Redesign of a Toyota Hilux Cargo Bed for Mining Support Activities: An Integrated Approach Based on Concurrent Engineering, the V-Model and DFMEA

Fernando Castillo Meneses[1*], Santiago Leonardo Castillo Pulido[1], Iris Ivonne Ovalle Salvador[1], Daniela Montserrat Samperio Díaz[1]

Industrial Design Engineering Program, Tecnológico Nacional de México / Instituto Tecnológico de Pachuca,Pachuca de Soto, Hidalgo, Mexico

DOI: https://doi.org/10.47772/IJRISS.2026.102000064

Received: 28 October 2026; Accepted: 02 November 2026; Published: 20 November 2026

ABSTRACT

Light pickups such as the Toyota Hilux serve as support vehicles in mining, where they carry tools, spare parts and maintenance equipment over unpaved and often wet roads. Their cargo beds, however, are designed for general use, and the literature on cargo bodies deals mainly with heavy haul and dump trucks. This paper presents the design and verification framework for a modular cargo bed system for an eighth-generation Toyota Hilux used in mining support activities in the state of Durango, Mexico. Concurrent engineering is adopted as the design approach, the V-model links each requirement to its verification, and design failure mode and effects analysis (DFMEA), following the AIAG-VDA method, is used to anticipate design risks. The reference vehicle was selected through a sequential screening of commercial relevance, availability of technical data and suitability for mining work. An exploratory interview with a professional who supplies materials to mining operations identified four preliminary design priorities: protection against abrasion and impact, safer access to cargo without loading over the sidewalls, organized and secured storage for maintenance equipment, and mechanical simplicity for maintenance. On this basis, a modular architecture was defined that keeps the original bed and adds removable modules: a protective anti-slip floor, side drawers, a front tool box and tie-down points with rated capacity. The paper reports this architecture together with a traceability matrix of eleven requirements and a first DFMEA failure analysis of the main interfaces. Verification will combine computer-aided design, linear static finite element analysis under four load cases, a payload and rear-axle check, and ergonomic assessment with REBA and the revised NIOSH lifting equation. The contribution is an integrated route that connects user needs, structural verification and design risk analysis for light mining support vehicles.

Keywords: Cargo bed redesign, Mining support vehicles, Concurrent engineering, DFMEA, Finite element analysi

INTRODUCTION

Mining operations depend on support vehicles that can carry tools, spare parts and equipment safely and in an orderly way. Harsh site conditions, though, make it worth asking whether these vehicles actually fit the job. Durango is a relevant setting for that question. It is one of the leading mining states in Mexico: in 2023 it contributed 22.7% of the national silver output, second only to Zacatecas, and it ranked second in zinc production (Cámara Minera de México [CAMIMEX], 2024). Operations of this kind rely on light pickups to move people, tools and supplies between work areas, workshops and warehouses.

This study takes the Toyota Hilux as the reference vehicle and focuses on redesigning its cargo bed to explore improvements in structural strength, ergonomics and adaptability to mining work. The research does not assume that the original bed has structural deficiencies. It looks instead for opportunities for improvement by assessing the bed's configuration, accessibility and capacity to organize equipment under real operating conditions.

Structural strength comes first, since any component must withstand the loads of its intended use. Ary et al. (2020) used finite element analysis to examine the structural behavior of a vehicle chassis, and Osborne and Prater (2010) compared conceptual and detailed finite element models for pickup truck boxes. Neither study deals with the Hilux cargo bed directly. Both show why geometry, material properties and loading conditions should be evaluated before any structural change is proposed.

Strength alone is not enough. Workers handle the vehicle every day, and tool arrangement, access height, available space and ease of handling all affect comfort and safety. Sakinala et al. (2024) studied ergonomic risks in underground mining machinery through worker participation and an assessment of working conditions, stressing that risks should be identified from actual tasks and environments. The redesign should therefore draw on the experience of the people who use the vehicle, not on technical criteria alone.

Feasibility is the other piece. It depends on manufacturing processes, assembly, material availability and the costs of implementation and maintenance. Formentini et al. (2022) reviewed design for manufacturing and assembly methods in mechanical product development, while Rihar et al. (2021) examined how concurrent engineering, teamwork and project coordination shape new product development. Combining these approaches allows the proposal to meet structural and ergonomic needs without losing sight of how it would be built and applied.

Published work on cargo bodies concentrates mostly on structural analysis, and mostly on large haul and dump trucks rather than light pickups (Whalen, 2002; Zhu et al., 2012). Ergonomic studies of vehicle bodies, for their part, seldom carry their findings into structural design (Reiman & Putkonen, 2012). This paper addresses that gap. Its objective is to propose a redesign of the Toyota Hilux cargo bed for mining support activities that improves structural resistance, ergonomics and adaptability within the manufacturer's payload limits, with manufacturing, maintenance and cost considered from the start. The contribution is methodological: requirements obtained in the field, structural verification by finite element analysis (FEA) and design risk analysis by DFMEA are combined within a single concurrent engineering and V-model framework. The sections that follow review the literature, set out the theoretical framework and the method, and present the preliminary results and their discussion.

LITERATURE REVIEW

The review covered three groups of studies: structural analysis of cargo bodies, ergonomics of vehicle bodies and mining machinery, and integrated product development methods. Priority was given to peer-reviewed articles and conference papers, and to theses only when they reported a complete finite element procedure. Works that treated vehicles only from an economic perspective, or that lacked technical detail on structure or ergonomics, were left out. Table 1 summarizes the studies retained.

Table 1: Studies retained in the literature review

Authors (year)	Object of study	Method	Relevance to this study
Osborne & Prater (2010)	Pickup truck boxes	Conceptual vs. detailed FE models	Supports the use of simplified FE models at the concept stage and detailed models later
Whalen (2002)	Dump bodies of large mining haul trucks	FEM of floor stiffener cracking	Shows that cracks concentrate at welded stiffener intersections of the floor
Zhu et al. (2012)	Dump truck body floor under ore impact	Explicit dynamic FEA	Relates impact mass and drop height to floor beam cracking
Ary et al. (2020)	Urban vehicle chassis	Static FEA	Example of structural assessment with defined loads and boundary conditions

Authors (year)	Object of study	Method	Relevance to this study
Reiman & Putkonen (2012)	Truck body work outside the cab	Participative video analysis	Identified 262 discomfort and risk factors and turned them into design proposals
Sakinala et al. (2024)	Underground mining machinery operators	Participatory ergonomics and fuzzy analysis	Supports identifying risks from real tasks with worker participation
Al-Ashaab et al. (2009)	Automotive electronic/software systems	Set-based concurrent engineering with the V-model	Direct precedent for combining concurrent engineering and the V-model
Formentini et al. (2022)	Mechanical products	Systematic review of DFMA methods	Basis for manufacturing and assembly criteria
Rihar et al. (2021)	New product development	Concurrent engineering implementation	Role of coordination and teamwork in concurrent engineering

Two patterns stand out. Structural studies of cargo bodies rely almost exclusively on FEA, and they deal with heavy dump bodies that carry ore, not with the beds of light vehicles that carry tools and people (Whalen, 2002; Zhu et al., 2012). Osborne and Prater (2010) are an exception on the vehicle side, but their work concerns modeling strategy rather than a redesign for a specific use. Ergonomic studies, in turn, identify risks well but stop before structural design (Reiman & Putkonen, 2012; Sakinala et al., 2024). No study was found that treats the cargo bed of a light mining support vehicle as a whole, linking user needs, structure and design risk. Fatigue life prediction, multi-objective optimization and discrete element modeling appear often in the heavy-truck literature; they fall outside the scope of this first study and are left for future work.

THEORETICAL FRAMEWORK

The Mining Support Vehicle and Its Cargo Bed

At a mining site, light support vehicles move tools, spare parts, consumables and technical staff between work faces, workshops and warehouses. They do not haul ore, but their availability has a direct effect on maintenance and repair times. The cargo bed of a pickup such as the Toyota Hilux is designed for general use. In mining, it has to cope with unpaved roads, abrasive dust, impacts during loading and unloading, and constant vibration. For this reason, the redesign draws on six theoretical areas: structural mechanics, material selection, ergonomics, design for manufacture and assembly, product development methodologies and design risk analysis.

Structural Strength and Finite Element Analysis

A structural component does its job when the stresses it carries stay below the strength of the material with a reasonable margin. For ductile materials such as steel, the most widely used criterion is von Mises distortion energy. It yields an equivalent stress (σ') that is compared with the yield strength (S^y) to calculate the safety factor, $n = S^y/\sigma'$ (Budynas & Nisbett, 2015).

When the geometry is complex, as in a bed with side rails, cross members, welds and anchor points, solving for stresses by hand stops being practical. FEA divides the part into small elements, solves the equilibrium equations in each one and produces stress and deformation maps (Zienkiewicz et al., 2013). How reliable the result is depends on three things: boundary conditions that reflect how the bed is actually mounted to the chassis, loads justified by real use, and a mesh that has converged. Ary et al. (2020) applied this approach to a vehicle chassis, and Osborne and Prater (2010) showed how the level of model detail should follow the stage of the design.

Static loading does not tell the whole story. On mine roads, the bed is subjected to repeated stresses that can cause fatigue cracks, especially at welded joints and abrupt changes in cross-section. The Palmgren–Miner rule

estimates cumulative damage as $D = \Sigma(n^i/N^i)$, where n^i is the number of cycles applied at a given stress level and N^i is the number of cycles the material could withstand at that level. Failure is expected as D approaches 1 (Miner, 1945). Fatigue is acknowledged here as a governing failure mechanism, but its quantitative assessment requires measured load spectra and is outside the scope of this study.

Material Selection

Choosing a material means balancing strength, weight, wear resistance, cost and ease of fabrication. Ashby (2011) proposes handling this trade-off with performance indices that relate those properties to the function of the part. Three material families are of interest here. Advanced high-strength steels allow thinner sections without losing stiffness. Wear-resistant steels stand up to abrasion from rocks and tools on the bed floor. Aluminum alloys cut weight, though their fatigue strength and weldability call for more care. Any change of material has to be checked against the manufacturer's rated payload, because every kilogram added to the bed is taken away from usable load capacity.

Ergonomics and Human Factors

Ergonomics studies how to fit work to people's capabilities. For a cargo bed, that means setting access heights, reach distances and the location of each tool based on the anthropometric measurements of the user population (Pheasant & Haslegrave, 2006). A bed that forces workers to climb in to reach the far end, or to lift heavy equipment over the side wall, raises the risk of musculoskeletal injury.

There are established tools for measuring this risk. The REBA method scores whole-body posture during a task (Hignett & McAtamney, 2000). The revised NIOSH lifting equation calculates the recommended weight limit for a lift based on height, distance and frequency (Waters et al., 1993). In Mexico, NOM-036-1-STPS-2018 regulates the identification and control of risks from manual load handling (Secretaría del Trabajo y Previsión Social [STPS], 2018). Whole-body vibration is assessed under ISO 2631-1 (International Organization for Standardization [ISO], 1997), which matters because technicians travel long stretches over rough terrain. Working with underground mining machinery, Sakinala et al. (2024) showed that these risks are best identified from actual tasks and with worker participation.

Design for Manufacture and Assembly

A redesign that cannot be built with the available resources never leaves the drawing board. Design for manufacture and assembly (DFMA) aims to reduce part count, standardize components and simplify joints in order to lower production costs and times (Boothroyd et al., 2011). In a cargo bed for mining, repairability carries extra weight: the modules that wear fastest should be replaceable in the mine's own workshop without specialized equipment. Formentini et al. (2022) reviewed how these methods are integrated into mechanical product development.

Concurrent Engineering and the V-Model

Concurrent engineering holds that design, manufacturing, cost and use should be addressed from the outset and in parallel rather than one after another (Prasad, 1996). This avoids finding out late in the process that a structural solution is impossible to build or awkward to use. Rihar et al. (2021) documented its implementation and highlighted the role of teamwork and project coordination.

The V-model complements this approach. On the left side, needs are broken down into system requirements and then into component requirements. On the right side, each level is verified and validated against what was defined at its counterpart (Forsberg & Mooz, 1991). Al-Ashaab et al. (2009) combined set-based concurrent engineering with the V-model in automotive development, which is the closest precedent for the framework used here.

Applied to this project, every requirement that emerges from the initial assessment has an associated verification: FEA for strength, ergonomic evaluation for access and cost estimates for feasibility.

Design Failure Mode and Effects Analysis

DFMEA anticipates how a design could fail, what the effects of each failure would be and which controls prevent or detect its causes before the design is released. The AIAG and VDA handbook organizes the analysis in seven steps: planning and preparation, structure analysis, function analysis, failure analysis, risk analysis, optimization and results documentation (Automotive Industry Action Group & Verband der Automobilindustrie [AIAG & VDA], 2019). Instead of the traditional risk priority number, the handbook ranks actions through an action priority table that combines severity, occurrence and detection ratings. In this study DFMEA is borrowed from the automotive quality toolset as a design tool; its use does not imply certification under IATF 16949.

Regulatory Framework

The proposed cargo bed is an aftermarket modification to a certified light vehicle operating in a Mexican mining workplace, so it must meet both occupational safety rules and vehicle and road regulations. Mexican Official Standards (NOM) are mandatory. ISO and AWS standards are voluntary in Mexico, and this study uses them only as technical references for testing.

At the mine, NOM-023-STPS-2012 applies to every workplace engaged in underground or open-pit exploration and exploitation, regardless of its scale, and the redesign must fit into the mine's risk analysis (STPS, 2012). For loading tasks, NOM-036-1-STPS-2018 governs ergonomic risk in the routine manual handling of loads, excluding those under 3 kg (STPS, 2018), and ISO 11228-1:2021 adds quantitative limits for lifting and carrying (ISO, 2021). These two documents set the criteria for access heights, reach and tool placement. If the added mass changes vibration exposure, NOM-024-STPS-2001 (STPS, 2002) and ISO 2631-1 apply, the latter with its 2010 amendment (ISO, 2010). Fabrication and repair must follow NOM-027-STPS-2008 for welding and cutting (STPS, 2008), with AWS D1.1/D1.1M:2025 as the reference for weld quality (American Welding Society, 2025).

On the vehicle side, the redesign must not degrade the safety devices required by NOM-194-SE-2021 (Secretaría de Economía, 2022). On federal roads, the load must be arranged, secured and covered so it does not endanger people or property, and it must not protrude laterally or exceed the permitted height (Secretaría de Seguridad Pública, 2012). This calls for anchor points, which will be checked using the static tests of ISO 27956:2009 by analogy (ISO, 2009). The manufacturer's gross vehicle weight rating, rated payload and axle limits are fixed constraints, since any mass added to the bed reduces usable payload. Within the V-model, each of these requirements is assigned a verification test (Table 2).

Table 2: Regulatory instruments applicable to the cargo bed redesign

Instrument	Type	Scope	Derived requirement for the redesign
NOM-023-STPS-2012	Mandatory (Mexico)	Safety and health in underground and open-pit mines	Redesign documented for inclusion in the mine's risk analysis
RFSST (2014), Art. 21	Mandatory (Mexico)	Employer program for handling, transport and storage of materials	Tool storage layout consistent with the site's materials program (STPS, 2014)
NOM-036-1-STPS-2018	Mandatory (Mexico)	Ergonomic risk in manual load handling (≥ 3 kg)	Access heights, reach and tool placement assessed against its criteria
NOM-024-STPS-2001	Mandatory (Mexico)	Occupational exposure to vibration	Vibration checked if added mass or its distribution changes
NOM-027-STPS-2008	Mandatory (Mexico)	Safety in welding and cutting	Safe fabrication and repair procedures for the bed

Instrument	Type	Scope	Derived requirement for the redesign
NOM-194-SE-2021	Mandatory (Mexico)	Safety devices in new light vehicles	No original safety device removed, obstructed or degraded
Federal Highway Traffic Regulation, Arts. 75 and 77	Mandatory (Mexico)	Securing and dimensions of loads on federal roads	Anchor points, side containment, no protruding loads
ISO 11228-1:2021	Voluntary reference	Limits for lifting, lowering and carrying	Quantitative limits for loading tasks
ISO 2631-1:1997/Amd 1:2010	Voluntary reference	Whole-body vibration measurement	Measurement method, if vibration is assessed
ISO 27956:2009	Voluntary reference	Lashing points and partitions in delivery vans	Static test method for anchor points (by analogy)
AWS D1.1/D1.1M:2025	Voluntary reference	Welding of structural steel	Weld procedure and inspection criteria for reinforcements
Manufacturer specifications	Mandatory constraint	GVWR, payload and axle ratings of the specific version	Added mass within rated payload

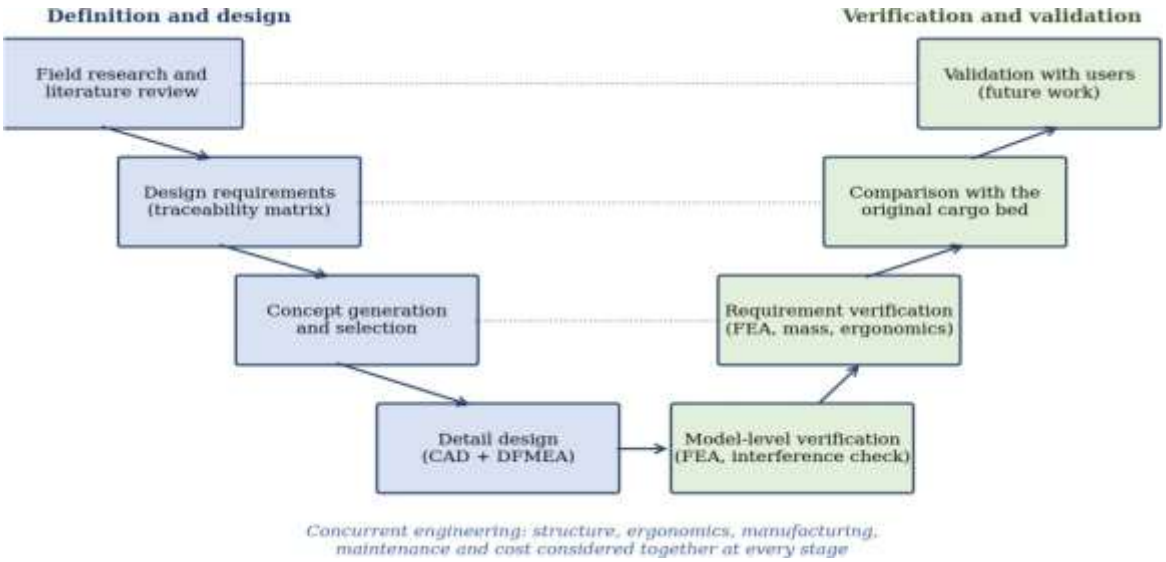
METHODOLOGY

Research Design

This is an applied, design-oriented study. The work reported here covers the definition stages of the project; the simulation-based comparison between the original and the proposed cargo bed, under the same load cases and criteria, is the next stage. The study is not experimental or quasi-experimental, since no variables are manipulated on physical specimens. Concurrent engineering provides the approach, meaning that structure, ergonomics, manufacturing, maintenance and cost are considered together at every decision. The V-model provides the structure. Its left side contains the five design stages (field research, requirements, concepts, detail design and evaluation), and its right side contains the verification of each requirement (Figure 1). DFMEA is applied during detail design to anticipate failures before any prototype is built.

Preliminary needs were obtained through an exploratory, open-ended interview with a professional who supplies materials and equipment to mining operations and is familiar with the use of the Toyota Hilux 4x4 diesel in mining support work. The interview did not follow the formal guide described below. Its purpose was to orient the requirements and the concept, and it is treated as evidence from a single key informant, not as a representative sample of workers or sites.

Figure 1: Methodological framework of the study



Selection of the Reference Vehicle

The reference vehicle was selected through a sequential screening based on three criteria, applied in order so that each one narrows the options left by the previous one. A weighted matrix was not used because its weights would have been difficult to justify. First, commercial relevance: the eighth generation of the Toyota Hilux was the generation sold in Mexico throughout 2016–2025, and it ranked second among pickups in 2024 with 21,370 units and third in 2025 with 19,661 units (Autocosmos, 2026; Durán, 2025). Second, availability of technical information: only versions with official specifications for payload, gross vehicle weight and bed dimensions are retained. Third, suitability for mining support work: the double-cab, four-wheel-drive diesel version was adopted provisionally because it carries a crew and its tools at the same time and offers traction on unpaved and sloped roads. This third step will be closed with the fleet of the participating operation; if the operation uses a different version, that version replaces the provisional one. Third-party safety ratings were considered only as context, since they assess occupant protection and not cargo bed performance.

Population and Sample

The study population comprises the light support vehicles of a mining operation in the state of Durango, Mexico, and the workers who load, unload and transport equipment in them. The identity of the operation is withheld for confidentiality. Sampling is purposive. Vehicles are included if they belong to the selected generation and version and are in regular service. Participants are included if they use the cargo bed in their routine tasks, and a key informant responsible for the fleet or for site safety is also interviewed. The number of workers depends on the access granted by the operation; interviews continue until new ones stop adding new needs (thematic saturation).

Instruments and Data Analysis

Two instruments were designed for the field stage. The field observation record documents, for each vehicle, its identification, the interior dimensions of the bed (length, width, width between wheel arches, side height, floor height above ground and tailgate height), visible damage (cracks, dents, corrosion, broken hinges or latches, previous repairs), the loads carried, the operating environment and the site's internal rules. Measurements are taken with a tape measure and a caliper and supported by photographs with a scale reference. The semi-structured interview has twelve questions for the key informant, about fleet use, loads, damage, repair costs and site rules, and eight shorter questions for workers, about tasks, heavy or awkward loads, climbing into the bed, load securing and tool access. Content validity of both instruments is checked through expert review and a pilot application before fieldwork. Participation is voluntary and anonymous, and workers are identified only by codes.

Interview data, including the exploratory interview, are analyzed through thematic analysis (Braun & Clarke, 2006). Observed facts and reported statements are coded separately, because they carry different weight as evidence. The resulting needs are converted into measurable requirements and recorded in a traceability matrix that assigns each requirement a verification method and links it to the DFMEA. Concepts are then generated and compared in a decision matrix whose criteria come from the requirements; the weights are reported with the matrix so the choice can be audited. The selected concept is modeled in CAD as a master assembly built on the measured envelope of the bed, which allows interference checks with the tailgate, the cab and the wheel arches.

The DFMEA follows the seven AIAG-VDA steps (AIAG & VDA, 2019). The structure analysis decomposes the bed into its modules and interfaces, the function analysis derives functions from the requirements, and failure modes are rated for severity, occurrence and detection to obtain the action priority of each one.

Structural verification uses linear static FEA with shell elements for sheet components. Material properties are taken from supplier datasheets for the materials finally selected. Boundary conditions represent the bed-to-frame mounting points. Four load cases are defined: (LC1) the rated payload of the selected version uniformly distributed over the floor; (LC2) the heaviest single item reported in the field, placed at the most unfavorable floor position; (LC3) combined vertical, longitudinal (braking) and lateral (cornering) inertial loads, with

accelerations taken from field measurement or from published values for unpaved roads; and (LC4) the rated force of each tie-down point applied in its most unfavorable direction. Mesh convergence is accepted when the maximum von Mises stress changes by less than 5% between two successive refinements. The design criterion adopted by the authors is a minimum safety factor of 2 against yield:

$$n = S^{y} / \sigma'^{max} \geq 2 \qquad (1)$$

The same load cases are applied to the original and to the proposed configuration, and the two are compared by maximum equivalent stress, maximum deformation, minimum safety factor and added mass. Because the modules reduce usable payload, the mass budget is checked with Equation (2), where Δm is the mass of the modules, m^{load} the operational load, m^{rated} the rated payload and m^{acc} the mass of accessories already installed:

$$\Delta m + m^{load} \leq m^{rated} - m^{acc} \qquad (2)$$

The rear axle load is obtained from a moment balance about the front axle, $F^{r} = \Sigma(m^{i}\, g\, x^{i}) / L^{wb}$, where x^{i} is the longitudinal position of each mass and L^{wb} the wheelbase, and it is compared with the manufacturer's rear axle rating. Ergonomic evaluation compares the current tasks, recorded in the field, with the same tasks under the proposed layout: REBA scores whole-body posture during loading and unloading (Hignett & McAtamney, 2000), the revised NIOSH equation gives the recommended weight limit for repetitive lifts (Waters et al., 1993), and the criteria of NOM-036-1-STPS-2018 are applied to loads of 3 kg or more.

RESULTS AND DISCUSSION

This section reports the outputs of the definition stages: the findings of the exploratory interview, the reference vehicle, the preliminary architecture, the requirements and verification plan and the first DFMEA iteration. Structural, payload and ergonomic results will be obtained in the verification stage.

Exploratory Interview Findings

The interviewee described mine access roads as unpaved and frequently affected by mud, water, humidity and loose rock. Impacts against mine walls were identified as a source of damage to the vehicle's protective components. These statements describe operating conditions to be checked during site observation; they do not establish impact loads or show that the original bed is structurally inadequate.

The original bed dimensions were considered generally sufficient, but loading material over the sidewalls was described as difficult. The loads mentioned include hand tools, compressors, pumps, ventilation equipment, cables, steel bars and drill bits, as well as diesel, oil and grease supplies for maintenance tasks. This variety supports evaluating accessible storage, an organized cargo layout and suitable tie-down points. The interviewee also stressed that fewer moving parts would make the bed easier to maintain, and pointed to an access step and adequate lighting as safety considerations.

Lifting assistance for heavy items was suggested, with an estimated handling range of about 80 to 100 kg. This figure is the informant's estimate, not a design load. A lifting device would add mass, mounting loads and stability concerns that require a separate assessment, so it is recorded as a candidate need and kept outside the scope of the present design.

Taken together, the interview points to four preliminary design priorities: protection against abrasion and impact, safer access to cargo, organized and secured storage for maintenance equipment, and mechanical simplicity.

These priorities are carried into the requirements in Table 5 and will be confirmed through field observation and further interviews.

Reference Vehicle

The screening produced the result summarized in Table 3. The generation is supported by sales data, while the

version is confirmed against the fleet of the participating operation before detailed design.

Table 3: Result of the sequential screening of the reference vehicle

Criterion	Evidence	Decision	Status
Commercial relevance	Only generation sold in Mexico in 2016–2025; 2nd best-selling pickup in 2024 and 3rd in 2025	Eighth generation	Supported by data
Technical information	Official specifications of payload, gross vehicle weight and bed dimensions	Versions with complete data	Applied in the verification stage
Mining suitability	Crew and tool transport; unpaved, wet and sloped roads; 4x4 diesel use reported in the interview	Double cab, 4x4, diesel	Supported by interview; fleet check in field stage

Preliminary Design Architecture

The preliminary architecture keeps the original bed as the main interface and adds removable modules, instead of replacing the bed (Figure 2). This decision has three consequences. The vehicle's original structure and safety devices are not altered, which simplifies compliance with NOM-194-SE-2021. Each module can be removed for maintenance or replaced in the mine's workshop, in line with DFMA principles (Boothroyd et al., 2011). And the redesign can be fitted to vehicles already in service. Its main constraint is space: modules must stay clear of the wheel arches, the tailgate swing and the original anchor points, so the interior dimensions L, W and H must be measured on the real vehicle before any part is detailed. Table 4 lists the modules and the requirement each one addresses.

Figure 2: Preliminary modular architecture of the cargo bed (schematic top view, not to scale)

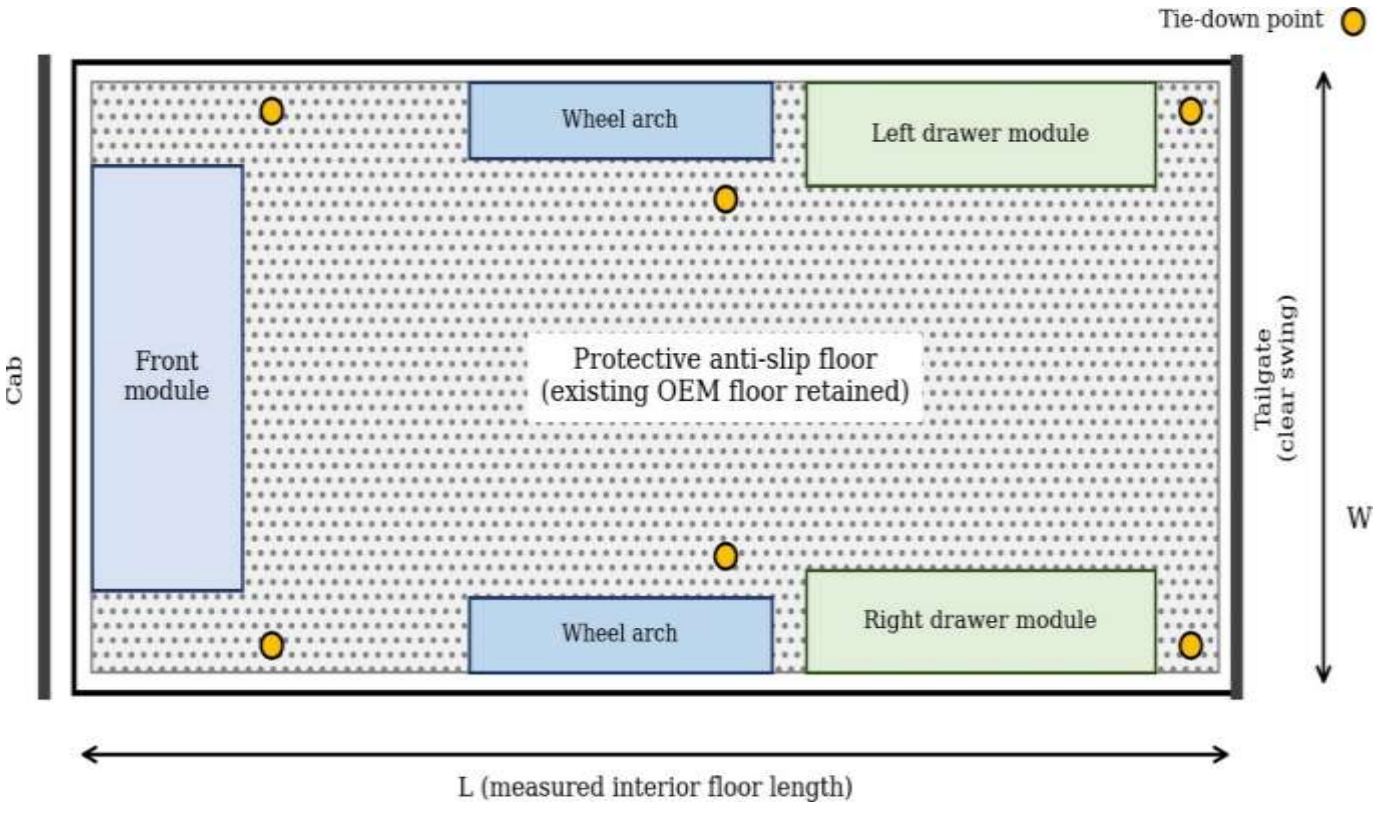


Table 4: Modules of the preliminary architecture

Module	Function	Material options under evaluation	Main verification
Protective anti-slip floor	Protect the original floor from impact and abrasion; reduce slipping	Anti-slip aluminum plate or coated steel	FEA (LC1, LC2); mass check
Side drawer modules (left and right)	Store tools with access from outside the bed	Formed sheet, aluminum or protected steel	Interference check; REBA/NIOSH; DFMEA
Front tool box	Store light tools without blocking the rear window	Folded sheet	Interference check; mass check
Tie-down points	Secure loads at points of documented capacity	Commercial anchors with rated capacity	Capacity check; LC4; static test by analogy
Fasteners and isolators	Join modules without drilling chassis members	Graded bolts; galvanic isolators	Torque control; DFMEA
Anti-corrosion finish	Resist dust, water and site chemicals	Industrial coating system	Material selection; inspection

For the tie-down points, only components with a documented rating are considered. Commercial recessed rings are available with a manufacturer-rated capacity of 2,000 lb, about 907 kg (Sierra Pacific Engineering and Products, 2019); the drawing does not state whether this value is a working load limit or a breaking strength, so this must be clarified with the supplier before the component is accepted.

Requirements and Verification Plan

Table 5 presents the traceability matrix in its current form. Each requirement has a verification method and, where relevant, a link to the DFMEA. Thresholds marked as field-defined are fixed with site measurements and with the official specifications of the selected version.

Table 5: Requirements traceability matrix

ID	Requirement	Source	Verification	Threshold
R1	The bed withstands LC1–LC4 without yielding	Theory; field loads	FEA	$n \geq 2$
R2	Added mass stays within the available payload and rear axle rating	Manufacturer; Eq. (2)	Mass calculation; weighing	Defined from official data
R3	Tools and cargo can be reached without climbing into the bed or lifting over the sidewalls	Exploratory interview; field observation	REBA; reach check in CAD	Field-defined
R4	Lifts during loading stay within the recommended weight limit	NOM-036-1-STPS-2018	Revised NIOSH equation	RWL
R5	Loads can be secured at points of documented capacity	Traffic regulation; DFMEA	Capacity check; LC4	Rated capacity
R6	No interference with tailgate, cab, lights or sensors	Vehicle constraints	CAD interference check	Zero interference
R7	Modules resist corrosion, mud and dust and drain water	Exploratory interview; site environment	Material selection; inspection	Field-defined

R8	Modules have few moving parts and can be removed with standard workshop tools	Exploratory interview; DFMA	Disassembly review	Field-defined
R9	No original safety device is removed or degraded	NOM-194-SE-2021	Compliance checklist	Full compliance
R10	Fabrication and maintenance cost is estimated and justified	Feasibility	Cost estimate	Defined with supplier quotes
R11	Safe access to the bed through a step and adequate lighting for loading	Exploratory interview; NOM-194-SE-2021	Reach and step-height check; lighting compatibility check	Field-defined

Preliminary DFMEA

The first DFMEA iteration covers the failure analysis of the main interfaces (Table 6). Severity, occurrence and detection ratings, and with them the action priorities, are assigned once field data on loads, damage and use are available, so that the ratings rest on evidence; action owners and post-action reassessment are recorded in the same iteration.

Table 6: Preliminary DFMEA, failure analysis of the main interfaces

Item	Potential failure mode	Effect	Potential cause	Planned prevention or detection control
Side drawer	Opens while driving	Tools fall onto the road; injury risk	Latch not rated for vibration	Locking latch in open and closed position; vibration review
Tie-down point	Pull-out or deformation	Load shifts; loss of control	Anchor or mounting below required capacity	Components with rated capacity; LC4 in FEA
Protective floor	Cracking at joints	Loss of protection; sharp edges	Stress concentration at welds or supports	FEA of LC2; weld procedure per AWS D1.1
Module mounting	Loosening of fasteners	Rattling; module displacement	Vibration; insufficient preload	Graded fasteners with locking; torque control
Whole system	Payload exceeded	Overloaded rear axle; reduced braking	Module mass not controlled	Mass budget, Eq. (2); weighing of prototype
Steel and aluminum interface	Galvanic corrosion	Weakened joints	Dissimilar metals without isolation	Galvanic isolators; coating system
Side protection	Deformation after contact with mine walls	Damaged modules; sharp edges	Lateral impact on narrow roads	Recessed module layout; impact review in DFMEA

DISCUSSION

The method differs from most published work on cargo bodies in where it starts. Studies of dump bodies begin with a known failure, such as floor cracking, and use FEA to explain it (Whalen, 2002; Zhu et al., 2012). Here the starting point is the work done with the vehicle, so FEA verifies requirements that come from observed tasks rather than from a failure already in service. This is closer to the approach of Reiman and Putkonen (2012), who derived design proposals from risks observed outside the cab, but it carries those requirements through to

structural verification and to a formal risk analysis. The modular architecture follows the same logic. By keeping the original bed and adding removable modules, it turns the redesign into a set of interfaces that can be verified one by one, which suits the V-model and lets the DFMEA work at module level.

The exploratory interview already shows why this starting point matters. Difficulty loading over the sidewalls, a wide mix of maintenance equipment and wet, rough roads are task-level conditions that a purely structural study would not capture. They translate directly into requirements on access, storage, securing and corrosion (R3, R5, R7 and R11), each with its own verification route.

The verification stage is expected to produce three outputs: requirements grounded in the tasks of mining support crews, confirmed in the field; a quantitative comparison between the original and the proposed configuration in terms of stress, deformation, safety factor and added mass; and an estimate of how the proposed layout changes posture and lifting risk during loading and unloading. If the modules prove too heavy for the available payload, Equation (2) will show it early, and the material options in Table 4 provide the alternatives.

The study has limitations. The needs reported so far come from one informant and will be checked against a larger group of users. The field stage covers a single operation, so its requirements may not transfer directly to other sites. The FEA is linear and static; fatigue, impact dynamics and vibration are not quantified, although the Palmgren–Miner framework identifies fatigue as a likely governing mechanism on mine roads. Lifting assistance for items of 80 to 100 kg, physical validation of a prototype and a version for the ninth-generation Hilux, introduced at the end of 2025, are left for future work.

CONCLUSION

This paper set out an integrated method for redesigning the cargo bed of a Toyota Hilux used in mining support activities in Durango, Mexico. Concurrent engineering keeps structure, ergonomics, manufacturing, maintenance and cost in view together, and the V-model ties every requirement to a specific verification. The definition stages selected the eighth-generation Hilux as the reference vehicle on the basis of sales data, drew four design priorities from an exploratory interview, defined a modular architecture that preserves the original bed, built a traceability matrix of eleven requirements and completed a first DFMEA failure analysis of the main interfaces. The methodological contribution is the integration of user-derived requirements, FEA and DFMEA in a single process for light mining support vehicles, a combination not found in the literature reviewed. The next stage covers fieldwork at the participating operation, the FEA comparison between the original and proposed beds, the payload and axle-load check and the ergonomic evaluation of the new layout.

ACKNOWLEDGEMENTS

The authors thank the mining materials professional who shared their experience in the exploratory interview, and the Tecnológico Nacional de México / Instituto Tecnológico de Pachuca for its academic support.

Ethical Approval

The study involved an exploratory, non-interventional interview with one adult professional, who participated voluntarily and agreed to the academic use of the information. No personal, health or identifying data were recorded, and the participant is not identified in the paper. Given its exploratory and non-interventional nature, the interview was not submitted to a formal ethics committee review. The planned field interviews follow the same principles of voluntary participation, informed consent and anonymity.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability

The anonymized notes of the exploratory interview are available from the corresponding author upon reasonable

request. Field data from the participating operation will be shared in anonymized form, subject to the operation's permission.

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