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A Malaysian CRS-Vehicle Compatibility Assessment Framework: Development and Application of the FitSURE Program

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ABSTRACT – *Child Restraint System (CRS) effectiveness depends not only on regulatory compliance but also on correct installation and compatibility with vehicle seating systems. This study presents the development and application of the FitSURE Programme (Fitment of Child Restraint Systems in Vehicles), a Malaysian-specific framework designed to assess CRS–vehicle compatibility under real-world conditions. FitSURE is based on structured physical installation trials of CRS models commonly available in Malaysia across representative passenger vehicles. Installations were evaluated using standardised fit, placement, and securing criteria aligned with ASEAN NCAP installation checks, and categorized as Pass, Fail, or Not Applicable. A total of 986 CRS installation cases were assessed. Results showed that second-row outboard seats achieved the highest compatibility, while center and third-row seats exhibited greater structural constraints. When adjusted for applicability, pass rates exceeded 85% across most CRS categories. FitSURE complements existing assessment frameworks by providing vehicle-specific guidance that supports informed CRS selection and safer child occupant protection in Malaysia.*

KEYWORDS: *Child Restraint System (CRS), Vehicle compatibility, CRS installation, child occupant safety, FitSURE*

1. INTRODUCTION

Child occupant safety remains a critical priority in global road safety policy, particularly as road traffic injuries continue to be a leading cause of preventable death among children worldwide (WHO, 2018). The effectiveness of Child Restraint Systems (CRS) in protecting children has been well established, with proper and correct CRS usage significantly reducing the risk of fatal and serious injury during vehicle crashes by up to 70% (Durbin et al., 2003; NHTSA, 2011). However, growing evidence indicates that compliance with CRS regulations alone does not ensure effective real-world protection.

High rates of CRS misuse have been consistently reported across diverse regulatory environments. Observational studies in the United States and Australia have documented misuse rates ranging from 70% to over 85%, with frequent errors including loose installation, incorrect belt routing, and improper recline angles (Koppel et al., 2008; NHTSA, 2011; Tsai & Perel, 2009). Malaysian studies conducted following the introduction of mandatory national CRS regulation similarly reported low rates of correct installation, despite increased awareness and ownership (Paiman et al., 2018). These findings demonstrate that regulatory enforcement and CRS availability do not automatically translate into correct or optimal use.

Recent research increasingly recognizes that CRS misuse is not solely a behavioural issue but is also influenced by structural incompatibilities between CRS design and vehicle seating geometry. Empirical studies have identified seat contour mismatch, limited belt length, ISOFIX anchorage accessibility, buckle stalk positioning, and insufficient floor support for load-leg systems as significant constraints on proper installation (Bing et al., 2015; Klinich et al., 2014). Dimensional mismatch analyses further indicate that installation difficulties may persist even among trained users (CChIPS, 2020). These findings suggest that installation feasibility is influenced by the interaction between CRS design and vehicle architecture, rather than by user knowledge alone.

Several international assessment programs have been introduced, which incorporate usability and installation considerations alongside crash performance evaluation. Australia's Child Restraint Evaluation Program (CREP) integrates dynamic crash testing with usability scoring to address the potential for misuse (Bilston & Brown, 2007; Kelly et al., 1996). Japan's CRS assessment framework combines crash performance with installation evaluation (Ono et al., 2003), while the National Highway Traffic Safety Administration (NHTSA) in the United States developed Ease-of-Use ratings to assess installation clarity and misuse risk (Macy et al., 2023). Within the ASEAN region, the ASEAN New Car Assessment Programme (ASEAN NCAP) includes CRS installation checks as part of its Child Occupant Protection (COP) assessment to encourage vehicle manufacturers to account for CRS compatibility during design (Husain et al., 2020).

In Malaysia, the mandatory CRS regulation introduced in 2020 significantly increased public awareness and adoption (Ang et al., 2020). However, the Malaysian vehicle landscape comprises compact hatchbacks, sedans, sport utility vehicles (SUVs), and multi-purpose vehicles (MPVs), each with varying anchorage configurations, seat geometries, and floor designs. Certification standards such as UN R44 and UN R129 ensure crashworthiness but do not assess installation feasibility across the full range of real-world seating environments. Consequently, installation success depends not only on regulatory compliance but also on structural compatibility between CRS design and specific seating positions.

Addressing this limitation requires a systematic, empirical approach to evaluating CRS–vehicle compatibility under practical installation conditions. This study presents the development and application of the FitSURE Programme (Fitment of Child Restraint Systems in Vehicles), a structured compatibility assessment framework tailored to the Malaysian market. FitSURE evaluates CRS–vehicle interactions through controlled physical installation trials and classifies each CRS–vehicle–seating position combination as Pass, Fail, or Not Applicable, thereby distinguishing installation failure from structural inapplicability.

A total of 986 CRS installation cases were assessed across representative passenger vehicles and commonly available CRS models. By translating installation feasibility into seating-position-specific compatibility matrices, this study provides empirical evidence of the structural constraints that affect CRS installation in the Malaysian vehicle context.

The contribution of this study is threefold. First, it introduces a structured compatibility categorization framework that explicitly differentiates between installation failure and vehicle design inapplicability. Second, it provides large-scale empirical data on CRS–vehicle compatibility across multiple seating positions and installation systems. Third, it demonstrates how compatibility-focused assessment complements existing regulatory and regional safety initiatives by bridging the gap between certification compliance and real-world usability. Through this approach, the FitSURE framework strengthens the evidence base for practical child-occupant protection and supports informed CRS selection across diverse vehicle environments.

2. METHODOLOGY

This study adopted an empirical, installation-based assessment design to evaluate CRS–vehicle compatibility under real-world conditions. Compatibility was operationalized as the ability to achieve correct placement and secure installation within defined vehicle seating positions.

2.1 Sampling

Passenger vehicles were selected using purposive sampling to represent high-market-share vehicle segments in Malaysia, including hatchbacks, sedans, SUVs, and MPVs. CRS models were selected based on commercial availability and representation across major restraint categories (infant carrier, convertible, combination, and high-back booster), incorporating both seatbelt-based and ISOFIX-based systems. A total of 986 CRS-vehicle-seating position installation cases were evaluated.

2.2 Compatibility Assessment Workflow

The structured compatibility assessment workflow is illustrated in Figure 1. For each CRS-vehicle-seating position combination, the assessment followed a sequential decision process:

1. Identification of seating position and installation permissibility;
2. Fit and placement evaluation;
3. Installation and securing assessment; and
4. Classification as Pass, Fail, or Not Applicable (N.A.).

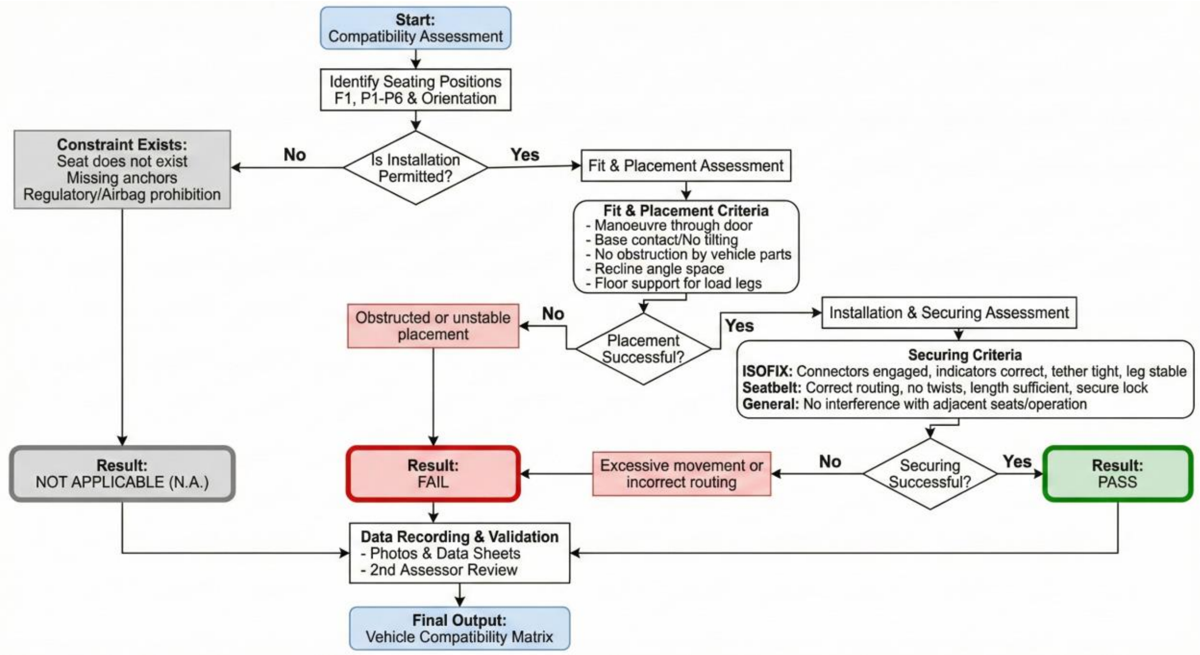

FIGURE 1: Structured CRS-vehicle compatibility assessment workflow

Each CRS was physically installed in the selected vehicle models by trained assessors from the Malaysian Institute of Road Safety Research (MIROS). Installations were conducted strictly in accordance with CRS manufacturer instructions and vehicle owner manuals. Where applicable, both seatbelt and ISOFIX installation methods were evaluated. Key installation aspects observed during the process included seat contour alignment, base stability, belt path accessibility, recline-angle compliance, ISOFIX connector engagement, top-tether routing, and load-leg floor support.

Installation permissibility was first verified to account for structural or regulatory constraints, including the absence of anchorage points or airbag restrictions. Where installation was permitted, fit and placement criteria were assessed, including base contact stability, the absence of obstructions, recline-angle feasibility, and, where applicable, load-leg floor support.

Installations that satisfied placement criteria proceeded to securing an evaluation. ISOFIX-based systems were assessed for connector engagement, indicator confirmation, tether tension, and load-leg stability. Seatbelt-based systems were evaluated for correct routing, absence of twisting, adequate belt length, and secure locking. Movement along the belt path exceeding 2 cm under standardised push–pull testing was classified as a failure of the securing criterion.

Installations were performed under controlled conditions to ensure consistency across assessments. Photographic documentation was collected for each installation to support verification and review.

2.3 Compatibility Categorization

Each CRS–vehicle seating combination was classified into one of three outcomes:

- **Pass**, indicating that the CRS could be installed safely and securely with all assessment criteria satisfied;
- **Fail**, indicating that one or more critical criteria could not be met, such as improper fit, insecure attachment, or inability to achieve the required recline angle;
- **Not Applicable (N.A.)**, indicating that installation was not feasible due to vehicle design constraints, absence of anchorage points, or manufacturer or regulatory restrictions, rather than CRS performance limitations.

This categorization was designed to deliver clear, practical outcomes while maintaining technical accuracy.

2.4 Data Recording and Validation

All installation outcomes were recorded using structured data sheets accompanied by photographic evidence. To ensure reliability and minimize subjective bias, each assessment was independently reviewed by a second trained assessor. Any discrepancies were resolved through consensus discussion. The validated results were subsequently compiled into CRS–vehicle compatibility matrices used to support analysis and reporting.

3. RESULTS AND DISCUSSION

3.1 Compatibility Outcomes Across Seating Positions

The FitSURE assessment evaluated 986 CRS installation cases across selected passenger vehicles and seating positions. Overall results showed that second-row outboard seating positions consistently achieved the highest compatibility rates, followed by front passenger seats where permitted. In contrast, second-row center seats and third-row seats recorded lower compatibility, with a higher proportion of *Fail* and *Not Applicable* outcomes due to physical and structural constraints.

Table 1 presents a heatmap of CRS–vehicle compatibility rates by seating position. Second-row outboard seats (P1 and P3) demonstrated consistently high compatibility, with adjusted pass rates exceeding 99%. In contrast, the second-row center seat (P2) recorded the lowest compatibility rate (39.2%), indicating substantial installation constraints. Third-row outboard seats (P4 and P6) showed moderate to high compatibility (88.9%), reflecting conditional feasibility depending on CRS design and vehicle geometry.

TABLE 1: Seating position compatibility heatmap, based on compatibility rate (%)

Seating position		Total Assessment	Pass, n (%)	Fail, n (%)	N.A., n (%)	Compatibility rate (%)
F1	Front passenger	203	78 (38.4)	2 (1.0)	123 (60.6)	97.5
P1	2nd row right	215	214 (99.5)	1 (0.5)	0	99.5
P2	2nd row center	209	51 (24.4)	79 (37.8)	79 (37.8)	39.2
P3	2nd row left	215	214 (99.5)	1 (0.5)	0	99.5
P4	3rd row right	72	48 (66.7)	6 (8.3)	18 (25.0)	88.9
P6	3rd row left	72	48 (66.7)	6 (8.3)	18 (25.0)	88.9

95-100	80-94.9	60-79.9	<60

Adjusted compatibility rate (Pass % excluding N.A. cases)

Seating position is critical to CRS-vehicle compatibility, with outboard seats demonstrating substantially higher installation feasibility than center seating positions. The consistently high compatibility observed in second-row outboard seats aligns with previous studies highlighting favorable belt geometry, seat width, and anchorage accessibility in these locations (Bing et al., 2015; Klinich et al., 2014). In contrast, the second-row center seat showed markedly lower compatibility, likely due to narrower seat pans, elevated contours, and unfavorable buckle positioning, factors widely documented as contributors to CRS installation difficulty (Brown et al., 2010; Koppel et al., 2008).

These findings are consistent with previous studies that identified seat geometry, cushion width, and anchorage accessibility as key determinants of successful CRS installation. Bing et al. (2015) and Klinich et al. (2014) similarly reported reduced compatibility in center seating positions due to narrow seat pans, unfavorable buckle locations, and contour mismatch. The FitSURE results reinforce the need for seating-position-specific guidance, as compatibility cannot be assumed uniformly across all seats within a vehicle.

3.2 Influence of CRS Design and Installation Method

Seatbelt-only CRS installations demonstrated comparatively high pass rates across a wide range of seating positions. CRS models equipped with ISOFIX and load-leg systems achieved high compatibility when installed in suitable seating positions but also recorded a greater proportion of *Not Applicable* outcomes, primarily due to vehicle floor design constraints and anchorage availability.

This pattern aligns with international findings that ISOFIX-based systems, while effective and user-friendly, are more sensitive to vehicle design limitations (Bing et al., 2015; Klinich et al., 2014). Studies have shown that load-leg compatibility is particularly dependent on floor geometry and underfloor structures, which vary across vehicle platforms. The FitSURE results, therefore, reflect structural feasibility rather than limitations in CRS performance.

3.3 CRS Category and Certification Standard

When *Not Applicable* cases were excluded, overall pass rates exceeded 85% across most CRS categories, indicating that correct installation is achievable when CRS are matched to appropriate seating positions. High-back booster seats recorded the highest pass rates, while combination and convertible CRS showed moderate compatibility, reflecting their broader range of installation configurations and space requirements.

Differences observed between R44 and R129 CRS were primarily influenced by installation characteristics rather than safety performance. R129 CRS, which more frequently incorporates ISOFIX and load-leg features, showed a higher proportion of *Not Applicable* outcomes. Similar trends have been observed in previous research, where advanced restraint technologies improved ease of use but reduced flexibility across diverse vehicle environments (Bilston & Brown, 2007; NHTSA, 2011). These findings highlight the importance of vehicle-specific compatibility assessment alongside certification standards.

3.4 Interpretation of Not Applicable Outcomes

A key contribution of the FitSURE framework is its distinction between *Fail* and *Not Applicable* outcomes. *Not Applicable* cases reflect vehicle design constraints, such as the absence of ISOFIX anchorages, insufficient floor support for load legs, or manufacturer restrictions on certain seating positions. These outcomes do not indicate deficiencies in CRS design or performance.

Previous studies have emphasized that incompatibility is often structural rather than user-driven. Tsai and Perel (2009) and Bing et al. (2015) reported that even trained users encountered installation difficulties when CRS geometry conflicted with vehicle seat design. By clearly identifying these constraints, FitSURE prevents misinterpretation of results and supports more accurate consumer decision-making.

3.5 Implications for Child Occupant Safety Practice

The FitSURE results reinforce established evidence that CRS misuse and incompatibility are influenced by both human and structural factors. While user education remains important, compatibility limitations cannot always be resolved through training alone (Durbin et al., 2003; Koppel et al., 2008). Therefore, providing clear, vehicle- and seat-specific guidance is critical to improving real-world CRS use.

In this context, FitSURE complements existing regional initiatives, such as ASEAN NCAP, by extending technical installation assessments into practical, market-relevant guidance. Similar to international usability-focused programs such as CREP and NHTSA's Ease-of-Use ratings, FitSURE translates complex installation constraints into actionable information that supports parents, retailers, and safety practitioners (Brown et al., 2010; NHTSA, 2011).

Overall, integrating empirical installation data with a structured compatibility categorization demonstrates that high levels of CRS installation success are achievable when appropriate seating positions are selected. The FitSURE Programme, therefore, represents a practical advancement in local child occupant safety efforts, strengthening the link between regulatory compliance and everyday CRS usability in Malaysia.

4. CONCLUSION

This study presented the development and application of the FitSURE Programme as a Malaysian-specific framework for assessing the compatibility of Child Restraint Systems (CRS) with vehicles. Through structured physical installation trials across commonly used Malaysian vehicles, FitSURE provides empirical evidence that CRS compatibility varies substantially by seating position, installation method, and CRS design characteristics.

The findings demonstrate that high installation success rates are achievable when CRS are matched to appropriate seating positions. Second-row outboard seats consistently offered the most favorable installation environment, while center and third-row seats presented greater structural constraints. Importantly, the distinction between *Fail* and *Not Applicable* outcomes clarifies that many installation limitations arise from vehicle design constraints rather than deficiencies in CRS performance or safety certification.

FitSURE complements existing regulatory and assessment frameworks, including ASEAN NCAP, by extending technical installation evaluations into practical, vehicle-specific guidance relevant to everyday use in the Malaysian market. While regulatory standards ensure crashworthiness, FitSURE addresses real-world fitment feasibility, thereby strengthening the link between compliance and effective CRS use.

By translating complex CRS–vehicle interactions into clear compatibility outcomes, the FitSURE Programme supports informed decision-making for parents, caregivers, retailers, and safety practitioners. Overall, FitSURE represents a meaningful contribution to Malaysia's child occupant safety ecosystem by reducing installation uncertainty, improving CRS usability, and promoting safer travel for child passengers.

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