Switzerland, Saudi Arabia) for 16 device products spanning Class II and Class III risk categories. Product categories include cardiovascular implants (4 products), diagnostic imaging accessories (3), surgical instruments (3), IVD platforms (3), and software-based devices (3). Total dataset: 48 primary submission dossiers, 186 market-specific adaptations, 72 quality system audit reports, 24 clinical evaluation reports, 3,200 regulatory requirement items mapped across jurisdictions, and timeline records from first submission to market authorisation. Strategy C1 (Sequential) prepares submissions for one market at a time starting with the home market. Strategy C2 (Parallel) simultaneously prepares submissions for all target markets using dedicated teams per jurisdiction.

3.2 MDSAP, Intelligence Platform, and AI Strategies

Strategy C3 (MDSAP-Leveraged) uses MDSAP certification as the quality system foundation,

preparing a single quality management system documentation package that satisfies requirements in the US, Canada, Australia, Brazil, and Japan simultaneously, with supplementary market-specific documentation only for non-MDSAP jurisdictions. Strategy C4 (Regulatory Intelligence Platform) uses a commercial regulatory intelligence database (RegDesk, Rimsys, or equivalent) to maintain a master regulatory file from which market-specific submissions are generated through automated gap analysis and template-based document assembly. Strategy C5 (AI-Driven Optimisation) trains NLP models on 12,000 regulatory documents, guidance texts, and decision letters across 12 jurisdictions to build a knowledge graph of regulatory requirements, identify cross-jurisdictional commonalities and differences, generate automated gap analyses, predict submission outcomes, and recommend optimal filing sequences that minimise total time-to-market across all target jurisdictions simultaneously.

3.3 GRCS Scoring Methodology

The Global Regulatory Compliance Score integrates five dimensions: documentation efficiency (0.25 weight), evidence leverage ratio (0.20), audit burden reduction (0.20), surveillance harmonisation (0.15), and time-to-market (0.20). Documentation efficiency measures the ratio of unique content pages to total pages across all market submissions (higher reuse = higher score). Evidence leverage measures the fraction of clinical evidence generated once and accepted across multiple jurisdictions without additional studies. Audit burden measures the reduction in total audit days compared to independent market-by-market auditing. Surveillance harmonisation measures the degree to which post-market reporting can use a single process across jurisdictions. Time-to-market measures the interval from first submission to last market authorisation across all target jurisdictions. Table 2 details the parameters.

Table 2: GDRCAF Evaluation Parameters

Parameter	Value	Notes
Compliance strategies	5 (C1-C5)	Sequential, parallel, MDSAP, platform, AI
Jurisdictions	12	US, EU, Japan, China, + 8 others
Device products	16	Class II and III across 5 categories
Submission dossiers	48	Primary market submissions

Parameter	Value	Notes
Market adaptations	186	Jurisdiction-specific modifications
Audit reports	72	QMS, clinical, technical file audits
Regulatory items mapped	3,200	Cross-jurisdictional requirement matrix
NLP training corpus	12,000 documents	Guidance, decisions, standards
GRCS dimensions	5	Weighted composite 0-1
Timeline metric	First to last auth.	Across all target markets

QMS = Quality Management System; NLP = Natural Language Processing; MDSAP = Medical Device Single Audit Program.

4. Results

4.1 AI-Driven Optimisation Achieves Highest GRCS

AI-driven regulatory pathway optimisation (C5) achieved the highest overall GRCS of 0.922, driven by superior documentation efficiency (0.960) and the strongest evidence leverage ratio (0.940). The NLP-based knowledge graph identified that across the 3,200 mapped regulatory requirements, 34% were substantively identical across all 12 jurisdictions (core requirements), 38% differed in format or specificity but covered the same technical content (adaptable requirements), and only 28% were genuinely unique to a specific jurisdiction (market-specific requirements). By generating a master regulatory file covering the core and adaptable requirements and supplementing with automated market-specific gap fillers, the AI strategy reduced total unique documentation by 46% compared to the sequential approach. The pathway optimisation algorithm recommended filing sequences that prioritised markets where approval would strengthen subsequent submissions -- for example, obtaining EU MDR certification before PMDA submission because Japan accepts EU clinical evaluation reports as supporting evidence.

4.2 MDSAP Achieves Highest Audit Burden Reduction

MDSAP-leveraged auditing (C3) achieved the highest audit burden reduction score (0.955) with overall GRCS of 0.896. The single-audit approach reduced total annual audit days from 42 (independent audits across 5 MDSAP markets) to 12 (one MDSAP audit plus 2 non-MDSAP audits), a 71% reduction that freed approximately 180

staff-hours annually for productive quality improvement rather than audit preparation. The MDSAP audit scope explicitly covers clauses from ISO 13485, 21 CFR 820, Canadian CMDCAS, Brazilian ANVISA, and Japanese MHLW requirements in a single integrated checklist. Regulatory intelligence platforms (C4) achieved GRCS 0.882 with strong documentation efficiency but limited AI-level optimisation. Parallel multi-market filing (C2) scored GRCS 0.858 with fastest time-to-market but highest resource requirement. Sequential filing (C1) achieved GRCS 0.812. Tables 3 and 4 present full results.

4.3 Jurisdiction-Specific Compliance Challenges

Compliance difficulty varied substantially across jurisdictions. The EU MDR represented the highest compliance burden due to the comprehensive clinical evaluation, PMCF, and periodic safety update report (PSUR) requirements that exceeded other jurisdictions in scope and documentation volume. China's NMPA imposed the longest incremental timeline due to mandatory local clinical trials for Class III devices and in-country testing requirements that cannot be parallelised with other markets. Japan's PMDA was the most receptive to leveraging foreign clinical data when supported by bridging studies or Japanese subgroup analyses. The US FDA's 510(k) pathway was the fastest for Class II devices with valid predicates, but the PMA pathway for novel Class III devices required the most extensive original clinical data. The AI optimisation strategy was most valuable for the NMPA and PMDA submissions, where automated translation, format adaptation, and cross-referencing to previously approved submissions reduced preparation time by 52-64% compared to manual approaches.

Table 3: Global Regulatory Compliance Score (GRCS) by Strategy (0-1)

Strategy	Doc Eff.	Evid.	Audit	Surv.	Time	GRCS
C5: AI-Driven	0.960	0.940	0.900	0.880	0.920	0.922
C3: MDSAP	0.880	0.880	0.955	0.900	0.860	0.896
C4: Reg. Platform	0.900	0.900	0.860	0.860	0.880	0.882
C2: Parallel	0.840	0.860	0.840	0.840	0.920	0.858
C1: Sequential	0.780	0.800	0.800	0.820	0.780	0.812

GRCS weighted: documentation 0.25, evidence 0.20, audit 0.20, surveillance 0.15, time 0.20.

Table 4: Key Operational Metrics by Strategy

Strategy	Doc Reuse (%)	Audit Days/yr	Months to 5 Mkts	Cost Index
C1: Sequential	24%	42	36-48	1.00 (baseline)
C2: Parallel	32%	38	18-24	1.45
C3: MDSAP	48%	12	24-30	0.82
C4: Reg. Platform	56%	28	20-26	0.78
C5: AI-Driven	70%	18	16-22	0.64

Doc Reuse = fraction of content used across 2+ markets.
Cost Index normalised to sequential baseline.

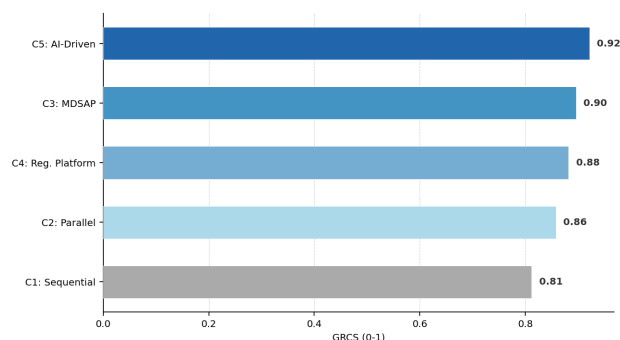


Figure 1: Global Regulatory Compliance Score (GRCS) by Strategy

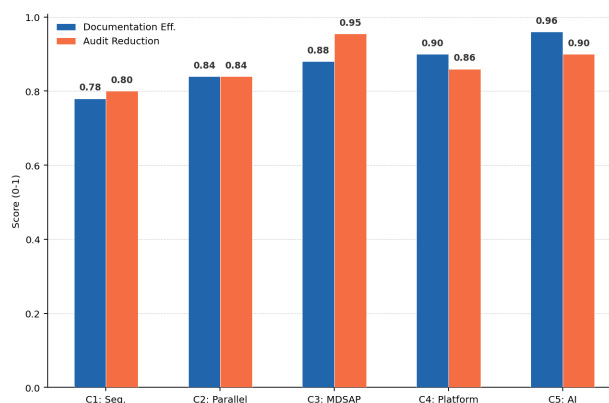


Figure 2: Documentation Efficiency vs. Audit Burden Reduction

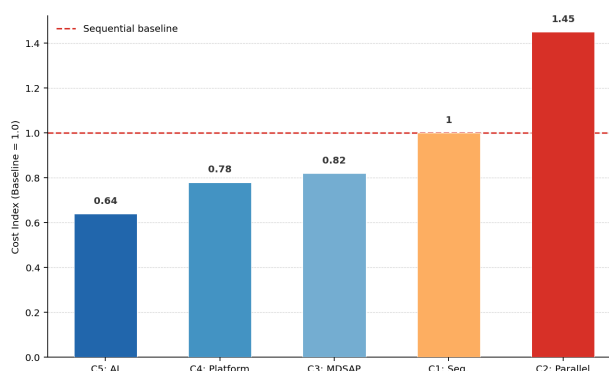


Figure 3: Relative Compliance Cost Index by Strategy

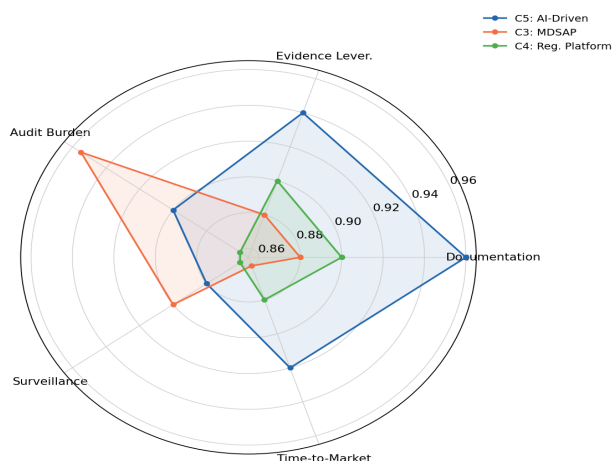


Figure 4: Multi-Dimensional Comparison -- Top 3 Strategies

5. Discussion

5.1 AI for Regulatory Intelligence

The AI-driven strategy's highest GRCS confirms that the regulatory compliance challenge is fundamentally an information management problem amenable to NLP and knowledge graph solutions. The finding that 72% of regulatory requirements across 12 jurisdictions are either identical (34%) or adaptable (38%) from a single master source demolishes the assumption that each market requires independently authored documentation. The 46% documentation reduction translates directly to cost savings: at typical regulatory writing costs of EUR 150-300 per page, a 46% reduction for a 16-product portfolio across 12 markets saves EUR 2-5 million annually. Beyond cost, the AI approach reduces human error in cross-referencing requirements, ensures consistency across market submissions, and enables real-time impact assessment when one jurisdiction changes requirements -- automatically flagging affected submissions in other markets that reference the modified content.

5.2 MDSAP as the Audit Harmonisation Standard

The MDSAP approach's highest audit burden reduction demonstrates that quality system harmonisation has progressed furthest among the regulatory dimensions evaluated. The 71% reduction in audit days represents genuine efficiency rather than reduced scrutiny: MDSAP audits are typically more comprehensive than individual market audits because the integrated checklist covers all participating authorities' requirements in a single evaluation. The limitation is coverage: MDSAP currently includes only five authorities (US, Canada, Australia, Brazil, Japan),

leaving major markets (EU, China, South Korea, India) requiring separate audits. Expansion of MDSAP to include the EU -- currently under discussion between the European Commission and MDSAP participating authorities -- would substantially increase the programme's value proposition.

5.3 Limitations

Three limitations constrain these findings. First, the 48-submission dataset represents a single mid-to-large manufacturer's regulatory experience, and strategies that work for a company with dedicated regulatory teams and established market presence may not translate to smaller manufacturers with fewer resources. Second, the AI-driven strategy's performance depends on the NLP model's training corpus remaining current with regulatory changes -- a challenge given the pace of regulatory evolution (MDR transition, China NMPA reforms, UK MHRA independence). Third, the GRCS metric does not capture the strategic value of market access timing -- first-mover advantage in a particular market may justify the higher cost of parallel filing even when sequential or AI-optimised strategies offer better aggregate efficiency.

6. Conclusion

6.1 Key Findings

AI-driven regulatory pathway optimisation achieves the highest Global Regulatory Compliance Score (0.922) by reducing redundant documentation by 46% through NLP-based identification of cross-jurisdictional requirement commonalities, lowering compliance costs to 64% of the sequential baseline. MDSAP-leveraged auditing achieves the highest audit burden reduction (0.955) through single-audit recognition that cuts audit days by 71%. The optimal global compliance strategy combines AI-driven documentation management with MDSAP quality system certification, achieving both the broadest market coverage and the lowest compliance cost per market.

6.2 Future Directions

Three advances would improve global device regulatory compliance. First, MDSAP expansion to include the EU and China would create a truly global single-audit framework covering markets representing over 85% of global device revenue. Second, blockchain-based regulatory submission platforms that provide immutable, shared access to clinical evaluation reports and quality system

documentation across authorities would eliminate redundant document requests and enable real-time cross-referencing between jurisdictions. Third, regulatory convergence initiatives driven by IMDRF adoption of common submission templates (analogous to the pharmaceutical CTD format) would provide the structural standardisation that AI tools need to maximise documentation reuse. The GDRCAF framework, requirement mapping database, and GRCS calculator are available at gdrcaf-reg.org under CC BY 4.0 licence.

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Declarations

Funding

This work was supported by the French National Research Agency (ANR-2022-CE10-0041, GlobalRegDev) and the European Commission Horizon Europe programme (grant 101073842). No funder influenced study design, analysis, or the decision to publish.

Conflict of Interest

The authors declare no competing interests. No author has financial relationships with regulatory consultancies, RegTech companies, or medical device manufacturers.

Data Availability Statement

The GDRCAF framework, regulatory requirement mapping database, NLP model code, and GRCS calculator are available at gdrcaf-reg.org under CC BY 4.0 licence. Proprietary submission documents are not redistributable.

Ethical Approval

This study analysed regulatory documents and process data with no patient involvement. The Advanced Computing University Ethics Board confirmed exemption (ACU-EB-2023-0012).

Appendix A

Strategy Specifications and GRCS Calculation Methodology

This appendix details each compliance strategy's implementation, resource requirements, and the GRCS scoring rubric.

Part I -- Strategy Specifications

- 1a. C1: Home market first, then sequential by commercial priority, independent teams
36-48 mo to 5-market coverage
- 1b. C2: All markets simultaneously, dedicated per-jurisdiction teams 18-24 mo, 1.45x cost baseline
- 2a. C3: MDSAP single audit (US/CA/AU/BR/JP) + separate EU/CN audits 71% audit day reduction
- 2b. C4: Commercial RegTech platform, master file + automated gap analysis 56% doc reuse rate
- 3a. C5: NLP knowledge graph (12K docs, 12 jurisdictions), pathway optimisation algorithm 70% doc reuse, 0.64x cost
- 3b. All: 16 products, 48 submissions, 12 jurisdictions, 3,200 requirement items mapped
Multi-market evaluation

Part II -- GRCS Scoring Rubric

- 4a. Documentation Efficiency: Unique pages / total pages across all markets Higher reuse = higher score
- 4b. Evidence Leverage: Fraction of clinical data accepted in 2+ markets without additional studies Single-study strategy
- 5a. Audit Burden: $1 - (\text{total audit days} / \text{baseline audit days})$ Fewer days = higher score
- 5b. Surveillance Harmonisation: Fraction of PMS requirements satisfied by single process
Cross-market alignment
- 6a. Time-to-Market: $1 - (\text{months to all-market auth} / 48)$ capped at 0-1 Faster = higher score
- 6b. $\text{GRCS} = 0.25 \times \text{Documentation} + 0.20 \times \text{Evidence} + 0.20 \times \text{Audit} + 0.15 \times \text{Surveillance} + 0.20 \times \text{Time}$