

University of Wales Trinity Saint David

School of Engineering



Reduction of Interior Damage to Improve
Delivered Quality for Aston Martin St Athan
BEng Manufacturing Systems Engineering
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Tia Ball

2220258

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Declaration and Acknowledgements

Declaration of Authenticity

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

Signed: Tia Ball

Date: 01/06/2026

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Abstract

Interior cosmetic damage is a significant delivered-quality concern in low-volume luxury automotive manufacturing, where customer expectations for visible and tactile finish are high. This dissertation evaluates whether the introduction of temporary protective covers reduced in-scope interior damage at Aston Martin St Athan. The intervention was assessed using a retrospective before-and-after evaluation comparing internal damage and warranty data from January 2022 to December 2023 against January 2024 to December 2025.

Internal results showed that the proportion of vehicles with at least one interior damage call reduced from 71.4% to 44.3%, representing a 37.9% relative reduction and exceeding the target reduction of 15%. However, total internal repair/rework time increased from 3195.97 hours to 4025.90 hours, while estimated internal labour repair cost increased from £111,890.79 to £140,946.76. Warranty cost also increased substantially from £49,163.34 to £636,384.36, indicating that internal prevalence improvement did not translate into reduced downstream cost. The findings suggest that protective covers are partially effective but not yet optimised. Further work should focus on cover design, adherence, cleanliness, removal timing, missed internal detection, transport handling and warranty coding.

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1 Introduction to Aston Martin Lagonda and the St Athan Facility

Aston Martin Lagonda is a British manufacturer positioned within the ultra-luxury vehicle sector, where brand value is closely tied to craftsmanship, design integrity, and the customer's perception of quality. Within this segment, the standard expected by customers typically extends beyond functional performance and durability to include visual appearance, tactile feel, and consistency of fit and finish across the whole vehicle. These expectations place particular emphasis on manufacturing quality systems, because customer perception can be affected by defects that would be considered minor in higher-volume markets.

To support its product strategy and broaden its market presence, Aston Martin expanded its manufacturing footprint to include the St Athan facility in Wales. The St Athan site was established to support production of the DBX programme and to enable entry into the luxury SUV market, where customers evaluate refinement, finish quality, and delivered condition to a very high standard. The operational environment at St Athan is therefore characterised by low-volume production with a high level of manual content and bespoke specification variation, which increases both complexity and the importance of standardised, repeatable processes. In this context, delivered quality is a key business requirement: it influences customer satisfaction at handover, dealer workload, warranty exposure, and brand perception, while also affecting internal cost through rectification and disruption.

Manufacturing quality within a luxury environment is not defined solely by dimensional conformance or functional checks. It also depends on effective control of customer-perception defects and the consistency with which processes prevent cosmetic issues from being introduced as the vehicle progresses through assembly, audit, rectification, and final preparation. As a result, engineering projects that strengthen process control and reduce preventable defects can contribute directly to business performance and delivered-quality outcomes.

1.1 Motivation of Research

The motivation for this research stems from the costs, disruptions, and reputational risks associated with cosmetic interior defects in a low-volume luxury manufacturing environment. In a premium product, the cabin is the primary customer interface: occupants interact continuously with visible and tactile surfaces such as leather, decorative trims, consoles, and door panels. Consequently, even relatively small marks can be judged unacceptable, particularly if they are visible under normal lighting or occur in high-attention zones. From an operational perspective, interior defects can therefore carry disproportionate consequences. Rectification may require repair activities, replacement of high-value assemblies, repeated inspection cycles, and additional vehicle movement through the repair and confirmation stages. Beyond direct cost, this creates hidden waste through re-handling, extended cycle time, capacity loss, and reduced first-time-through performance. This aligns with cost-of-poor-quality theory, where internal failures, rework, external failures and warranty claims are treated as business losses created by non-conformance and preventable process variation (Crosby, 1979; Feigenbaum, 1991; Juran and Godfrey, 1999).

Operational evidence supports the problem's relevance. The 2025 interior dataset available for this dissertation contains 446 records with a total recorded cost of approximately £190,738, demonstrating that interior cosmetic issues remain a material cost exposure and therefore represent a meaningful improvement opportunity. The distribution of defects is not uniform; a relatively small number of categories and locations account for a significant share of the total cost, indicating that a focused approach targeting dominant mechanisms and high-impact touchpoints is more likely to deliver measurable improvement than broad, non-specific actions.

A further motivation arises from how cosmetic issues are classified and managed in practice. Downstream assessment, particularly at dealer level, may treat certain leather surface defects as damage requiring rectification even when internal systems record them as "Imperfections". In practical terms, scuffing and surface marring on leather are often indistinguishable to the customer from handling-induced damage, and they trigger the same operational response: rework, repair, or replacement. For this reason, the scope of the dissertation focuses on preventable cosmetic defects and includes defects recorded as "Damaged", as well as leather "Imperfection" records where the defect mechanism is consistent with contact-induced scuffing or marring. Defects that are not practically preventable through production process controls within the study timeframe, such as fraying/splitting or inherent non-contact material variation, are excluded to maintain feasibility and ensure actions remain within manufacturing influence.

From a technical standpoint, interior damage is suitable for an applied engineering dissertation because it can be linked to identifiable mechanisms and controllable factors. Common mechanisms include abrasion and scratching from sliding contact, scuffing from repeated handling, indentation from localised impact, contamination and staining from environmental or cleaning interactions, and vibration-related fretting, where protective layers or adjacent parts move relative to one another. These mechanisms are influenced by process variables such as handling sequence and touch frequency, part presentation and packaging, selection and retention of protective materials, tool/fixtures interfaces, and workplace ergonomics. A mechanism-led perspective therefore enables countermeasures to be selected and tested based on physical cause-and-effect rather than relying solely on inspection or generic behavioural reminders (Bhushan, 2013; Montgomery, 2019).

Overall, the motivation for this dissertation is to reduce preventable interior cosmetic defects at St Athan using a structured, evidence-based approach that prioritises the highest-impact issues, develops production-feasible countermeasures, and evaluates effectiveness without an unacceptable increase in cost or throughput penalty. This focus aligns with the expectations of an industrial engineering project that applies appropriate methodology and critical evaluation to a real-world manufacturing problem.

1.2 Delivered Quality and Operational Drivers

Within the ultra-luxury vehicle sector, delivered quality is a primary determinant of customer satisfaction because the customer experience is influenced strongly by visible finish and tactile interaction, particularly within the cabin. Unlike many functional defects, cosmetic defects are judged immediately and subjectively, and customer tolerance is typically low when expectations are defined by premium pricing and brand positioning. In this context, perceived quality is influenced not only by functional reliability but also by visual, tactile and craftsmanship-related attributes that shape customer judgement at handover (Garvin, 1984; Stylidis, Wickman and Söderberg, 2015). As a result, manufacturing quality must be managed not only through conformance to technical specifications, but also through robust control of appearance-related outcomes that influence perceived craftsmanship and refinement at handover. This is consistent with the view that product quality is multidimensional, including not only conformance and performance but also aesthetics and perceived quality (Garvin, 1987).

From an operational perspective, interior cosmetic defects represent a cost-of-poor-quality driver that extends beyond the direct repair or replacement of damaged components. Interior

damage can generate repeat handling, rework loops, additional inspection, and disruption to planned flow, which increases labour demand and reduces first-time-through performance. These effects align with established cost-of-poor-quality principles, where internal failure costs, external failure costs, appraisal activity and prevention activity must be considered together when assessing the business impact of defects (Feigenbaum, 1991; Juran and Godfrey, 1999; Oakland, 2014). In low-volume environments, these effects are amplified because skilled labour is a constrained resource, and because rework activity is often performed on high-value assemblies with limited tolerance for secondary damage. Consequently, the financial impact of interior damage includes both the visible costs captured in repair records and the less visible opportunity costs associated with capacity loss and schedule risk.

Interior damage is also a systems problem rather than a single-point failure. Defects can be introduced during installation, during subsequent downstream operations, during rework activity, or during vehicle movement and preparation for delivery. This means that a reliance on final inspection alone will not provide a sustainable solution; inspection can contain defects but does not prevent them being created. More robust performance is typically achieved by targeting the mechanisms of damage and controlling exposure through engineered measures, for example improved part presentation, protection strategy, and tool/fixtures interfaces, supported by standardised work and visual management. In practice, effective countermeasures tend to be those that reduce the opportunity for contact or reduce the severity of contact, rather than those that depend solely on behavioural compliance under time pressure.

These business and operational drivers justify a mechanism-led improvement approach that prioritises preventable cosmetic defects and validates countermeasures under realistic production constraints. The project's success criteria therefore reflect the need to deliver measurable delivered-quality improvement while maintaining practical feasibility, including limits on unit-cost increase and the requirement to avoid negative throughput impact.

1.3 Project Aim, Objectives and Success Criteria

1.3.1 Aim

The aim of this dissertation is to evaluate whether the introduction of temporary protective covers reduced in-scope cosmetic interior damage at Aston Martin St Athan, and to identify further actions required where the results indicate that the current protection strategy is not fully effective. The project focuses on delivered-quality improvement by comparing internal damage performance before and after the introduction of protection, considering both vehicle-level damage prevalence and the operational burden associated with repair/rework time and labour cost.

1.3.2 Objectives

To meet this aim, the dissertation first defines the operational scope of in-scope interior damage, including the defect types and protected components relevant to the protective cover intervention. It then establishes a pre-intervention baseline using internal production damage data and warranty cost information from January 2022 to December 2023. Post-intervention performance is then evaluated using comparable internal and warranty data from January 2024 to December 2025.

The dissertation evaluates the intervention using volume-normalised measures so that changes in production volume do not distort the comparison between the pre- and post-intervention periods. The primary measure is the proportion of vehicles with at least one in-scope interior damage call. Secondary measures include defect quantity, defects per vehicle (DPV), repair/rework time, estimated internal labour repair cost and warranty cost. Warranty cost is interpreted separately as a lagging delivered-quality indicator because it can be influenced by claim severity, repair route, dealer labour rates, replacement decisions, transport damage and warranty coding.

A further objective is to interpret whether the protective covers delivered the level of improvement expected, considering both positive and negative outcomes. Where the results show improvement in vehicle-level prevalence but continued repair burden, the dissertation identifies likely causes requiring further investigation, including protection design, coverage, retention, cleanliness, removal timing and adherence to standard process.

Finally, the dissertation develops evidence-based recommendations for further improvement. These recommendations focus on strengthening protection control, improving end-of-process photographic evidence, revising standard operating procedures, assigning cross-

functional ownership, and establishing monitoring methods to support sustained delivered-quality performance.

1.3.3 Success Criteria

The intervention is assessed against predefined success criteria to avoid judging effectiveness by intent alone. The protective cover strategy would be considered successful if it achieved at least a 15% reduction in in-scope interior damage prevalence versus baseline, remained within the agreed unit-cost constraint of £10 per vehicle, and showed no evidence of negative throughput impact. Where these criteria are only partially met, the dissertation identifies the remaining gaps and proposes further work required to improve control.

1.4 Timing Plan

The timing plan was developed to manage the dissertation across the academic year and to ensure that each stage of work was completed in a logical sequence. The project originally began as an improvement study focused on reducing interior damage through the use of temporary protective covers. As the work developed, the project became more focused on evaluating the effectiveness of the protective cover intervention that had already been introduced into production in November 2023.

This change in direction meant that the timing plan was adapted from a trial-based improvement project to a retrospective evaluation and recommendation-based project. The main emphasis therefore shifted towards defining the defect scope, extracting and cleaning available internal and warranty data, comparing pre- and post-intervention performance, interpreting the operational impact, and developing practical recommendations for further control of interior damage.

1.4.1 High-Level Gantt Plan

The high-level timing plan is shown in Figure 1. It covers the main stages of work from initial problem definition through to final dissertation submission. The early stages focused on defining the business problem, confirming the relevance of interior damage to delivered quality, and completing the supporting literature review. This was followed by defining the operational scope of in-scope damage, confirming the protected components, and establishing the pre- and post-intervention comparison periods.

The middle stage of the project focused on data extraction, cleaning and analysis. Internal damage data was used to assess vehicle-level damage prevalence, defect type, defects per vehicle (DPV), rework time and estimated labour cost. Warranty data was also included as a lagging indicator to assess whether changes in internal damage performance were reflected downstream after vehicle delivery.

The final stage of the project focused on interpreting the results and completing the dissertation. This included assessing whether the protective cover intervention met the agreed success criteria, identifying limitations in the available data, and developing recommendations for further investigation, improved adherence, revised standards and stronger monitoring.

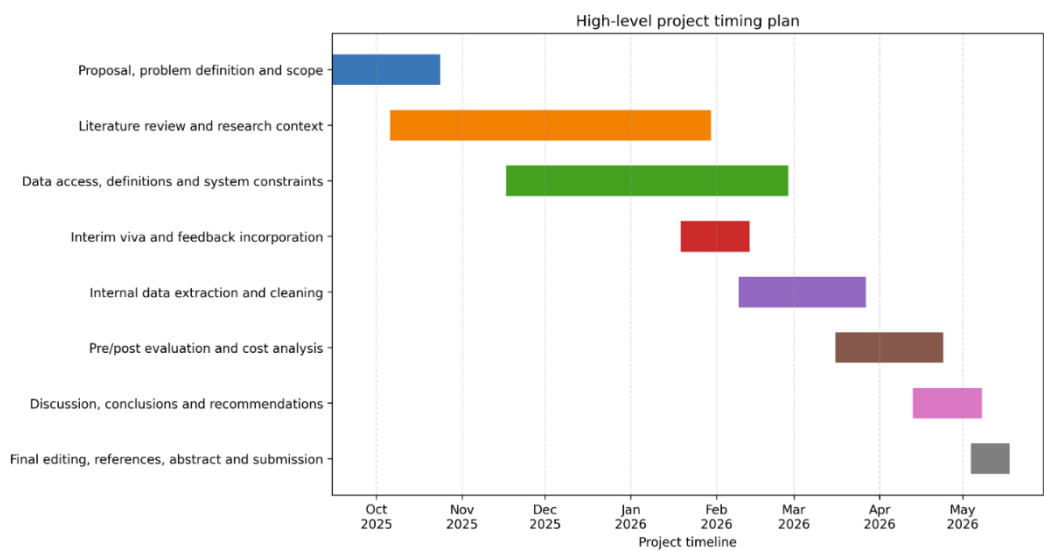


Figure 1 - Overview of Dissertation Project Phases

1.4.2 Final-Phase Plan

The final-phase timing plan is shown in Figure 2. This plan was used to manage the final weeks before submission and focused on completing the analysis, updating the methodology, writing the Results chapter, developing the Discussion and Conclusions chapter, and producing the Recommended Further Work chapter. The final phase also included time for checking consistency between the aim, methodology, results, discussion and conclusions.

The final-phase plan was particularly important because the available data required careful interpretation and consistency checks. Internal systems operated using a rolling four-year lookback window, meaning that records before January 2022 could not be retrieved. The plan therefore included time to document this data limitation, incorporate the available internal and warranty results, and ensure that conclusions were bounded to the available evidence.

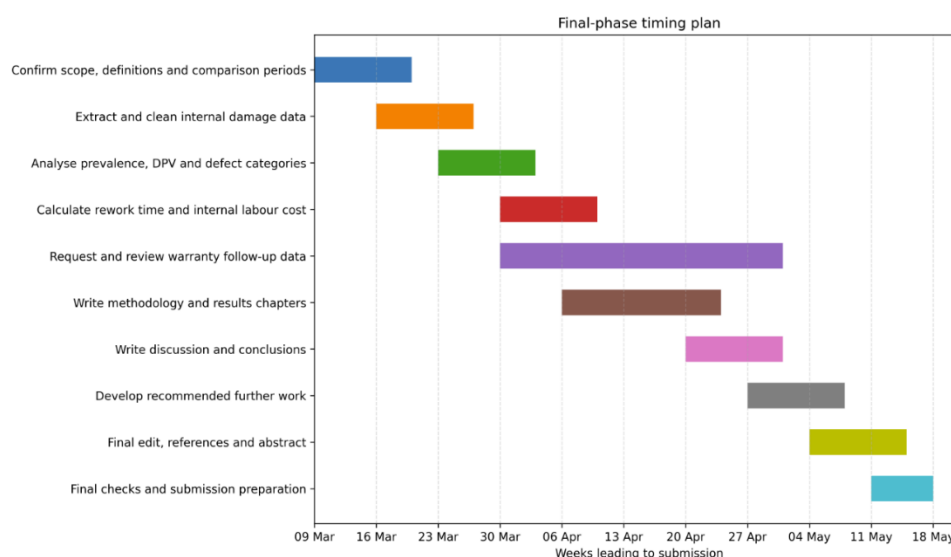


Figure 2 - Final Phase Dissertation Timing Plan

1.4.3 Key Milestones and Deliverables

The project was managed through a series of key milestones. These milestones ensured that the work progressed from problem definition through to evidence-based recommendations.

1.4.3.1 Milestone 1: Problem Definition and Project Scope

The first milestone was to define the project problem and confirm the focus on preventable cosmetic interior damage. This included identifying the relevance of interior damage to delivered quality, warranty exposure, rework burden and customer perception.

1.4.3.2 Milestone 2: Literature Review and Research Context

The second milestone was to complete the literature review. This established the technical context for interior damage mechanisms, measurement-system reliability, temporary protective covers, standardised work and prevention-based quality control.

1.4.3.3 Milestone 3: Data Extraction and Baseline Definition

The third milestone was to extract available internal and warranty data and define the comparison periods. The pre-intervention period was defined as January 2022 to December 2023, while the post-intervention period was defined as January 2024 to December 2025.

1.4.3.4 Milestone 4: Internal Performance Analysis

The fourth milestone was to analyse internal performance before and after protective cover introduction. This included vehicle-level damage prevalence, defect quantity, DPV, rework time and estimated internal labour repair cost.

1.4.3.5 Milestone 5: Interpretation and Discussion

The fifth milestone was to interpret the results against the project success criteria. This included identifying the mixed outcome: vehicle-level damage prevalence reduced, but internal repair/rework time and labour cost increased.

1.4.3.6 Milestone 6: Recommendations and Final Report Completion

The final milestone was to develop recommendations based on the findings and complete the dissertation. The recommendations focused on protective cover adherence, cover design, cleanliness control, photographic evidence, revised standards, cross-functional ownership and longer-term monitoring.

1.4.4 Dependencies and Critical Path

The critical path for the project depended on access to reliable internal damage data and a consistent definition of the analysis scope. The literature review could be developed in parallel with early data investigation, but the Results, Discussion and Recommended Further Work chapters depended on completion of the pre- and post-intervention comparison.

The main dependency was the availability of internal and warranty data. Internal damage data was required to assess vehicle-level prevalence and repair burden, while warranty data was used to assess whether the internal damage trend was reflected downstream after vehicle delivery. However, because warranty cost can be affected by claim severity, repair route, dealer labour rates, replacement decisions, transport damage and warranty coding, it was interpreted as a lagging delivered-quality indicator rather than direct proof of the point of damage creation.

The critical path was therefore:

scope definition → data extraction → data cleaning → pre/post comparison → interpretation → recommendations → final report completion.

1.4.5 Risks and Contingencies

Several risks affected the timing and scope of the project. The first risk was data availability. Internal systems operated using a rolling four-year lookback window, which limited access to records before January 2022. This was managed by defining a consistent two-year pre-intervention and two-year post-intervention comparison window.

The second risk was the interpretation of warranty data. Warranty information is a lagging indicator and may be influenced by time-in-service, dealer repair decisions, replacement choices, claim coding, labour rates, transport damage and customer-facing inspection standards. This was managed by treating warranty cost as a downstream delivered-quality indicator rather than as direct proof of where each defect was created.

The third risk was that the available data could show performance trends but could not fully prove the exact point of damage creation or the level of adherence to the protection standard. This was managed by framing the dissertation as a retrospective evaluation rather than a controlled experiment, and by developing recommendations for further investigation into cover design, cleanliness, removal timing, refitting discipline and production ownership.

The fourth risk was that the protective covers may not have been applied consistently in normal production. Observations indicated that debris could become trapped under covers when they were removed and refitted, some covers were not always reapplied, and some door card covers had poor fit and could fall off. These issues were incorporated into the Discussion and Recommended Further Work chapters as areas requiring further control.

Overall, the timing plan supported completion of the dissertation by adapting the project from an initial improvement-trial concept into a realistic evidence-based evaluation. This ensured that the final report remained aligned with the available data, acknowledged limitations honestly, and produced practical recommendations for further delivered-quality improvement.

2 Literature Review and Research Context

2.1 Purpose and Scope of the Literature Review

This literature review establishes the research context for reducing cosmetic interior damage within low-volume, high-value automotive manufacturing. It reviews the physical mechanisms through which interior damage is created, alongside the process conditions that increase exposure during assembly, internal logistics, rework and preparation for delivery. The review also considers how cosmetic defects are measured and classified, recognising the influence of judgement-based inspection and the need for consistent operational definitions. Prevention strategies are then evaluated with particular emphasis on temporary protective covers, supported by discussion of relevant durability and compatibility test methods and the practical implications of implementation (for example cleanliness control, retention, application/removal standards and human factors). The chapter concludes by synthesising the evidence into a clear research gap: the need for production-feasible evaluation of protective cover introduction that demonstrates net benefit, sustainability of improvement, and acceptable operational impact under normal operating conditions.

To establish an evidence-based foundation for prevention, the literature is first reviewed in terms of what constitutes interior damage within a manufacturing setting and why it persists as a recurring delivered-quality issue. This provides the basis for examining the dominant physical mechanisms that create damage, the reliability of judgement-based measurement systems, and the practical effectiveness and trade-offs of controls such as temporary protective covers.

2.2 Defining Interior Damage and Why It Is Difficult to Control

In automotive manufacturing, interior damage is typically defined as customer-visible or customer-touch cosmetic degradation of trim components, including scratches, scuffs, marring, abrasion haze, dents/indentations, staining, residue, and contamination (Bhushan, 2013). In the luxury segment, these defects are particularly critical because perceived craftsmanship and finish consistency strongly influence customer satisfaction at handover, meaning tolerance to minor cosmetic issues is low (Juran and Godfrey, 1999).

Control of interior damage is challenging for two main reasons. First, damage is usually multi-factor, arising from the interaction between material susceptibility (surface hardness, coating system, texture), process exposure (touch frequency, contact pressure, sliding distance), and the local environment (debris and cleaning practices), which is consistent with

established tribological and surface durability behaviour (Bhushan, 2013; Chu, 1997). Second, cosmetic defects are often assessed through judgement-based inspection, meaning recorded outcomes can vary with lighting conditions, viewing angles, inspector experience and acceptance criteria. Unless operational definitions and scoring rules are standardised, apparent improvement can reflect variation in measurement rather than genuine process change (AIAG, 2010; Montgomery, 2019). For this reason, effective improvement requires both mechanism-led prevention reducing exposure at the point of creation and measurement discipline sufficient to distinguish real performance shifts from recording noise (Deming, 1986; Juran and Godfrey, 1999).

2.3 Mechanisms of Interior Damage Relevant to Production and Delivery

Although interior damage can appear as a wide range of cosmetic defects, the underlying causes can be grouped into a small number of repeatable physical mechanisms. This classification is useful because it links defect appearance to controllable exposure factors within manufacturing and delivery processes and supports selection of targeted countermeasures and appropriate test methods (Bhushan, 2013; Montgomery, 2019).

2.3.1 Abrasion, Scuffing and Scratching (Sliding Contact)

Scratching and scuffing occur when surfaces experience sliding contact with harder bodies, such as tools, fasteners or trim edges, or when contaminants act as third-body abrasives, such as dust or grit trapped between surfaces. Polymer, coated and glossy interior surfaces can be sensitive to visible marking because scratch response depends on contact load, surface hardness, coating behaviour, friction and the presence of third-body debris (Bhushan, 2013; Chu, 1997; Myshkin, Petrokovets and Kovalev, 2005; Stachowiak and Batchelor, 2013). In interior assembly, abrasion risk increases with repeated handling and constrained installation manoeuvres that require contact between components. For coated surfaces and glossy trims, micro-scratches can accumulate into haze that is visible under directional lighting, which is consistent with established scratch and mar behaviour in polymeric and coated surfaces (Bhushan, 2013; Chu, 1997). Abrasion is therefore influenced by both process design, such as touch points and handling path, and housekeeping, particularly debris control. From a prevention perspective, abrasion mechanisms are best addressed by reducing unnecessary touches, reducing contact severity through softer interfaces, and introducing sacrificial barriers such as temporary protection where contact cannot be eliminated (Womack and Jones, 2003; Imai, 1997).

2.3.2 Impact and Indentation Damage (Localised Contact Events)

Dents and impressions are commonly caused by localised impacts, dropped tools, fixture edge contact, or collisions during kitting and movement. Indentation can also occur where soft materials experience concentrated loads (kneeling, leaning, or pushing during fitment). These defects can be low frequency but high cost if replacement of assemblies is required, which aligns with cost-of-poor-quality drivers associated with rework and replacement activity (Juran and Godfrey, 1999). The literature on mistake-proofing suggests that engineered prevention is typically more reliable than behavioural controls because it reduces reliance on vigilance under production pressure (Shingo, 1986). In practice, this supports the use of compliant contact surfaces, edge guards, insertion guides, and tool interface modifications that physically prevent contact with sensitive zones (Shingo, 1986).

2.3.3 Contamination, Staining and Residue

Contamination includes fingerprints, oils, adhesive residue, dust deposition, fibres, and cleaning streaks. Contamination mechanisms are often linked to glove selection, wipe type, cleaning chemistry, and the timing and method of protection removal. Certain coatings and leathers may be sensitive to specific cleaners, while some protective materials can leave residue or transfer. Contamination is therefore best treated as a controlled process using approved materials and standardised work with point-of-use availability, rather than an ad hoc response during inspection that can introduce additional variation and secondary marking (Imai, 1997; Montgomery, 2019).

2.3.4 Vibration-related Fretting and Transport Damage

Even where direct contact damage is controlled during assembly, secondary damage can occur during internal transport and vehicle movement. Vibration and relative motion can create fretting marks where adjacent parts rub or where protective covers move against the surface. This failure mode is particularly relevant to protection systems: a cover can prevent major scratches but, if debris is trapped or retention is poor, it can introduce micro-abrasion under vibration. Tribology principles indicate that small-amplitude relative motion under load can generate surface wear, particularly when debris is present (Bhushan, 2013). Prevention therefore requires attention to retention, cleanliness at application, and compatibility between the protective material and the surface, alongside defined handling and movement practices (Imai, 1997; Womack and Jones, 2003).

2.3.5 Environmental Influences and Ageing Effects

Temperature and humidity can influence material behaviour and defect visibility. For example, surface softening can increase susceptibility to marring, while cold conditions may

make certain plastics less forgiving to impact. Environmental conditions can also influence polymer response to contact loading and therefore the visibility threshold for surface marking (Chu, 1997). In manufacturing settings, these factors are typically controlled indirectly through storage conditions, time-to-handover, and standardised cleaning processes; however, they should be considered when interpreting trends and when selecting protection materials and dwell times (Montgomery, 2019).

2.3.6 Measuring Interior Damage: Definitions, Scoring and Measurement-System Reliability

The literature on quality improvement consistently emphasises that valid conclusions require a stable and repeatable measurement system. For cosmetic damage, variation can arise from inspection conditions and inspector judgement. Therefore, an operational definition of “damage” is required, including minimum size or visibility thresholds, prohibited zones, severity ranking, and standard viewing conditions. Measurement Systems Analysis principles highlight the need to assess repeatability and reproducibility where judgement is involved, and to document scoring rules to reduce variation over time (AIAG, 2010). Quality management system standards also emphasise the importance of controlled records, consistent process criteria and documented evidence when evaluating conformity and process performance in manufacturing environments (ISO, 2015; IATF, 2016).

A practical limitation in industrial case studies is that historical datasets may contain mixed classifications. For example, leather scuffing may be recorded as “Imperfection” in one system while being treated operationally as damage requiring rectification in another. In such cases, a defensible approach is to define inclusion criteria based on mechanism rather than label, and to apply those criteria consistently when analysing baseline and post-change performance (AIAG, 2010; Montgomery, 2019). This dissertation adopts that logic by including leather “Imperfection” records where the defect mechanism corresponds to contact-induced scuffing or marring, because these outcomes are practically equivalent to damage in delivered-quality terms.

This measurement issue is directly relevant to the evaluation of protective covers. If damage categories, inspection conditions or coding practices vary between periods, apparent performance changes may reflect recording variation as well as genuine process change. For this reason, the dissertation applies consistent inclusion rules and interprets results alongside known limitations in defect classification and downstream warranty coding. These mechanisms indicate that prevention should prioritise reduction of sliding contact, debris-driven abrasion and secondary marking during handling and movement, which provides the rationale for evaluating temporary protective covers applied to high-risk components such as

door cards, centre console, instrument panel and steering wheel (Bhushan, 2013; Imai, 1997).

2.4 Standards and Test Methods Relevant to Interior Surfaces and Protection Systems

Interior damage prevention sits at the intersection of material durability and process exposure. Standardised test methods are relevant for two reasons: they provide repeatable ways to compare the susceptibility of interior materials and finishes to visible marking, and they support evaluation of protection materials (for example whether a cover can itself induce abrasion, leave residue, or increase scratch visibility). However, a critical limitation is that many laboratory tests apply simplified motions and controlled loads that may not fully represent the mixed-mode contact conditions experienced during assembly, internal logistics, rework activity, and delivery preparation. Therefore, standards are most effective when used as screening and benchmarking tools and when complemented by process-representative evaluation under realistic conditions (Bhushan, 2013; Montgomery, 2019).

2.4.1 Surface Durability Testing for Interior Materials

Automotive interior surfaces commonly include polymer trims, coated decorative surfaces, and leather or coated textiles, which can exhibit visible marking even under relatively low contact loads depending on finish and lighting. Scratch and mar behaviour is strongly influenced by contact geometry, normal load, surface hardness and coating response, consistent with tribology principles and automotive coating durability research (Bhushan, 2013; Seubert et al., 2012). Where coatings and surface finishes are involved, scratch resistance can be assessed using standard methods such as constant-load scratch testing, which provides a controlled basis for comparing systems and identifying thresholds for visible damage initiation (ISO, 2019).

Abrasion resistance is also relevant because repeated low-severity contacts can accumulate into haze and micro-marring. For organic coatings, abrasion resistance is commonly assessed using Taber abrasion approaches that provide comparative wear behaviour under defined test parameters (ASTM International, 2019). These tests can be useful for identifying whether a finish is inherently susceptible to rapid visible wear, although they do not capture all assembly-specific contact scenarios (Bhushan, 2013).

For textiles and leather-associated appearance issues, colour fastness to rubbing provides a standardised method to assess marking and transfer risk under controlled rubbing conditions, which can be relevant when interpreting scuff-type outcomes that may be

recorded as “Imperfection” but are treated operationally as damage requiring rectification (ISO, 2016).

2.4.2 Protection System Compatibility and Unintended Consequence Testing

Temporary protective covers introduce additional interfaces into the system and can therefore reduce direct contact damage while also creating new risks. Compatibility evaluation should therefore include whether protection materials can generate micro-abrasion, trap debris, or alter appearance on removal. Where polymeric protection films or covers are used, instrumented scratch testing provides a structured approach for evaluating scratch behaviour and damage visibility for plastics and polymeric coatings, supporting comparison of different protective materials and surface combinations (ASTM International, 2020). In addition, abrasion testing can be used to indicate whether protection materials may contribute to wear if micro-movement occurs under vibration or repeated handling (ASTM International, 2019).

A key practical consideration is that protection effectiveness depends not only on material properties but also on application cleanliness, retention, and removal timing. Consequently, protection evaluation should consider not only protective performance in isolation but also the process conditions that influence debris entrapment and contact severity, particularly where vibration-related fretting may occur during internal movement (Bhushan, 2013).

2.4.3 Need for Process-Representative Evaluation and Measurement Discipline

Although standards provide important benchmarks, real manufacturing conditions introduce variability in contact paths, handling pressure, operator technique and environmental cleanliness. Therefore, manufacturing-focused improvement studies often require process-representative evaluation methods, such as operational data review, controlled A/B comparisons where feasible, production validation or trend analysis, supported by stable measurement definitions. This aligns with quality engineering principles that emphasise consistent operational definitions and reliable measurement systems when assessing change over time (AIAG, 2010; Montgomery, 2019).

In summary, standards-based testing is valuable for understanding surface susceptibility and for preventing unintended consequences of protection materials, but a robust conclusion on damage reduction typically requires evidence from operational data and realistic process evaluation (Bhushan, 2013; Montgomery, 2019).

2.5 Prevention Strategies in the Literature and Industrial Practice

Prevention strategies for cosmetic interior damage can be grouped into three broad approaches: reducing exposure to damaging contacts, reducing material or surface susceptibility to visible marking, and improving early detection and containment at source. Quality management literature consistently argues that inspection alone does not create quality and that sustainable improvement requires prevention to be designed into the process, with particular emphasis on reducing variation and controlling the conditions that create defects (Deming, 1986; Juran and Godfrey, 1999). In low-volume luxury manufacturing, where manual content and frequent handling are common, these principles are directly relevant because a large proportion of cosmetic defects arise through repeat contact and process variability rather than through isolated, random events (Womack and Jones, 2003).

2.5.1 Reducing Exposure Through Process Design and Standardised Work

A primary lever for damage reduction is minimisation of avoidable contact and handling. Lean manufacturing emphasises the elimination of non-value-added motion and re-handling, which reduces opportunities for scratches, scuffs, and contamination to be introduced (Womack and Jones, 2003). Standardised work provides a consistent task sequence and defines acceptable touch points and handling routes, which stabilises manual operations and reduces variation between operators and shifts (Imai, 1997). In constrained interior assembly tasks, workspace design and part presentation are important enabling conditions; if components must be manoeuvred in limited space without appropriate staging or guides, the likelihood of incidental contact increases even when operators are trained (Imai, 1997). Therefore, process design controls should be supported by practical workstation organisation and point-of-use provision of protective materials and cleaning resources to avoid ad hoc handling behaviours (Imai, 1997; Juran and Godfrey, 1999). Standardised work is therefore important because it defines the safest repeatable method, reduces variation between operators and supports improvement by making abnormal conditions easier to identify (Ohno, 1988; Liker, 2004).

2.5.2 Engineered Prevention: Fixturing, Tooling Interfaces and Mistake-Proofing

Where damage mechanisms are repeatable, engineered controls typically provide the most robust prevention because they reduce reliance on vigilance and behavioural compliance. Mistake-proofing (poka-yoke) approaches aim to prevent errors from being possible or to make them immediately obvious, which is particularly relevant for cosmetic defects where a single slip can create a high-cost outcome (Shingo, 1986). In an interior trim context, engineered controls can include compliant contact surfaces, physical guides that prevent

tool contact with “no-touch” zones, controlled insertion fixtures, and protective bumpers or sleeves applied to tools and fixtures (Shingo, 1986).

From a quality engineering perspective, engineered controls also support stability: they reduce variation in contact pressure, contact location, and handling path, which are key drivers of scratch and mar formation in polymeric and coated surfaces (Bhushan, 2013). Consequently, where feasible, prevention strategies are strengthened by prioritising engineered measures at the highest-risk touchpoints rather than relying solely on increased inspection or reminders (Deming, 1986; Shingo, 1986). This also aligns with automotive quality-system expectations, where robust process control and evidence of effective prevention are central to reducing repeat defects and maintaining conformity in production (IATF, 2016; VDA, 2016).

2.5.3 Packaging, Internal Logistics Containment and Protection Retention

Cosmetic damage can be introduced outside the immediate installation step through kitting, storage, internal movement, and rework loops. Packaging and containment strategies seek to prevent component-to-component contact, control debris, and maintain orientation and stability during movement. This is particularly important where vibration or repeated movement can generate fretting marks or micro-abrasion over time (Bhushan, 2013). In practical terms, this supports containment design that limits relative motion, uses clean interface materials, and ensures parts are presented in a way that minimises touches and awkward handling (Imai, 1997; Womack and Jones, 2003).

Where temporary protection is applied, retention is a key factor. A protective cover that shifts during movement can introduce abrasion mechanisms, especially if debris is trapped beneath the cover. This implies that the effectiveness of protection is influenced not only by material selection but also by process controls for clean application, secure retention, and defined removal points (Bhushan, 2013; Montgomery, 2019).

2.5.4 Temporary Protective Covers: Benefits, Trade-Offs and Failure Modes

Temporary protective covers are a widely used control for cosmetic damage because they act as a sacrificial barrier when direct contact cannot be eliminated through process design alone. In principle, covers reduce the likelihood that tools, fasteners, adjacent components, or operator contact will mark the finished surface, and they can be particularly attractive when part redesign is not feasible within project timescales (Juran and Godfrey, 1999).



Figure 3 - Seat Protective Cover Fitted During Production

However, protective covers introduce trade-offs that must be managed. The literature and industrial practice commonly identify the following risks:

- I. Trapped debris: grit under a cover can act as a third-body abrasive, creating micro-scratches under vibration or during removal, consistent with tribological wear mechanisms (Bhushan, 2013).
- II. Residue/transfer: certain protection materials can leave residue or alter surface appearance, increasing cleaning demand and potentially creating secondary defects (Montgomery, 2019).
- III. Additional handling: applying and removing protection adds steps, and if not integrated into standard work, it may increase touches and exposure (Imai, 1997).

- IV. Inconsistent application/coverage: partial coverage and variation in application can create boundary-edge marking and inconsistent outcomes, reinforcing the need for standardised procedures (AIAG, 2010).
- V. Interference with assembly: protection can hinder access and fitment, increasing rework risk unless the application/removal strategy is designed to support assembly needs (Montgomery, 2019).

Temporary protection can therefore become a secondary damage source if retention, cleanliness and material compatibility are not controlled as part of the process standard (Rabinowicz, 1995; Bhushan, 2013). These trade-offs indicate that protection introduction should be treated as an engineered process change rather than simply adding material. Effective implementation requires selection of compatible cover materials, controlled cleanliness at application, consistent retention, and clear standards for the correct point of removal (Imai, 1997; Shingo, 1986).

2.5.5 Human Factors and Compliance

Human factors influence the effectiveness of both engineered and administrative controls. Even a technically robust countermeasure can fail if it is slow, awkward, or perceived to conflict with throughput expectations. Operational excellence literature emphasises that sustainable improvement requires alignment between process expectations and workplace conditions, including realistic task timing, availability of materials at the point of use, and visible standards that support consistent behaviour (Imai, 1997).

From a measurement perspective, sustaining improvement also requires stable defect definitions and consistent scoring. Where visual judgement is involved, measurement-system variation can mask deterioration or create false improvement signals, supporting the importance of documented scoring rules and periodic checks of inspection consistency (AIAG, 2010; Montgomery, 2019).

2.5.6 Source Containment and Feedback to Prevent Defect Travel

While prevention is the primary objective, early detection and containment remain important to avoid defect travel and escalation. Source inspection principles argue that defects should be detected as close as possible to the point of creation, because later discovery increases cost and reduces learning opportunity (Shingo, 1986). In interior assembly, this implies in-process checks at high-risk steps and rapid feedback to the relevant operation when defects are detected, enabling corrective action before subsequent operations conceal the damage or introduce additional contact risks (Juran and Godfrey, 1999).

2.6 Critical Comparison of Approaches and Implications for this Dissertation

Across the literature and industrial practice, three broad approaches are commonly used to reduce cosmetic interior defects: improving material robustness, redesigning processes and engineered interfaces to reduce exposure, and introducing temporary protection as a sacrificial barrier. Each approach can be effective, but each also carries limitations that influence feasibility within a manufacturing improvement project.

A material robustness approach seeks to reduce susceptibility by selecting finishes, coatings, or material systems that are more resistant to scratching, marring and visible wear. Tribology literature indicates that surface marking behaviour is strongly dependent on material properties, surface hardness, and coating response, and that visible damage thresholds vary substantially between systems, supporting material selection as a valid long-term lever (Bhushan, 2013; Chu, 1997). However, in a luxury environment, material and finish choice is often constrained by styling intent and supplier lead times, and changes may require revalidation and requalification, which limits feasibility as a short-term intervention within an academic-year project (Juran and Godfrey, 1999).

A process and engineered controls approach targets exposure rather than susceptibility by reducing touch frequency, controlling contact interfaces, and eliminating repeatable contact points through workplace design and mistake-proofing. Lean and operational excellence frameworks emphasise that unnecessary handling and motion increase defect opportunity, meaning that process stability and reduced variation are fundamental to defect prevention (Imai, 1997; Womack and Jones, 2003). Mistake-proofing literature further argues that engineered prevention is typically more reliable than behaviour-only controls, because it reduces reliance on vigilance under production pressure (Shingo, 1986). This approach is often feasible and sustainable when high-risk touchpoints are known, but it may require cross-functional coordination and time to design, trial and implement physical changes to tooling, fixtures, or part presentation (Shingo, 1986; Montgomery, 2019).

A protection approach introduces temporary covers, films, sleeves, or guards to create a sacrificial barrier between the finished surface and potential contact sources. Protection can be attractive in industrial settings because it may be deployed more rapidly than material redesign, particularly when high-value surfaces are frequently handled (Juran and Godfrey, 1999). However, protection systems also introduce trade-offs that can offset benefits if not controlled: debris entrapment can cause third-body abrasion, retention failure can lead to fretting under vibration and added handling steps can increase exposure and cycle time if protection is not integrated into standardised work (Bhushan, 2013; Imai, 1997). In addition, judgement-based defect recording can create false signals in performance evaluation if

definitions and scoring are not stable, reinforcing the importance of measurement discipline when assessing whether protection produces net benefit (AIAG, 2010; Montgomery, 2019).

In this retrospective dissertation context, where the protection intervention had already been implemented, the key implication is that evaluation must consider both outcome change (damage reduction) and unintended consequences (defect migration, new failure modes, time/cost impact and compliance). This aligns with quality engineering principles that emphasise system-wide evaluation, stable measurement, and explicit consideration of variation and confounding factors when interpreting before-and-after performance (Deming, 1986; Montgomery, 2019). Consequently, the dissertation treats protective covers as a process control whose effectiveness must be demonstrated under normal operating conditions rather than assumed by design intent alone (Juran and Godfrey, 1999).

2.7 Research Gap and Dissertation Contribution

The reviewed literature supports the view that cosmetic interior defects are driven predominantly by contact mechanisms and exposure frequency within manual assembly and handling systems, consistent with tribological principles of wear and scratch formation on polymeric and coated surfaces (Bhushan, 2013; Chu, 1997). The literature also indicates that prevention is generally more effective than reliance on downstream inspection and rework, and that robust improvement requires reduction of variation and engineered controls at the point of defect creation (Deming, 1986; Shingo, 1986). Temporary protective covers are therefore a plausible manufacturing control where redesign is impractical, because they act as a sacrificial barrier and can reduce direct contact damage on high-risk surfaces (Imai, 1997; Juran and Godfrey, 1999).

However, a recurring gap in industrial practice is the limited availability of production-feasible, mechanism-led evaluation that demonstrates whether protection delivers net benefit under real operating conditions. Protection is commonly implemented with the intent to reduce scratches and scuffs, yet it can introduce secondary failure modes such as debris-driven micro-abrasion, increased handling time, inconsistent application, and defect migration to unprotected areas if the underlying exposure mechanisms are not fully controlled (Bhushan, 2013; Imai, 1997). In addition, judgement-based cosmetic scoring can obscure true performance changes unless measurement definitions are stabilised, which is particularly relevant for longitudinal before-and-after comparisons (AIAG, 2010; Montgomery, 2019).

This dissertation addresses that gap by evaluating the introduction of temporary protective covers as an interior damage control within the Aston Martin St Athan production context. The study is framed as a retrospective, quasi-experimental before-and-after evaluation using internal and warranty data streams, recognising that full experimental control is not possible in a live manufacturing system (Shadish, Cook and Campbell, 2002). The contribution is to provide an evidence-based assessment of whether protection applied to high-risk interior components delivers measurable improvement, whether any improvement is sustained, and what operational trade-offs or unintended consequences should be managed to strengthen the control strategy (Montgomery, 2019; Juran and Godfrey, 1999). Where evidence is incomplete due to data constraints, limitations are stated explicitly and conclusions are bounded to the available support, consistent with good practice in industrial quality evaluation (Deming, 1986; AIAG, 2010).

3 Methodology and Data Analysis Approach

3.1 Research Design and Justification

This dissertation evaluates a completed manufacturing intervention intended to reduce preventable cosmetic interior defects. Temporary protective covers were introduced into production in November 2023 and applied to key high-risk interior trim areas, including the front door cards (LH/RH), rear door cards (LH/RH), centre console, instrument panel and steering wheel.

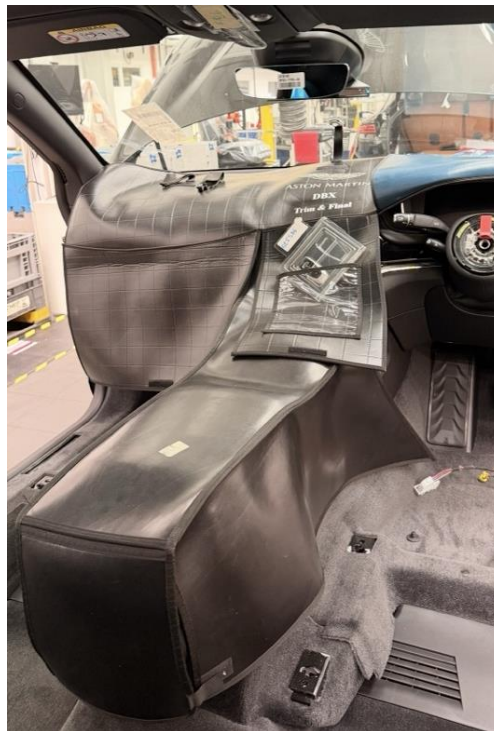


Figure 4 - Instrument Panel Protective Cover Fitted During Production

Although additional protective covers were introduced during the same period for other vulnerable exterior or peripheral components, the scope of this dissertation remains focused on in-scope interior cosmetic damage. Because the intervention had already been implemented operationally, the study adopts a retrospective before-and-after, quasi-experimental evaluation design.

This approach is consistent with applied industrial research, where real-world process constraints often require practical case-study and quasi-experimental designs rather than fully controlled laboratory experiments (Shadish, Cook and Campbell, 2002; Robson and McCartan, 2016; Saunders, Lewis and Thornhill, 2019; Yin, 2018). It is appropriate in this

context because randomised experimentation was not feasible, and evidence therefore had to be derived from operational data and structured comparison across time periods. However, the design also requires acknowledgement of potential confounding factors and the limits of causal inference.

The evaluation is structured to determine whether the intervention is associated with a measurable change in interior damage indicators and whether any change is sustained. The analysis is framed neutrally: it tests whether the protective covers delivered net benefit compared with baseline, rather than assuming effectiveness by intent. This aligns with quality engineering principles that emphasise evidence-based assessment and control of variation when evaluating improvement actions (Deming, 1986; Montgomery, 2019). As the available data does not fully identify the exact point of damage creation or the level of adherence to the protection standard, the study is used to evaluate performance trends and develop evidence-based recommendations rather than to prove a single definitive root cause.

3.2 Scope and Operational Definition of In-Scope Defects

“In-scope interior damage” is defined as preventable cosmetic defects arising through handling, assembly, internal logistics, rework/inspection activity, or delivery preparation that require rectification to meet delivered-quality expectations. The scope includes defects recorded as “Damaged” and leather-related “Imperfection” records where the defect mechanism is consistent with contact-induced scuffing or surface marring, recognising that dealer-level assessment may treat these issues as damage requiring rework. This mechanism-based rule is applied consistently to minimise classification bias and improve comparability between pre- and post-intervention periods, consistent with Measurement Systems Analysis (MSA) guidance for judgement-based defect classification (AIAG, 2010).

The steering wheel was included within the in-scope interior protection area because it is a customer-facing component and is exposed during production, inspection, rework and final preparation activities.



Figure 5 - Steering Wheel Protective Cover Fitted During Production

Defects considered not practically preventable within the manufacturing control window (for example fraying/splitting and inherent non-contact material variation) are excluded to maintain feasibility and ensure that conclusions relate to controllable process exposure.

3.3 Data Sources and Study Periods

Two complementary data streams are used:

- I. Internal damage data (leading indicator): records of interior damage calls identified within production and internal quality activities.
- II. Warranty data (lagging indicator): claims associated with interior cosmetic issues, used to assess whether any change is reflected downstream.

A data availability constraint applies to the internal systems used for historical extraction. Internal reporting platforms operate on a rolling four-year lookback window, which limits how far back records can be accessed at the time of extraction. As the analysis for this dissertation was conducted in May 2026, the earliest data that could be retrieved consistently begins in January 2022, while records prior to January 2022 were unavailable

within the system. This constraint is treated as a system limitation rather than a study design choice and is documented to ensure transparency when interpreting baseline performance and longitudinal comparisons.

The study uses a structured period definition to improve interpretability and reduce transition noise:

- I. Pre-intervention comparison period: January 2022 to December 2023.
- II. Post-intervention comparison period: January 2024 to December 2025.
- III. November to December 2023 is acknowledged as a transition period because the protective covers were introduced in November 2023; however, the two-year pre-intervention comparison window is retained to maintain consistency with the available internal and warranty datasets.

This structure supports assessment of both step change and sustainability and reflects good practice when evaluating operational interventions over time (Montgomery, 2019; Shadish, Cook and Campbell, 2002).

3.4 Metrics and Success Criteria

The primary internal outcome measure is the proportion of vehicles with at least one in-scope interior damage call. For the pre-intervention comparison window January 2022 to December 2023, 5652 vehicles were built and 4034 vehicles had at least one interior damage call, corresponding to a baseline prevalence of 71.4%. For the post-intervention comparison window January 2024 to December 2025, 7506 vehicles were built and 3326 vehicles had at least one interior damage call, corresponding to a prevalence of 44.3%. Reporting the outcome as a proportion (rather than counts alone) provides a consistent basis for comparison despite changes in production volume between periods.

Secondary measures are used where data availability permits:

- I. Damage calls per vehicle to capture frequency intensity.
- II. Distribution by component/area (door cards, centre console, instrument panel, steering wheel) to test whether any change is concentrated in the protected parts.
- III. Rework time associated with interior damage, used to assess labour burden and repair severity.

In addition to prevalence-based internal metrics, baseline impact is also quantified using cost data from both internal and warranty records. Cost measures are included because cosmetic defects can vary widely in severity and rectification requirement, meaning a reduction in

high-severity events may deliver greater operational benefit than an equivalent reduction in low-severity events. For the pre-intervention cost window January 2022 to December 2023, the total recorded internal cost associated with in-scope interior defects was £111,890.79, while the total recorded warranty cost for the same period was £49,163.34. These baseline values provide a business-case reference for evaluating post-intervention performance and enable assessment of whether any change in defect frequency is accompanied by a meaningful reduction in financial impact.

Cost-based interpretation is reported alongside count and rate measures because recorded cost can be influenced by changes in repair practice, part pricing, coding behaviour, and the proportion of cases requiring full replacement versus local repair. For this reason, cost trends are interpreted together with the distribution of defect types and affected components, particularly those targeted by the protective covers (Montgomery, 2019).

Warranty evaluation uses:

- I. Claim count and total claim cost over time for relevant interior damage issues.
- II. Targeted filtering to the protected component set where the warranty dataset allows reliable mapping using part descriptors and/or system classification.

Success criteria are defined prior to analysis to ensure conclusions are evaluated against objective targets. The intervention would be considered successful if it achieved a $\geq 15\%$ reduction in in-scope damage versus baseline while remaining within a $\leq £10$ per vehicle unit-cost constraint and showing no evidence of negative throughput impact. These criteria reflect the need to deliver net benefit without introducing unacceptable operational penalties, consistent with cost-of-poor-quality improvement principles (Juran and Godfrey, 1999).

3.5 Data Preparation and Classification Consistency

Data preparation is performed to ensure consistent application of scope rules and comparability across time periods. This includes standardising date formats, removing obvious duplicates, and documenting inclusion/exclusion rules for defect categorisation. Where internal and warranty datasets use different classification fields, mapping is performed using the best available combination of subsystem/part descriptors and defect-text indicators consistent with the operational definition of in-scope damage.

Because cosmetic defect scoring is judgement-based, the study treats measurement variation as a known risk. In line with MSA guidance, the analysis relies on consistent operational definitions and documented rules applied across the full dataset to reduce the

likelihood that apparent performance change reflects recording variation rather than genuine process change (AIAG, 2010; Montgomery, 2019). Any uncertainty in classification or mapping is treated as a limitation and is explicitly discussed.

3.6 Analysis Approach

The analysis proceeds in four stages:

3.6.1 Baseline Characterisation

This stage summarises internal and warranty defect prevalence, counts and cost during the pre-intervention period, including confirmation of dominant defect groupings and affected components.

3.6.2 Targeted Component Focus

This stage assesses whether changes post-intervention are concentrated in the components where protection was applied (door cards, centre console, instrument panel, steering wheel), which is necessary to test alignment between intervention and outcomes.

3.6.3 Before-and-After Comparison

This stage compares pre- and post-intervention performance for the primary metrics using the defined two-year comparison windows, while acknowledging November–December 2023 as a transition period within the baseline window. Where data allows, results are presented by month/quarter to support interpretation of trend stability.

3.6.4 Robustness Checks and Interpretation

This stage reviews potential confounders such as reporting changes, production volume shifts, seasonality and concurrent process updates. Trend-based interpretation is used to reduce reliance on single-point comparisons and to identify whether any change is sustained over time (Montgomery, 2019).

Statistical methods are selected to match the data structure and the retrospective design. Where appropriate and supported by the available data, comparisons of proportions and simple trend analysis are used to support evidence-based conclusions, while maintaining transparency that the design is quasi-experimental and not fully controlled (Shadish, Cook and Campbell, 2002). This approach is consistent with applied operations management, where performance evaluation should consider flow, quality, capacity and cost together rather than treating defect reduction as an isolated metric (Slack, Brandon-Jones and Johnston, 2019).

3.7 Ethics, Safety and Confidentiality

The dissertation is based on analysis of operational manufacturing and warranty records and does not involve human subject experimentation. Any observational inputs or stakeholder discussions are used to interpret mechanisms, feasibility, and implementation context rather than to generate personal data. Results are reported in aggregated form suitable for academic reporting, and sensitive operational identifiers are excluded where unnecessary.

3.8 Limitations

The before-and-after evaluation design cannot fully isolate the protective-cover effect from other changes occurring over the same period, such as workforce changes, process updates, supplier variation, or shifts in recording practice. Warranty outcomes may also lag manufacturing change due to time-in-service effects and dealer reporting behaviour. These limitations are mitigated through the use of two data streams, internal and warranty data, alongside component-targeted analysis aligned to the protected parts and trend-based interpretation over extended time windows.

Although warranty data is now available for both comparison periods, the dataset does not identify exactly where each warranty defect was created. Warranty cost may be influenced by defect severity, dealer repair decisions, replacement choices, labour rates, claim coding, transport damage and customer-facing inspection standards. For this reason, warranty cost is interpreted as a downstream indicator of delivered-quality performance rather than direct proof of the point of damage creation. This is consistent with real-world case-study research, where operational evidence can support practical conclusions but may not provide the same level of causal control as a designed experiment (Robson and McCartan, 2016; Yin, 2018). The conclusions are therefore bounded to the available operational evidence and should be updated if more detailed warranty root-cause or location-level data becomes available (AIAG, 2010; Montgomery, 2019).

4 Results and Findings

This chapter presents the findings from the internal and warranty data used to evaluate the impact of protective cover introduction. Results are reported using volume-normalised measures where possible to support fair comparison between the pre- and post-intervention periods. The internal results focus on vehicle-level damage prevalence, defect type, defects per vehicle (DPV), repair/rework time and estimated labour cost. Warranty cost is included as a lagging indicator to assess whether changes in internal damage performance were reflected downstream after vehicle delivery.

4.1 Internal Damage Prevalence Before and After Protective Cover

Introduction

Table 1 summarises the internal prevalence of vehicles with at least one in-scope interior damage call across the defined pre- and post-intervention periods. In the pre-intervention period, from January 2022 to December 2023, 5652 vehicles were built and 4034 vehicles had at least one recorded interior damage call, giving a prevalence of 71.4%. In the post-intervention period, from January 2024 to December 2025, 7506 vehicles were built and 3326 vehicles had at least one recorded interior damage call, giving a prevalence of 44.3%.

This represents a reduction of 27.1 percentage points and a 37.9% relative reduction in the proportion of vehicles affected. Reporting the result as a prevalence rate rather than a count is important because production volume increased between the two periods. Although more vehicles were built during the post-intervention period, a lower proportion of vehicles had an interior damage call, indicating an improvement in the internal damage rate.

Table 1 - Internal Vehicles with ≥ 1 Interior Damage Calls Pre- and Post-Intervention

Period	Vehicles built (n)	Vehicles with ≥ 1 interior damage call (n)	Prevalence (%)
Jan 2022 – Dec 2023	5652	4034	71.4
Jan 2024 – Dec 2025	7506	3326	44.3

Figure 6 presents the same vehicle-level prevalence result visually and includes vehicle build volume for context, showing that the reduction in affected vehicles was achieved despite higher production volume in the post-intervention period.

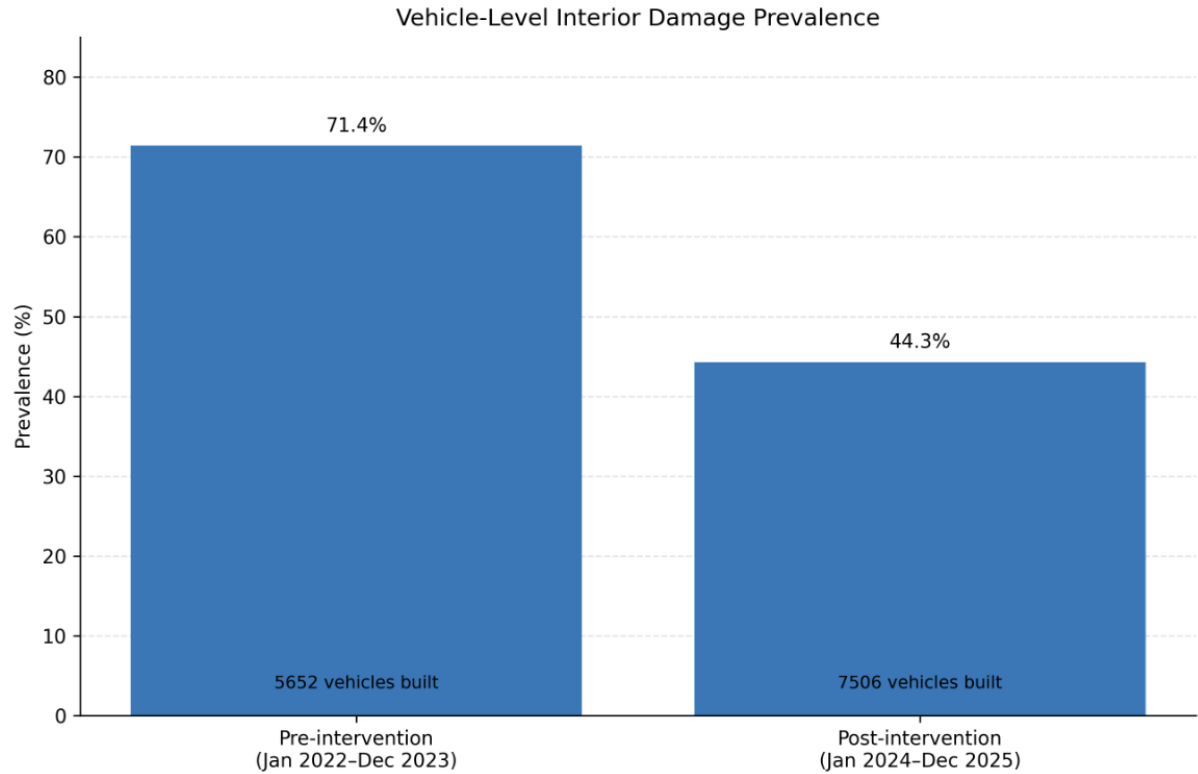


Figure 6 - Vehicle-Level Interior Damage Prevalence Before and After Protective Cover Introduction, with Vehicle Build Volume Shown for Context

4.2 Internal Rework Time and Cost Impact by Defect Type

Table 2 compares the internal rework burden associated with the three main interior damage call categories before and after the introduction of protective covers. The categories included in this analysis are scuff, damage and scratch, as these represent the main repairable internal cosmetic defect types within the available dataset. The comparison uses the same two-year windows as the damage prevalence analysis: January 2022 to December 2023 for the pre-intervention period and January 2024 to December 2025 for the post-intervention period. DPV values are reported directly from the internal system output and are therefore retained using the system-defined denominator for each reporting period.

Table 2 - Internal Rework Burden by Defect Type Before and After Protective Cover Introduction

Period	Defect type	Defect quantity	DPV	Repair/rework time	Mean time to repair
Jan 2022 – Dec 2023	Scuff	6263	1.11	65 days, 7 hours, 4 minutes	15 minutes
Jan 2022 – Dec 2023	Damage	4062	0.72	58 days, 18 hours, 42 minutes	21 minutes
Jan 2022 – Dec 2023	Scratch	1068	0.19	9 days, 2 hours, 12 minutes	17 minutes
Jan 2024 – Dec 2025	Scuff	8216	0.96	143 days, 12 hours, 2 minutes	25 minutes
Jan 2024 – Dec 2025	Damage	302	0.04	4 days, 12 hours, 18 minutes	21 minutes
Jan 2024 – Dec 2025	Scratch	1559	0.18	19 days, 17 hours, 34 minutes	18 minutes

In the pre-intervention period, the combined repair/rework time for scuff, damage and scratch defects was 133 days, 3 hours and 58 minutes, equivalent to approximately 3195.97 hours. Using an A-grade technician labour rate of £35.01 per hour, this equates to an estimated internal labour repair cost of £111,890.79.

In the post-intervention period, the combined repair/rework time for the same three categories was 167 days, 17 hours and 54 minutes, equivalent to approximately 4025.90 hours. Using the same A-grade technician labour rate of £35.01 per hour, this equates to an estimated internal labour repair cost of £140,946.76.

Table 3 shows the internal labour repair cost comparison before and after protective cover introduction.

Table 3 - Internal Labour Repair Cost Comparison Before and After Protective Cover Introduction

Period	Total repair/rework time	Total hours	Labour rate (£/hour)	Estimated labour repair cost (£)
Jan 2022 – Dec 2023	133 days, 3 hours, 58 minutes	3195.97	35.01	111,890.79
Jan 2024 – Dec 2025	167 days, 17 hours, 54 minutes	4025.90	35.01	140,946.76

The internal labour repair cost therefore increased by £29,055.97, representing a 26.0% increase between the pre- and post-intervention periods. This result should be interpreted alongside the prevalence reduction shown in Section 4.1. Although the proportion of vehicles with at least one interior damage call decreased, the total labour burden associated with the three main repairable defect types increased. This indicates that the post-intervention period contained fewer affected vehicles proportionally, but higher repair effort within the scuff and scratch categories, particularly scuff defects.

4.3 Rectification Approach and Severity Considerations

Interior damage severity is not measured only by whether a defect exists, but also by the level of rectification required. For internal damage calls, repair is normally preferred where feasible because many interior parts are supplied as customer-specific kitted assemblies. These kits are produced to match the customer's selected colour, trim and material specification, meaning replacement of a single damaged part may require a one-off order or, in some cases, replacement of a wider matched interior set. As a result, technician repair time is often lower cost and lower disruption than full part replacement, provided the defect can be repaired to the required delivered-quality standard.

Warranty cases follow a similar principle, although the cost structure differs because dealer labour must be paid and customer waiting time becomes a more significant concern. Where a dealer repair can restore the part to the required standard, rework may still be preferred. However, where the defect type, severity, or customer impact makes repair impractical, replacement may be selected because it can provide a faster or more robust resolution. Therefore, cost trends should be interpreted alongside defect count and severity, because a smaller number of high-severity cases may create greater financial impact than a larger number of minor repairable marks.

4.4 Warranty Impact

Warranty data was used as a lagging indicator to evaluate whether internal changes were reflected downstream after vehicle delivery. Warranty cost for in-scope interior damage in the baseline period January 2022 to December 2023 was £49,163.34. Warranty cost for the same defect scope in the post-intervention period January 2024 to December 2025 was £636,384.36. Figure 7 presents the warranty cost comparison visually and includes vehicle build volume for context.

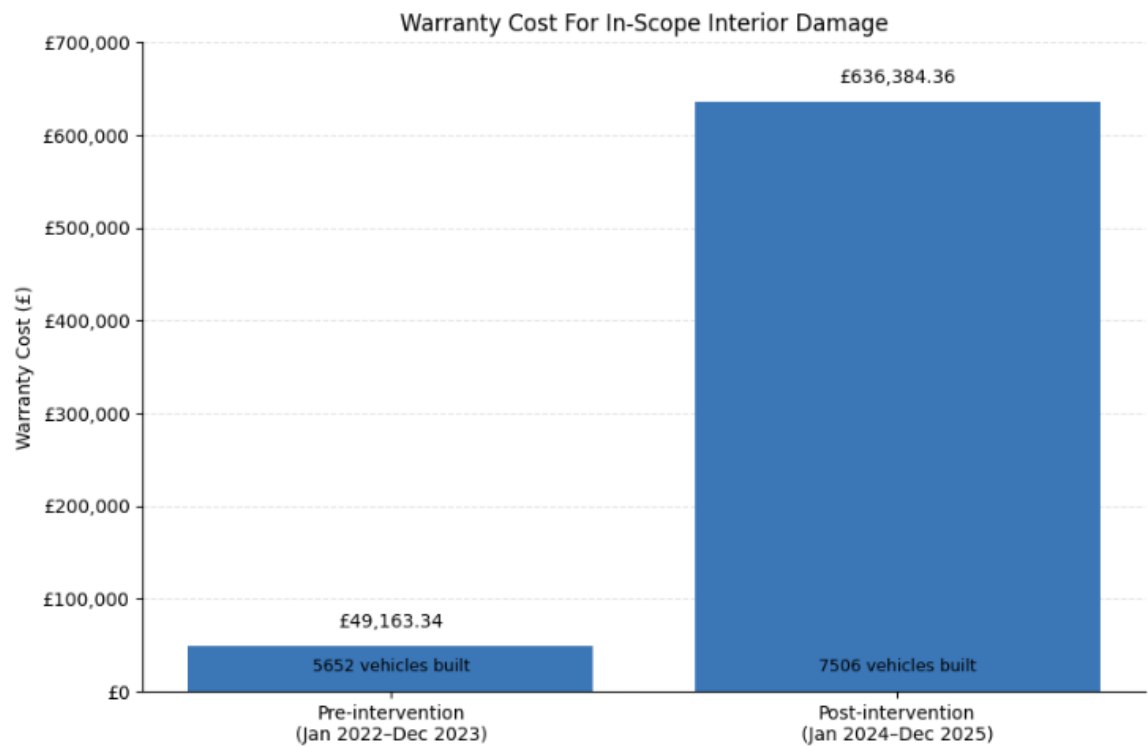


Figure 7 - Warranty Cost for In-Scope Interior Damage Before and After Protective Cover Introduction, with Vehicle Build Volume Shown for Context

This represents an increase of £587,221.02, equivalent to approximately 1194.4% compared with the baseline period. When warranty cost is normalised against vehicle build volume, the baseline period equates to approximately £8.70 per vehicle built, compared with approximately £84.78 per vehicle built in the post-intervention period. This represents an increase of approximately £76.08 per vehicle built, or 874.5%. Therefore, the warranty increase cannot be explained by higher production volume alone.

The warranty result does not align with the improvement shown in internal vehicle-level damage prevalence. Although the proportion of vehicles receiving at least one internal interior damage call reduced after protective cover introduction, downstream warranty cost

increased substantially. This suggests that the internal improvement did not translate into reduced warranty exposure and requires further investigation into defect severity, replacement decisions, missed internal detection, transport damage, dealer handling and warranty coding.

5 Discussion and Conclusions

5.1 Overview of Findings

The results indicate that the introduction of protective covers was associated with a reduction in the proportion of vehicles receiving at least one interior damage call. During the pre-intervention period, January 2022 to December 2023, 71.4% of vehicles had at least one recorded interior damage call. During the post-intervention period, January 2024 to December 2025, this reduced to 44.3%. This represents an absolute reduction of 27.1 percentage points and a relative reduction of 37.9% in the proportion of vehicles affected.

However, the wider results show that the outcome is not purely positive. Although fewer vehicles were affected proportionally, the total internal repair/rework time for the three main defect types increased from 3195.97 hours pre-intervention to 4025.90 hours post-intervention. As a result, estimated internal labour repair cost increased from £111,890.79 to £140,946.76, representing a 26.0% increase. This creates a mixed result: vehicle-level prevalence improved, but the labour burden associated with repairable interior damage increased.

5.2 Interpretation of the Reduction in Vehicle-Level Damage Prevalence

The reduction in vehicle-level prevalence suggests that the overall likelihood of a vehicle receiving at least one interior damage call decreased after the introduction of protective covers. This is important because production volume increased from 5652 vehicles in the pre-intervention period to 7506 vehicles in the post-intervention period. Therefore, the reduction cannot be explained by a lower number of vehicles being built. Reporting the outcome as a percentage of vehicles affected provides a more reliable comparison than using raw counts alone.

This result is also consistent with the intended function of temporary protective covers. The literature indicates that protection can reduce direct contact between finished surfaces and potential damage sources where contact cannot be fully eliminated through process design (Bhushan, 2013; Juran and Godfrey, 1999). In this case, the reduction in affected vehicles suggests that protective covers may have contributed to improved containment of some damage mechanisms, particularly where damage was caused by incidental contact during assembly, internal movement, rework or final preparation.

However, the result should not be interpreted as proof that the covers alone caused the improvement. The study uses a retrospective before-and-after design, meaning other

operational changes during the same period may also have influenced the result. These may include changes in workforce experience, inspection practice, part handling, production mix, reporting behaviour, supplier quality or wider process discipline. For this reason, the reduction should be interpreted as an associated improvement rather than a fully isolated causal effect.

5.3 Interpretation of Internal Rework Time and Labour Cost

The internal rework results show a different pattern from the vehicle-level prevalence results. Total repair/rework time increased by 829.93 hours, from 3195.97 hours to 4025.90 hours. The associated labour cost increased by £29,055.97, from £111,890.79 to £140,946.76. This indicates that while fewer vehicles were affected proportionally, the total repair burden increased across the main repairable defect categories.

A key driver of this increase appears to be the scuff category. Scuff defects increased from 6263 to 8216, and the mean time to repair increased from 15 minutes to 25 minutes. This suggests that post-intervention scuff defects may have required longer repair activity, or that the nature, location or severity of scuffs changed over time. Scratch defects also increased in total quantity and repair time, while damage defects reduced substantially. This pattern suggests that the intervention may have reduced some forms of more obvious damage, while scuffing remained a significant issue or became more visible within the defect mix.

This is an important finding because the protective covers were expected to deliver a stronger reduction in repair burden than the results currently show. The reduction in vehicle-level prevalence suggests some improvement in overall damage occurrence; however, the increase in scuff quantity, scuff repair time and total labour cost indicates that the current protection approach is not fully controlling the dominant repair burden. This may suggest that the protective cover design is not sufficiently effective for the highest-risk contact mechanisms, or that the protection process is not being applied consistently throughout the production and delivery stages.

Possible causes include incomplete coverage of high-risk areas, variation in application quality, poor retention during vehicle movement, covers being removed too early, debris being trapped beneath the protection, or operators not consistently following the intended protection standard. These explanations cannot be confirmed from the current dataset alone, but they provide a clear direction for further investigation. These potential causes align with the damage mechanisms identified in the literature review, particularly abrasion from sliding contact, debris-driven third-body wear, poor retention during movement and inconsistent

protection removal timing (Bhushan, 2013; Imai, 1997; Montgomery, 2019). The results therefore support refinement and control of the protection process rather than simply assuming that the presence of protective covers is sufficient to prevent interior damage.

When total labour cost is normalised against vehicle volume, the result is more balanced. The estimated internal labour repair cost per vehicle built reduced slightly from approximately £19.80 per vehicle pre-intervention to approximately £18.78 per vehicle post-intervention. This suggests that increased production volume partially offsets the higher total labour cost. However, the repair cost per affected vehicle increased from approximately £27.74 to approximately £42.38, indicating that vehicles requiring repair in the post-intervention period may have required more labour per affected unit. This supports the view that the result should be interpreted in terms of both frequency and severity, rather than frequency alone.

5.4 Effectiveness Against the Success Criteria

The first success criterion required a reduction of at least 15% in in-scope interior damage versus baseline. Based on vehicle-level prevalence, this criterion was met because the proportion of vehicles affected reduced by 37.9% relative to baseline. This indicates a meaningful improvement in the rate of affected vehicles.

However, the cost-related criterion is less clearly achieved. Although the labour cost per vehicle built reduced slightly, total internal labour repair cost increased by 26.0% across the two-year comparison period. This means that the intervention cannot be described as an unqualified cost reduction based on the currently available internal results. The cost outcome is mixed: the vehicle-level rate improved, but total repair effort and total labour cost increased.

The throughput criterion also remains only partially assessed. Repair/rework time provides a useful indicator of labour burden, but it does not fully confirm whether production throughput was negatively affected. Additional evidence would be required, such as technician capacity, offline repair queue time, first-time-through performance, or vehicle delay data. Therefore, the throughput criterion cannot be fully confirmed using the current dataset alone.

5.5 Warranty Interpretation

Warranty performance does not follow the same pattern as the internal vehicle-level prevalence result. Although internal prevalence reduced after protective cover introduction,

warranty cost increased substantially in the post-intervention period, even after normalising against vehicle build volume. This indicates that the factory-level improvement did not translate into a reduced downstream cost burden.

This finding suggests that the remaining interior damage concerns may be more severe, more expensive to rectify, or more likely to escape internal detection and be identified later by dealers or customers. It may also indicate that some damage is being introduced after the vehicle leaves the factory, such as during transport, dealer handling or final customer preparation. Differences in dealer repair decisions, part replacement choices, labour rates and warranty coding may also have contributed to the increase. Warranty cost is interpreted cautiously because external failure cost can be influenced by claim severity, repair route, labour rate, replacement decisions and coding practice, not only by the number of defects created in production (Feigenbaum, 1991; Juran and Godfrey, 1999).

The warranty result therefore changes the overall interpretation of the intervention. The protective covers appear to be associated with fewer internally recorded affected vehicles, but they cannot be considered successful from a delivered-quality perspective if downstream warranty cost has increased. Further investigation is required to determine whether the warranty increase is driven by missed internal detection, defect severity, post-factory handling, claim coding, or weaknesses in the current protection process.

5.6 External Validity and Transferability

The findings are most directly applicable to the Aston Martin St Athan production environment because the results are based on site-specific processes, materials, inspection standards, production mix and repair practices. The conclusions should therefore not be treated as universally transferable to all vehicle manufacturing environments without further validation. However, the underlying mechanisms are transferable because abrasion, scuffing, scratching, contamination and contact damage are common risks in manual trim assembly and vehicle preparation processes.

The results are particularly relevant to low-volume, high-value manufacturing environments where manual handling content is high, customer tolerance for cosmetic defects is low, and repair or replacement of bespoke interior components is costly. In these environments, temporary protection may reduce some direct contact damage, but only where cover design, coverage, retention, cleanliness and removal timing are controlled consistently. Therefore, the broader learning from this dissertation is not that protective covers are automatically

effective, but that they must be treated as a controlled process with defined standards and regular adherence checks.

5.7 Limitations of Findings

The main limitation of this evaluation is that it is based on a retrospective before-and-after comparison rather than a controlled experiment. This means that the protective covers were not tested in isolation under controlled conditions. Other factors may have changed between the pre- and post-intervention periods, including production volume, operator experience, inspection consistency, reporting practices, supplier quality or wider process changes.

A second limitation is that the analysis relies on recorded defect data. Cosmetic defects are judgement-based and can be influenced by inspection conditions, reporting discipline and classification rules. This is particularly important for scuffs, scratches and leather surface marks, where different observers may classify similar marks differently. For this reason, the results should be interpreted as operational evidence rather than a perfect measurement of all interior damage.

A third limitation is that repair time is used as a practical proxy for severity. This is appropriate because longer repair time generally indicates greater labour burden, but it does not capture all forms of severity. For example, a low-time repair may still affect customer perception if it occurs in a highly visible area, while a high-time repair may be caused by access difficulty rather than damage severity alone. Therefore, repair time should be interpreted alongside defect type, affected component and warranty outcomes, rather than as a complete measure of damage severity on its own.

5.8 Conclusion

Overall, the protective cover intervention appears to be associated with an improvement in vehicle-level damage prevalence, with the proportion of affected vehicles reducing from 71.4% in the pre-intervention period to 44.3% in the post-intervention period. This represents a 37.9% relative reduction, exceeding the project's target of a 15% reduction in in-scope damage prevalence. However, the repair time, labour cost and warranty results indicate that the current protection approach has not delivered the level of improvement expected. Total repair/rework time increased from 3195.97 hours to 4025.90 hours, while estimated internal labour repair cost increased from £111,890.79 to £140,946.76. Warranty cost also increased substantially, from £49,163.34 to £636,384.36, indicating that the internal prevalence improvement did not translate into reduced downstream cost. The findings therefore suggest

that protection alone is not sufficient unless the design, coverage, retention, cleanliness, application/removal process and post-factory damage controls are managed consistently. The intervention should be treated as partially effective in reducing internal vehicle-level prevalence, but not yet effective in reducing the overall repair and warranty cost burden. Future work needs to identify whether the remaining cost burden is caused by ineffective cover design, poor adherence to the protection standard, incorrect removal timing, debris entrapment, uncovered contact points, missed internal detection, transport damage, dealer handling or warranty coding effects.

6 Recommended Further Work

6.1 Overview

The findings from this dissertation show that the introduction of protective covers was associated with a reduction in the proportion of vehicles receiving at least one interior damage call. However, the increase in repair/rework time and internal labour cost indicates that the intervention did not deliver the level of improvement expected. The results therefore suggest that further work should focus on understanding why the current protection strategy is not fully controlling interior damage, rather than assuming that the presence of protection is sufficient.

It should also be acknowledged that the available data was more limited than anticipated at the start of the project. The analysis provided useful evidence on overall damage prevalence, defect type, rework time, estimated labour cost and warranty cost, but it did not provide complete visibility of all root causes, adherence issues, exact point of damage creation, claim severity drivers or the specific reasons for the post-intervention warranty cost increase. For this reason, the recommendations have shifted from solely analysing the historic data to defining practical next steps for further investigation, process control and cross-functional ownership.

6.2 Immediate Actions: 0–3 Months

The first recommended action is to complete a focused audit of the current protective cover process. This should assess whether covers are being fitted correctly, whether they remain fitted throughout the required production stages, whether they are removed too early, and whether they are reapplied after technicians have removed them to complete work. This is important because current observations suggest that dirt and debris can become trapped underneath covers when they are repeatedly removed and refitted. In addition, some technicians may not consistently refit the covers, and some covers may not be fitted at all. These issues would reduce the effectiveness of the intervention and could explain why scuff-related repair time remains high.

The audit should include direct line-side observation, technician feedback and photographic evidence of non-conforming conditions. Attention should be given to the door card covers, as these have been observed to fall off due to poor fit. Where covers do not remain securely in place, the issue should be treated as a design or process failure rather than an operator-only

problem. A protection system cannot be considered robust if it relies on repeated manual correction or if it is difficult to use consistently during normal production conditions.



Figure 8 - Door Card Protective Cover Fitted During Production

A second immediate action is to review the standard operating procedure for protective cover application, removal and refitting. The current process should be checked to confirm whether it clearly defines when the covers must be fitted, who is responsible for refitting them after removal, what condition the surface must be in before protection is applied, and when the cover can be removed permanently. The standard should also include basic cleanliness checks to reduce the risk of trapping debris beneath the cover. The procedure should define how protective covers are stored when temporarily removed. At present, covers may be held line-side in shared containers, which creates a risk of debris transfer, creasing or contamination before refitting. Storage requirements should therefore specify a clean, dry and protected location that prevents floor contact and reduces the likelihood of debris being trapped beneath the cover. Where no clear standard exists, a revised standard should be developed and communicated to production teams.

6.3 Strengthening Defect Identification Before Sale

A further recommendation is to improve the defect identification process before vehicles leave the facility. At present, photographic evidence is taken at the end of the process before vehicles are sold or released from site, but this is normally limited to wider images of each side of the vehicle from a distance. This provides limited visibility of individual interior panels and may not capture smaller scuffs, scratches or localised damage clearly enough to support root-cause investigation or warranty defence.

It is recommended that the current end-of-process photographic standard is revised to include close-up images of individual high-risk panels and protected components. This should include, where practical, door cards, centre console, instrument panel, steering wheel and other areas known to generate repeated damage concerns. A more detailed photographic record would support two purposes. Internally, it would help identify defects that have escaped earlier inspection and allow the business to understand where damage is still being missed before sale. Externally, it would provide stronger evidence to distinguish between damage created within the facility, damage occurring during transport, and damage identified later by the dealer.

This recommendation is particularly important for warranty interpretation. If a defect is reported after delivery, stronger photographic evidence from the point of release would help determine whether the issue was present before dispatch or introduced later in the delivery chain. This could reduce ambiguity in warranty claims and support more accurate allocation of responsibility between manufacturing, transport and dealer handling.

6.4 Medium-Term Actions: 3–6 Months

Following the initial audit, the protective cover design should be reviewed against the main failure modes identified during production use. The current evidence suggests that some covers are not fully effective because they can allow dirt or debris beneath them, require repeated removal and refitting, or fail to remain securely fitted. The door card covers should be prioritised because poor fit has already been observed. Design improvements could include revised attachment features, improved edge retention, clearer coverage of high-risk contact zones, and materials that reduce the risk of marking if minor movement occurs.

A controlled validation activity should then be completed after any cover design or process changes are made. This does not need to be a large-scale experimental study, but it should compare a defined sample of vehicles using the revised protection method against the current method. The validation should record defect type, location, whether protection was

present, whether debris was observed, whether the cover had moved, and whether the cover had been removed and refitted during the process. This would provide stronger evidence on whether the revised standard reduces the scuff and scratch burden that remained significant in the post-intervention results.

Training and ownership should also be strengthened. The protective cover process should not sit only within warranty analysis, because many of the likely causes occur within production control, production operations, inspection, rectification and vehicle movement. The findings from this dissertation therefore need to be transferred to the departments that directly control cover application, adherence, removal timing and workstation practice. Clear ownership should be assigned for maintaining the protection standard, auditing adherence and reacting when non-compliance or design failure is observed. Sustained improvement requires the protection standard to be embedded into daily management, process audit and standardised work rather than treated as a one-off corrective action (Imai, 1997; Liker, 2004; VDA, 2016).

6.5 Longer-Term Actions: 6–12 Months

In the longer term, Aston Martin should consider introducing a more formal monitoring process for interior damage and protective cover performance. This could include a simple dashboard showing damage prevalence, DPV, repair time, affected component, defect type and cost over time. Tracking these measures monthly would make it easier to identify whether improvements are sustained or whether damage begins to increase again due to process drift. Monthly monitoring would also support continuous improvement by allowing abnormal trends to be detected earlier and linked back to process conditions before they become embedded as repeat failure modes (Deming, 1986; Montgomery, 2019).

A further long-term action is to link defect records more closely to photographic evidence and location-level data. Where possible, defects should be recorded with clear location information, image evidence, defect type and suspected process stage. This would support more accurate root-cause analysis and reduce reliance on broad defect categories. It would also help distinguish between damage that is likely to be caused during production, vehicle movement, transport, dealer handling or customer use.

Finally, the warranty results require more detailed investigation to explain why downstream cost increased despite the reduction in internal vehicle-level damage prevalence. Warranty cost is a lagging indicator, but it remains essential for assessing whether internal improvements are reflected after delivery. The completed warranty comparison showed that

total warranty cost increased substantially after the protective covers were introduced, indicating a need to investigate claim severity, replacement decisions, missed internal detection, transport damage, dealer handling, warranty coding and customer-facing defect detection.

6.6 Final Recommended Approach

The recommended approach is to treat protective covers as a partially effective but currently under-optimised control. The reduction in vehicle-level damage prevalence suggests that protection may be contributing to improvement, but the increase in scuff-related repair burden shows that the current system is not robust enough. The priority should therefore be to improve the protection process through adherence audits, revised standards, better photographic evidence, cover design review and cross-functional ownership.

The most immediate priority is to confirm whether the remaining damage is caused by poor cover design, poor adherence, debris entrapment, early removal or uncovered contact points. Once this is understood, the business can revise the protection standard and validate whether the updated process reduces both the number of affected vehicles and the labour burden associated with repair. This would provide a stronger basis for sustained delivered-quality improvement and a clearer route to reducing both internal rework and future warranty exposure.

6.7 Summary of Recommended Actions

Table 4 summarises the recommended further actions by timeframe, indicative effort and expected benefit. The table is intended to show how the recommendations can be prioritised in practice, moving from immediate process-control actions through to medium-term validation and longer-term monitoring.

Table 4 - Summary of Recommended Further Actions, Indicative Effort and Expected Benefit

Recommendation	Timeframe	Indicative effort	Expected benefit
Audit protective cover adherence, including correct fitment, removal timing and refitting after work	0–3 months	Low	Identifies whether poor adherence is reducing the effectiveness of the protection process
Revise cover procedure for application, storage, cleanliness, refitting and removal timing	0–3 months	Low to medium	Improves consistency and reduces variation between technicians and process stages

Recommendation	Timeframe	Indicative effort	Expected benefit
Improve end-of-process photographic evidence by capturing close-up images of high-risk panels	0–3 months	Medium	Improves defect detection before release and supports warranty/transport responsibility decisions
Review and redesign poorly fitting covers, particularly door card covers	3–6 months	Medium	Reduces cover movement, fall-off and uncovered contact points
Evaluate alternative cover materials or suppliers where current protection allows marking, debris entrapment or poor retention	3–6 months	Medium	Reduces risk of secondary scuffing and improves compatibility with interior surfaces
Complete controlled validation of any revised cover design or process standard	3–6 months	Medium	Confirms whether changes reduce scuff, scratch and repair-time burden under normal production conditions
Review fixtures, packaging and high-risk contact points around protected components	3–6 months	Medium	Reduces damage mechanisms not fully controlled by covers alone
Introduce monthly monitoring of damage prevalence, DPV, repair time and labour cost using a dashboard/SPC approach	6–12 months	Medium	Supports sustained control and early detection of process drift
Investigate the drivers of the post-intervention warranty cost increase	6–12 months	Medium	Identifies whether the increase is driven by claim severity, replacement decisions, missed internal detection, transport damage, dealer handling, warranty coding or customer-facing defect detection

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