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Civilian armored vehicle operations in Brazil – challenges and production processes improvements: a qualitative survey

Guido Muzio Candido[1*], Paulo Carlos Kaminski[1]

[1] Mechanical Engineering Department, Polytechnic School of the University of Sao Paulo, Av. Prof. Mello Moraes, 223, ZIP 05508-030, Sao Paulo, SP, Brazil; guido.candido@usp.br (GMC); pckamins@usp.br (PCK)
*Correspondence: guido.candido@usp.br

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Abstract
Armoring civilian vehicles requires specialized knowledge and experience that many armoring companies lack as they are not direct or indirect suppliers of vehicle manufacturers. This limits their access to automotive quality and manufacturing certifications or detailed vehicle designs, which can result in loss or malfunctioning of automotive components during the armoring process. Therefore, this study aimed to investigate the challenges faced by Brazilian civilian armoring companies and identify opportunities for improvement in their production processes. Qualitative research was conducted using a questionnaire-based survey of eight specialized firms in Brazil, as well as literature related to DFMA, design for manufacturing and assembly, quality, automotive, and ballistic references. The study results include detailed armoring operation steps, qualitative survey reports, and helpful literature references for armoring practitioners to generate a standard armoring procedure for different vehicle models. Following best practices in automotive and armoring procedures collected in the survey responses can standardize and enhance ballistic protection operations while preserving the original vehicle systems' functionalities and warranties. This work provides valuable information for armoring companies to improve their operations and interfaces with automotive systems and follow automotive and ballistic references.

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1. Introduction

The practice of armoring civilian passenger vehicles has become increasingly significant in the automotive aftermarket sector, particularly in countries that experience high levels of urban violence, such as Brazil. In this country, the robbery rate is almost seven times higher than in the United States of America (USA) and 33 times that of Poland. According to the United Nations Global Report (UNODC, 2022), in 2019, Brazil had a rate of 561 robberies per 100,000 people, one of the highest in the South American area. In contrast, Mexico had a rate of 261 (in 2018) and 244 in Colombia (in 2017). On the other hand, in 2019, the USA had an estimated rate of 81, and Poland had a rate of 17.

In this context, Brazil has the highest per capita number of civil armored vehicles (CAVs) with handgun protection, ahead of the USA, Colombia, and Mexico.

According to *Associação Brasileira de Blindagem* [Brazilian Armoring Association] (ABRABLIN, 2023), since the beginning of the 2000s, the automotive armoring sector in Brazil showed continuous growth, reaching almost 26,000 new armored units in 2022, evidenced by the increase in the vehicle protection service and ballistic materials companies installed in the country. Regarding the total number of new automobiles and light-duty commercial vehicles (local and imported) registered in Brazil between 2011 and 2022, the production of CAVs has consistently increased its ratio related to the automakers' production, with expectations of significant growth, as shown in Table 1.

Table 1. New vehicles registered from 2011 to 2022 and new armored vehicles produced in Brazil (units per year).

Year	New automobiles registered [1]*	New light-duty commercial vehicles registered [2]*	Total new vehicles registered (T) [1+2]*	Total new armored vehicles produced (AV) **	AV/T Ratio %
2022	1.576.666	383.796	1.960.462	25.916	1.322
2021	1.558.467	418.643	1.977.110	20.024	1.013
2020	1.615.942	338.877	1.954.819	13.837	0.708
2019	2.262.073	403.510	2.665.583	18.842	0.707
2018	2.102.114	373.224	2.475.338	11.912	0.481
2017	1.856.584	319.400	2.175.984	15.145	0.696
2016	1.688.289	300.307	1.988.596	18.865	0.949
2015	2.123.009	357.523	2.480.532	18.086	0.729
2014	2.794.687	538.796	3.333.483	11.731	0.352
2013	3.040.783	539.113	3.579.896	10.156	0.284
2012	3.115.223	518.960	3.634.183	8.384	0.231
2011	2.901.647	524.184	3.425.831	8.106	0.237

* Source: ANFAVEA (2023).
** Source: ABRABLIN (2023).

Ordinarily, civilian vehicles are armored after undergoing entire assembly at Original Equipment Manufacturers (OEMs) and are subsequently sold to customers at dealerships. In this aftermarket segment, AASPs are not OEM stakeholders or suppliers. Thus, usually, they do not consider or apply the OEM design requirements, such as automotive design engineering or even automotive product development process (PDP), as detailed in Canuto da Silva & Kaminski (2017). In addition, the armoring firms do not apply quality standards (IATF, 2016), perceived quality (Stylidis et al., 2015), or design for manufacturing and assembly criteria (Boothroyd et al., 2010) when performing ballistic protection on vehicles.

As a result, some automakers describe in specific chapters of their in-vehicle owners' manuals that any modification or replacement of components due to armoring operations will void the guarantees of their cars. For example, components not manufactured by Toyota, nor marketed or used in the vehicle's original manufacture, are not included in the vehicle's warranty period, including the warranty period of the armoring services and its parts (Toyota Brasil, 2022).

Therefore, the quality and guarantees of automotive parts that interface with ballistic components installed in passenger compartments, which are related to Original Equipment Manufacturer (OEM) design, such as safety components, body panels, and other original parts, are lost due to armoring services. This includes the brake systems and rear suspensions that may be modified during the armoring process. Thus, customers often need to know or be aware of losing these OEM warranties after starting the armoring.

Usually, AASPs protect various types of passenger vehicle brands and models simultaneously in the same production line with the same shop floor teams. Additionally, as there is no armoring design or standard requirements, these firms in Brazil need to adopt quality and process standard procedures for each step of armoring operations. Therefore, each AASP, with or without ISO 9001 standard certifications, defines different disassembly criteria for automotive components and assembly criteria for ballistic materials according to its shop floor manufacturing procedures, layouts, resources, and controls.

Based on the scenario, this work proposes an armoring benchmarking guideline in civil vehicles based on literature references and production process improvements collected in a qualitative survey to keep the original functionalities and warranties of OEM components involved in the armoring operations.

2. Literature review

2.1. Civilian vehicle systems

According to Eurostat (2022), the statistical office of the European Union, a civilian vehicle is a road motor vehicle, other than a motor cycle, intended for the carriage of passengers and designed to seat no more than nine persons (including the driver). The term civilian or passenger vehicle also covers microcars (small cars), taxis, and other hired passenger cars, provided that they have fewer than ten seats. This category may also include vans designed and used primarily for the transport of passengers, as well as ambulances and motor homes. Excluded are motor coaches, buses, and mini-buses/mini-coaches (Eurostat, 2022).

Bhise (2017) defines an automobile product as a system containing several other systems (e.g., body system, powertrain system, chassis system, and electrical/electronic system). As a result, the vehicle has many different attributes (i.e., characteristics that its customers expect, such as performance, fuel economy, safety, comfort, styling, and package). In addition, Bhise (2017) also described that an automotive product is considered a system that involves some lower (or second) level systems.

The vehicle designs and their systems include design standards, design requirements, and design guidelines on vehicle attributes and associated vehicle systems. The standards include necessary background information, design and performance requirements, test procedures, and guidelines (for design and/or installation) to achieve the required level of performance (Bhise, 2017). For instance, during the development process of a series vehicle body, a multitude of requirements has to be considered concerning stiffness, energy-absorbing capability and structural integrity in a crash, noise vibration and harshness (NVH) behaviour, durability, surface quality, corrosion resistance, production costs and recyclability amongst others (Urban and Wohlecker, 2012).

2.2. Civilian armored vehicles (CAVs)

According to Candido and Kaminski (2019), a CAVs consists of a ballistic protection system for a driver and occupants in an automobile system, which is assembled with protective materials, such as stainless-steel parts, bullet-resistant glasses, and aramid plates. Depending on a specific level of ballistic protection, using these materials with the corresponding thickness, they are resistant to firearm shootings, protecting the passenger compartment. Thus, the goal of a CAV is essential to protect the occupants in a bullet-resistant compartment that can resist fire guns until the driver can maneuver out of a sudden attack.

Virtually indistinguishable from a regular vehicle from the outside, the armored automobiles are usually inside reinforced with stainless steel parts, aramid plates, and armored glasses to resist handgun calibers up to .44-Magnum, according to the National Institute of Justice of USA standard, named NIJ 0108.01 (NIJ, 1985). NIJ divides the level of attack potential into six protection classes. In Brazil, the NIJ IIIA ballistic protection level is assigned to short weapons, the maximum authorized by the Brazilian Army for armor passenger vehicles. The armored windows are made of multi-layered bullet-resistant glass for IIIA level and are thick, approximately 18 to 21 mm. In addition, car body structures of passenger compartments, closures, and wheels receive opaque ballistic protection materials. Therefore, with the addition of these components, these CAVs are heavier than their original counterparts. Depending on what protection level the vehicle has been retrofitted for, the model type, and the size of the passenger compartment to be armored, its final weight could be, according to AASPs, from 200 to 400 kilograms heavier than the standard unarmored vehicle version.

2.3. Vehicle system with armoring system

Armoring operations in passenger vehicles require changes and replacements in some automotive systems to fit the ballistic parts together with the passenger compartment components. Adjustments on the vehicle's components include reworking interior trim pillars and door trim panels, replacing windows and rear suspensions, and adding screw holes in body panels. Figure 1 presents a vehicle system and subsystem overview, some with armoring interfaces. As the vehicle system is very complex, the armoring operation requires high automotive engineering knowledge and analysis to avoid damages or compromises to the primary safety, structural, electronic, or any other vehicle functionalities. Nevertheless, it also requires high ballistic engineering knowledge and analysis to avoid open and weak areas in the passenger compartment of firearm shootings.

To develop a ballistic protection design in an automotive system or a civilian vehicle, first, it is necessary to understand the specific design of each automobile, especially the components and the systems that interface with protection parts. Usually, this interface stands in the passenger compartment, such as car bodies, structures, doors, windows, roofs, seats, interior trims, electronics, and other components affected, such as rear suspension and safety systems.

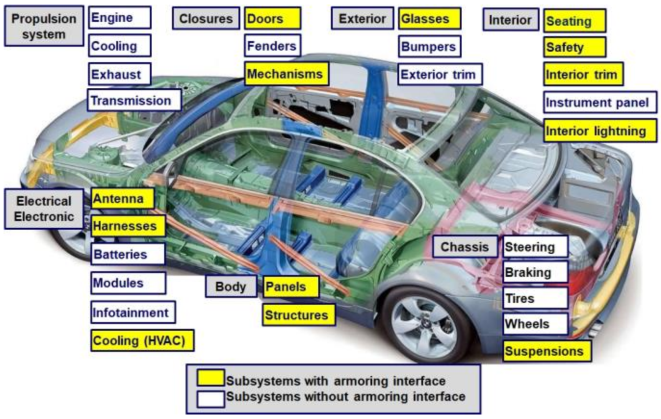

Fig. 1. Automotive systems and subsystems with and without armoring interface. Source: adapted from Net car show (2022).

In general, after disassembly of the interior finish parts of the passenger compartment, the AASP operators start to assemble the protection components. Figure 2 shows the typical locations of protection components in CAV. First, stainless steel parts are attached to A, B, C (and D for sport utility vehicles, SUVs) pillars, door lock areas, roof rails, and other small areas of the car. Next, the operators assembled the aramid plates in uniform and flat regions, such as the roof, tailgate inner panel (SUVs), under the hood (near the windshield), and inside the door panels. Finally, the armored glass set replaced the original automaker windows.

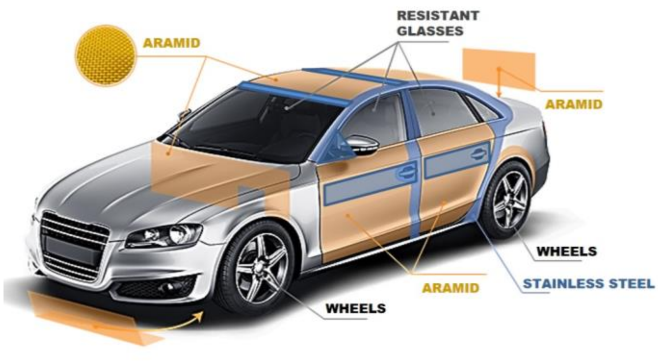

Fig. 2. Civilian armored vehicle and ballistic protection parts layout. Source: Karvi (2020), cited in Candido et al. (2022).

In principle, civilian passenger vehicles were not previously designed to receive additional armor components. Therefore, the thickness, dimensions, and locations of ballistic elements, such as armored glasses, stainless steel parts, and aramid plates, must be designed to allow the feasibility of assembly and installation of this ballistic system in each vehicle model. Therefore, it is essential to know not only the characteristics and ballistic properties of each type of protection part and the correct place of application but also to have automotive knowledge of the vehicle project, the characteristics of the systems through which the parts will be installed and the direct contact interfaces of ballistic components with automotive parts when performing armoring operations.

2.4. Operation flow of automotive armoring

Based on the simplified description of the AASPs to the final customers of the stages of the armoring operation, the respective flow is briefly presented in Figure 3. After the customer order and prepayment, AASP generates a service order describing the materials and levels of protection that the vehicle owner has requested. Thus, the armoring operation begins. First, the income vehicle is inspected before disassembly (step 3). Next, all protective materials added to the car are selected to armor the automobile. AASP then completely dismantles the interior of the vehicle. To fit the armored glasses, thicker than the original, door trim panels and frames are modified.

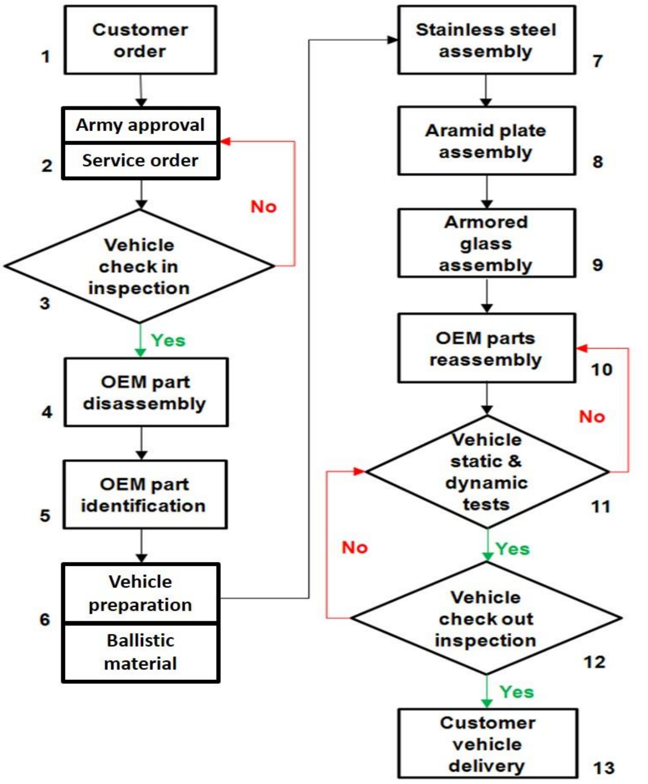

Fig. 3. Simplified civil vehicle armoring flowchart. Source: Candido & Kaminski, 2022.

AASP continues the armoring process by covering the passenger compartment with protective ballistic steel and aramid plates. Next, AASP installs armored glasses. These are made to fit OEM window channels, giving them an original automaker finish. AASP then reassembles the interior finish parts of the vehicle just as received. At this point, the vehicle is armored, keeping its OEM appearance. After the static and dynamic tests (step 11), the vehicle is wholly inspected (step 12) and delivered to the customer's destination (step 13). In case of test failure, e.g., excessive wind noising, the AASP disassembles the parts affected, fixes them, and performs the tests again. Finally, the checkout inspection confirms that armoring service is completed and the vehicle is ready to be delivered to the customer.

3. Methodology

Initially, bibliographical research was carried out to review the knowledge and the interface between automotive and ballistic protection systems. Next, due to the relatively new field of investigation in civil armored vehicle operations, in terms of few references published, this work also adopted a qualitative survey through an exploratory approach with interviewed experts in eight AASPs established in Brazil, with different industrial practices in the second half of 2022. Qualitative surveys consist of a series of open-ended questions crafted by researchers and centered on a particular topic (Braun et al., 2020). Thus, in this study, the authors followed the framework from Blessing & Chakrabarti (2009), which consists of research clarification (RC) of the problem. The aims are to identify and refine a research problem that is both academically and practically worthwhile and realistic.

Therefore, based on the RC steps, shown in Figure 4, this methodology involves obtaining an overview of the general understanding of civil vehicle armoring operations, including literature and interviews in the AASPs.

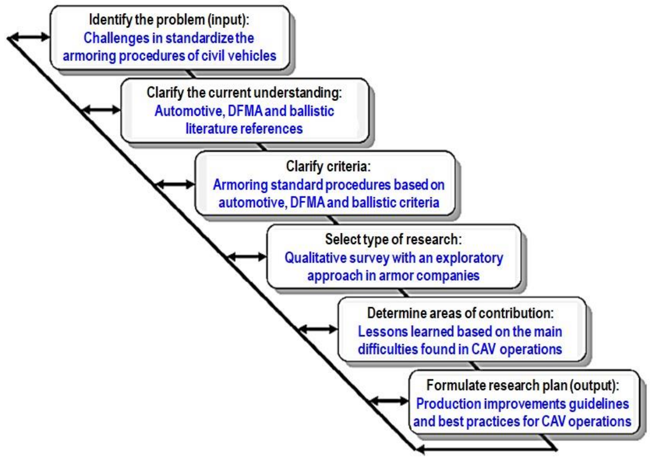

Fig. 4. Main steps in the research clarification methodology. Source: adapted from Blessing & Chakrabarti (2009).

Following the RC sequence, it is possible to plan and formulate the questions of the most relevant armoring operations research in companies to present, as the purpose of this paper, the armoring procedure guidelines and best practices proposals. Furthermore, owing to the proactiveness and partnership of the companies interviewed, it has been possible to carry out a detailed armoring operation flow to understand the steps of vehicle protection.

3.1. Criteria for choosing armoring companies

The selection criteria for armor companies to carry out the questionnaire to identify the main difficulties in armor operations considered focusing on companies located in the region of the country with the highest number of new armored vehicles sold, the number of armored vehicles produced per month, the number of operators, the longest time in the market, i.e., more time in activity, and whether they have an engineering manager responsible for ballistic parts projects.

Based on these premises, according to ABRABLIN (2023), 65% of the Brazilian production of CAVs is produced in the State of Sao Paulo, Brazil. Thus, the interviews were conducted in eight armoring companies in Sao Paulo and nearby cities in the second half of 2022. These companies have been in the protection vehicle business since the early 2,000s; the production of new CAVs in these companies varies between 30 to 100 units manufactured per month with shop floor operators between 25 and 70 employees in one shift. In addition, three of these companies interviewed have received armor certification from automakers, such as BMW, GM, Jaguar Land Rover, Toyota, and VW.

3.2. Criteria for preparing the questionnaire

The questions were formulated following the simplified operation flow for armoring vehicles, which is summarized in Figure 3. The aim of developing the questions was to identify daily difficulties faced by production line operators in each sequence of the armoring operations with greater clarity. Before sending the questionnaire to the interviewers, the questions related to each operation stage were reviewed for relevance. A pilot test was conducted by applying the questionnaire initially to an expert engineer from one armoring company. During the pilot test, it was observed that some items needed revision and adjustments to improve understanding, which led to the refinement of the questionnaire. Finally, the questionnaire was sent to the eight AASPs, and one expert engineer from each facility was selected via email or telephone.

4. Results and discussion

A questionnaire related to automotive and ballistic systems was presented to experts with technical and management positions working in AASP companies to identify the difficulties with civil armor vehicles. Subsequently, an interview was conducted either personally or by telephone as field research at armored firms, using the reviewed questions that were sent to the companies. The most relevant answers to the questionnaire about the main difficulties of civil armor vehicles in eight AASPs are presented in Table 2. Appropriate solutions were considered when it was verified that the majority of the interviewees reported similar challenges, as determined by the authors.

Table 2. Questions to AASPs and relevant correspondent answers of CAV operations.

Questions about CAV operations	Relevant answers from eight AASPs expert respondents
1. Please provide a detailed description of the sequence of armoring operation steps utilized by your company.	• Detailed armoring operation flowchart according to steps presented in Figure 5.
2. What are the main difficulties in armoring operations related to disassembling automotive parts?	• Wide variety of models and versions to proceed with the armoring; • Operators have not been previously trained or prepared to work on new vehicles; • Lack of technical information from automakers: parts and procedures; • Incorrect procedures of disassembly of the finishing parts and electronic components.
3. What are the primary challenges in armoring operations related to the installation of high-hardness materials, such as stainless steel?	• Perform try-outs of stainless steels assembly on the vehicle; • Adjust stainless-steel parts and stamping tools (mold and cutting); • Increase tack time with a new stainless-steel part that needs dimensional changes to fit the passenger compartment interface parts of the vehicle.
4. What are the main difficulties in armoring operations related to installing armored glasses?	• The greater thickness of the armored glasses (from 18 to 21 mm) requires high-quality control during the assembly; • Risk of high interferences with the automotive parts, especially at windshield and doors to fit armored glasses on it; • Manually installation of heavily armored glasses, especially windshields, and sunroofs.
5. What are the main difficulties in armoring operations related to installing aramid plates?	• Install aramid plates in curved surfaces of the car (e.g. rear wheel inner panel); • Increase the interferences of aramid plates with automotive parts, mainly in the narrow areas between finishing parts and vehicle body panels. • Depending on the aramid plate thickness required and aramid location, modifications not previewed may be required to guarantee the automotive parts interfaced with the armoring system.
6. What are the main difficulties in armoring operations related to reassembling automotive parts?	• Reassemble the original components over the armored parts; • Keep the same fixing points and geometries within the original gaps and flushes of the automotive parts; • No access to automaker specifications and service manuals for reassembly operations.

7. What are the main difficulties in armoring operations related to modifying existing automotive parts?	• Manual cutting and welding operations in the automotive parts to properly fit the armoring parts, such as upper reinforcement of the inner door panel (door glasses), tailgate inner panel reinforcement (aramid plates in SUV), cover trim pillars (stainless steels) and upper instrument panel cover (windshield).
8. What are the main difficulties in armoring operations related to determining the root causes of recurring shop floor problems?	• Different brands and vehicle models in the same production line; • High technologies, complexities, and quality of new automotive parts; • No access to automaker specifications and service manuals for disassembling and reassembling of automotive parts;
9. Have any difficulties in any other step not been mentioned or considered as relevant?	• Lack of specialized shop floor professionals in armored vehicles; • Lack of military or government standards to verify and certify the correct application of ballistic components inside the vehicles; • No security assurances in terms of ballistic protection design and operations; • No quality assurance in terms of automotive safety features functionalities.
10. Are there any inconsistencies between your company and its internal partners (employees), or external partners (suppliers and logistical partners)?	• Conformity of ballistic parts (different dimensions, out-of-material specifications, different number of aramid layers, armored glasses with distortions and out-of-design geometries); • Logistic problems (delays) related to armored glasses (bottleneck).
11. What are the main difficulties in armoring operations related to the technology of ballistic materials available in Brazil? Do they meet the company's needs?	• Despite the composites, materials that replace stainless steel parts, being much lighter than stainless steel (up to 80% less in mass), they are much more expensive; • The armored glasses still require layers of polymers and glasses, which adds more weight to the vehicle for the NIJ-IIIA level.
12. What are the main difficulties in armoring operations related to the technological evolution of automobiles, such as the electrification, onboard electronics, cameras, sensors, and airbags, in addition to the launch of new models in a shorter life cycle?	• The need for a specific electronic engineer to support the AASPs especially for electric and hybrid vehicles; • The new vehicles have more technology, modules, and batteries, making the armoring a complex operation and demanding attention in automobile specifications, especially during the reassembly phase; • Shop floor operators have not been previously trained or prepared due to the variety of new components to be done on each automobile;
13. What are the main difficulties in armoring operations related to technical requirements requested by OEM to obtain armoring certification?	• Lack of traceability before, during, and after the assembly of stainless steel, armored glasses, and aramid plates; • No standard work procedures are available on the shop floor for each armoring stage.
14. What does an OEM armoring certification consist of? Are they valid for a specific period? Does it refer to a particular vehicle?	• The OEM certifications are valid only for the specific vehicle model throughout the life cycle of that model; • AASPs are responsible for armoring services and ballistic parts warranties added to the vehicle.

The compilation of the responses of the eight expert respondents from each firm presented in Table 2 shows that the difficulties in each of the armoring operations are similar among the AASPs. And at the same time, it offers the necessary directions to focus on solutions proposed by the authors.

4.1. CAV operation detailed flow

According to the interviews carried out in the armoring companies, it was possible to understand and describe, based on the AASPs responses, how each stage of the ballistic protection of passenger vehicle operations is performed in detail.

Therefore, when compiling and analyzing the answers for each company, the authors prepared and presented the comprehensive armoring operation flow illustrated in Figure 5.

After the customer order, AASPs formalize an agreement contract with the new vehicle's owner and generate a service order on the shop floor to put into effect the armoring operation of the new vehicle. The firm describes in this contract the detailed description of bullet-resistant components and the level of protection the vehicle will receive.

It also includes the terms of responsibilities, the armoring services warranties, and the ballistic protection certifications of each component (opaque and transparent) assumed from AASP to the vehicle's owner. After the contract is signed, the armoring process begins. Next, the AASPs identify the vehicle model and the respective armor parts. Then, in the sequence, they inspect it in detail before disassembling the automotive components (step 11): checking if the engine, warning lamps, lighting, electronics, and safety equipment are working correctly and verifying any damage, scratches, or risks all around the vehicle. If AASP detects any problem related to original vehicle guarantees, they notify the customer and request the respective dealer the corrective actions before proceeding with the operation.

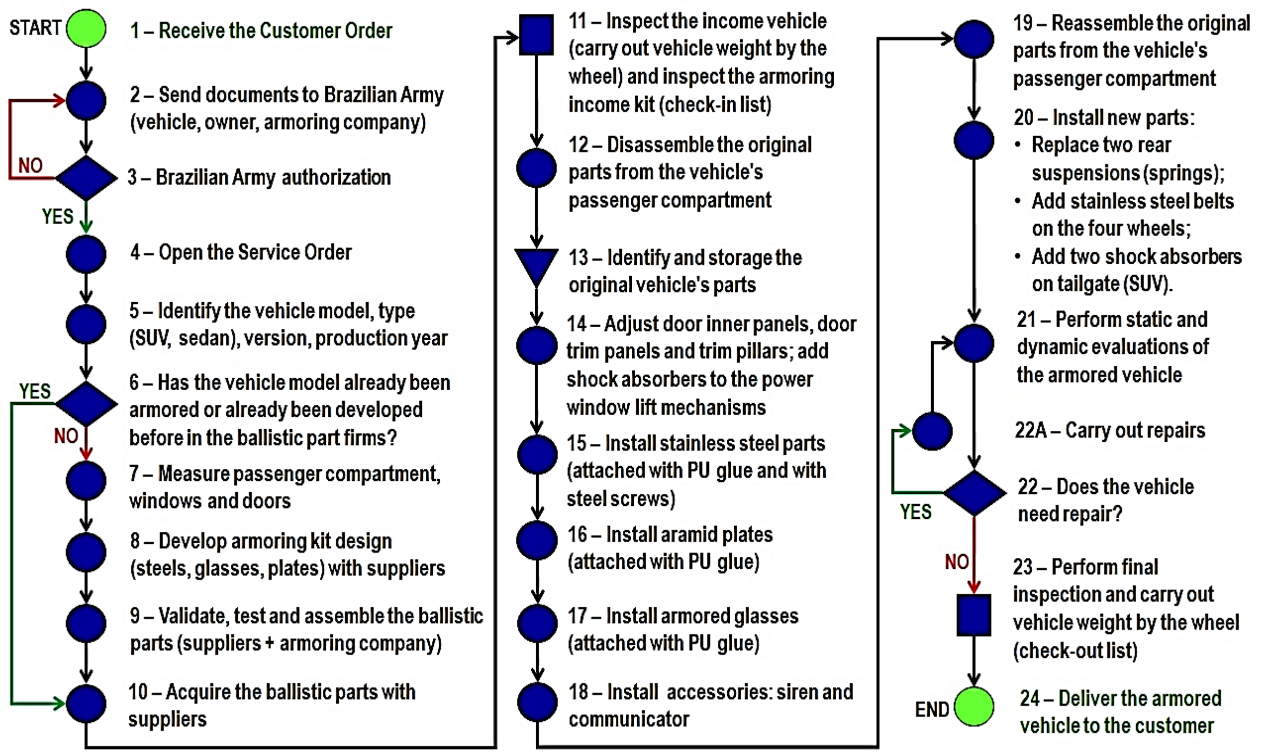

Fig. 5. Detailed flowchart of CAV operation.

The bullet-resistant components added to the vehicle, if available at the ballistic suppliers, are selected to armor the automobile. However, suppose protective materials must be corrected or out of quality standard (visual aspect only). In that case, the AASP performs the same procedures of the vehicle income check to the respective ballistic suppliers to replace the components.

In case when a protective part is not available in a specific dimension for a brand-new vehicle that came at AASP, the current process flow changed. The operator measures (or scans) the passenger compartment area, such as the roof, doors, pillars, glasses, and trunk, which enables the ballistic stakeholders (AASP suppliers) to design, produce and deliver the ballistic components to protect and safeguard each of these areas previously cited.

Situations may occur at AASPs where the design of a new ballistic protection component requested by an "A" armor firm does not fit or does not correspond to the current design already requested by a "B" armor firm from the same ballistic supplier. In other words, there may be more than one design for the exact vehicle in the same armoring parts supplier to produce different armoring components for AASPs because these companies have different vehicle armoring processes.

AASP completely dismantles the vehicle's interior after covering the entire car surface with protective adhesive tapes, exposing only its frame. All the vehicle's interior parts are removed and assigned a controlled number corresponding to the vehicle to ensure everything is found. To fit the armored glasses in the vehicle body, thicker than the original, door trim panels and door frames are modified.

After the static and dynamic tests (step 21), the vehicle is wholly inspected (step 23) and finally delivered to the customer's destination (step 24). In case the AASP test fails, e.g., excessive wind noising, the firm identifies the non-conformity root causes, disassembles the parts affected, fixes them, and performs the tests again. The checkout inspection is a final quality audit that AASP guarantees that armoring service is completed and the vehicle can be delivered to the customer.

4.2. Production processes improvements guidelines and literature references for CAV operations

Faced with the difficulties reported in the responses and the detailed armoring operation flow shown in Figure 5, the authors presented in Table 3 the production processes improvements guidelines of solutions applied on AASPs shop floor followed by the literature references as benchmarks for civil vehicle armoring operations. The literature on armoring operations based on Design for Excellence (DfX) references, adapted from Candido et al. (2022), was researched in parallel with a qualitative survey of armoring companies. Additional references in Table 3 were included because the content had more adherence to the themes respectively of each stage of the armoring operation related to armoring standards or designs, automotive manufacturing processes, quality and design processes, and supply chain management.

Table 3, identifies the most appropriate guidelines for each step of the armoring operation according to the respective automotive, ballistic, and DFMA tool references applied to processes with a wide variety of vehicles and low production volumes.

Table 3. Production processes guidelines and corresponding literature reference to support civil vehicle armoring operations.

Armoring operation stage	Production processes guidelines' compilation	Literature reference keywords	Reference authors (year)
1. Develop armoring kit design (steel, glasses, plates) with suppliers.	• Comply with ballistic standards, define armoring requirements & tolerances; • Follow ballistic supplier guidelines; • Design armoring parts using the DFMA® method; • DFM for low-quantity production.	• Armor system – Ballistic protection. • Armor design ceramics, composites, analytical modeling, numerical simulation. • Design, assembly, disassembly. • DFA, DFM, DFMA, engineering design, product development, systematic review.	• ABNT NBR 15.000 (2005) • Gálvez & Paradela (2009) • Boothroyd & Alting (1992) • Formentini et. al (2022)
2. Disassemble automotive parts.	• Consider the DFMA®, DFD, and DFS methods for vehicle disassembly; • Establish a standard work for each operation stage to deal with a variety of vehicle models and versions; • Program regular operator training courses to be prepared to work on new vehicles.	• DFMA®, disassembly, green design, sustainability. • Product design, product life cycle, disassembly planning, sustainability, emerging technology.	• Mamat et al. (2019) • Chang et al. (2017)
3. Install stainless steel parts, aramid plates, and armored glasses.	• Design and test with suppliers the ballistic protection parts (new vehicle); • Create quality audits on the shop floor for ballistic protection parts assembly; • Obtain 3D of the vehicle to design the ballistic parts correctly; • Create equipment to install armored glasses; • Standardize the operation of polyurethane glue application in armored glasses and aramid plates; • Increase design partnerships with aramid suppliers, especially for curved surfaces (rear wheel inner panel) and narrow areas which are difficult to access, and install the protective parts.	• Design for manufacture and assembly, architecture, construction, manufacturing, assembly, and design guidelines. • Blast waves, ballistic impact, shielding armors, material classification, multi-layered.	• Tan et al. (2020) • Pai et al. (2022)
4. Reassemble automotive parts.	• Create standard works for the reassembly of the automotive components over the armored parts; • Train the operators at OEM factories to keep the original fixing points and geometries (dimensional and positioning) within the original gaps and flushes.	• ASP, DFA, DFMA®, DFE, DFR, part concatenation method. • Book chapter n. 10: Assembly system.	• Kolur et al. (2020) • Swift & Booker (2013).
5. Modify automotive parts to fit armor components.	• Side door and rear door panels: optimize the cutting process in the inner panel to fit the aramid and armored glasses and minimize the reduction of structural stiffness; • Avoid cutting the upper instrument panel to fit the armored windshield interface by redesigning the inserted steel in the armored windshield; • Avoid cutting a part of the trim pillars to fit the stainless-steel parts.	• Sustainability, aftermarket, remanufacturing, strategic planning, automotive, supply chain, reverse logistics. • Sustainable production, design for remanufacturing, and material selection.	• Subramoniam et al. (2009) • Yang et al. (2017)
6. Determine the root causes that conducted to shop floor problems.	• Provide regular training to operators to deal with high automotive technologies, complexities, and quality of new vehicles;	• Assembly processes in the automotive sector.	• Baraldi & Kaminski (2018)

	• Provide technical information with OEM to proceed with the disassembling and reassembling of automotive parts.		
7. Solve internal (employees) or external (suppliers) non-conformities.	• Adopt automotive quality requirements to add value provided by IATF 16949-2016 over ISO 9001 for improving operation and for receiving ballistic parts; • Adopt automotive supply chains related to armored parts.	• ISO 9001, IATF 16949, meta-standards, quality management systems, automotive sector. • Supply chain, risk management, automotive industry, Brazil.	• Laskurain-Iturbe et al. (2020) • Vanalle et al. (2019)
8. Consider the technological evolution of automobiles.	• Include an electronic engineer to support the AASPs during the development and assembly phases, especially for electric and hybrid vehicles; • Update knowledge of vehicle technologies.	• Eco-design, manufacturing, Product design, supply chain, sustainable design.	• Ramani et al. (2010).
9. Receive the OEM Armoring Certification.	• Adopt the automaker's quality production process for armoring operations; • Provide the traceability control of automotive and ballistic protection parts; • Create standard work procedures on the shop floor for each armoring stage; • Create regular training for operators for ballistic and automotive knowledge; • Create a BOM for armored parts; • Create a maintenance service manual for dealers related to CAVs.	• Manufacturing system, production quality, maintenance management. • Quality, method, design and manufacturing process, vehicle, armor. • Minimum Automotive Quality Management System Requirements for sub-tier suppliers.	• Colledani et al. (2014) • Rusiński et al. (2009) • IATF (2017)

4.3. Product and processes considerations in CAV operations

Based on the answers of the experts from each AASPs, and the guidelines with corresponding literature references to support civil vehicle armoring operations, the following key relevant product and process findings and implications for the industry related to automotive and ballistic criteria are highlighted as follows:

- Vehicle systems: Check automotive components and systems functionalities, especially those with the interface to ballistic components added, such as electric, electronic, safety, and structural systems; doors and rear doors opening systems; rear window defogging system; the anti-smash system at door window; sunroof opening system; safety system alerts, especially curtain, and side airbags;
- Manufacturing processes: Follow each OEM's disassembly sequences processes using as much as possible their tools, technics, and procedures;
- Automotive safety features: Apply OEM electronic diagnosis control at CAVs for checking safety, engine, electrical and electronic systems;
- Vehicle handling: Protect the body panels, equipment, and passenger compartment surfaces with appropriate adhesive liners to avoid damages such as rips, dents, and scratches in visible areas, especially in wet areas (doors) during the ballistic protection operation;
- OEM requirements: Comply with OEM electromagnetic compatibility standards as a ballistic design input to avoid electric and electronic troubleshooting during and after the installation of ballistic protection components inside the vehicle; Comply with OEM corrosion avoidance and protection requirements due to the possibility of damaging panels and structures such as rips, dents, and scratches in visible areas that can generate corrosion spots; follow OEM when proceeding with reassembly operation;
- Finishing: Keep the OEM exterior finishing design after interior trim parts are changed, mainly to curtain airbag interface parts;
- Noising: Consider the addition of proper automotive felts or dense foams to avoid the squeaks and rattles effect in the passenger compartment during the usage of the vehicle due to the contact of the body panels with the stainless steels added;
- Increase ballistic and automotive knowledge among the shop floor employees.

The results show that most companies face challenges in standardizing the armoring procedure and preserving the original vehicle systems' functionalities. However, the best practices collected from the survey responses can be used to enhance ballistic protection operations and improve production processes.

5. Summary and conclusion

Civil vehicles are ballistic protected against firearms up to level IIIA in NIJ standard in Brazil, the largest country in the world for armoring passenger automobiles. As most of the literature on this subject usually focuses on military armored vehicles, this work provided meaningful automotive and ballistic protection production process improvements to allow their system's integration into civilian vehicles.

Essentially, the shop floor operators in AASPs assemble ballistic protection parts previously designed inside the passenger compartment of the vehicles. Next, they modify some automotive parts to fit the addition of ballistic protection components, reassemble the original parts in the vehicle, and test and deliver to the customer. If not appropriately performed following automotive quality standards, production procedures, OEMs, and ballistic standards, these operations may cause loss or malfunction of automotive components and systems, such as electronic, safety, or structural systems.

Faced with this scenario, the authors carried out a qualitative research in eight AASPS. Based on the simplified armoring flow, a preliminary questionnaire was reviewed and performed with a representative sample of the AASP respondents as far as is practicable. It means that results from the survey can be conducted onto the population, which in this survey is considered armoring vehicle companies in the automotive after-sales market with a calculable degree of reliability (Hutton, 1990).

Most armoring companies that provide ballistic protection services in civil vehicles in Brazil are not direct (tier 1) or indirect (tier 2) suppliers of vehicle manufacturers, as confirmed through research. Therefore, usually, most of these firms do not have automotive quality and manufacturing certifications and do not have access to vehicle designs, such as drawings, statements of works, tolerances, specifications, or engineering requirements, related to structural, safety, electric, electronic, among others component references with interfaces in the armoring system. In addition, even though the ballistic material suppliers recommended to AASPs the procedures to assemble the protection components, the armor company technician knowledge in automotive and ballistic still needs to be improved.

The obtained answers allowed for the presentation of a detailed flow of civil vehicle armoring operations. This process consists of disassembling the interior finish components and the windows of the passenger compartment of the new civilian vehicle, adding the ballistic protection components inside the vehicle in the roof, side, and door panels, and reassembling the interior vehicle parts covering the ballistic components. Usually, as these operations are performed manually, it requires several adjustments on the body panels. Therefore, the armoring operation depends on the ballistic skills, automotive experience, assembly precision, handling, and care of operators on the AASP's shop floors.

In addition, it is verified that AASP companies adopt distinct procedures for installing protective parts with different designs for identical vehicles. Therefore, there are no specific armoring assembly standards or mandatory requirements regarding how the AASPs must proceed to install the components to guarantee vehicle protection.

Thus, the study presented production processes improvements guidelines, literature references, and automotive considerations to help AASPs develop and perform the armoring operation stages with an interface with the automotive systems by following automotive and ballistic references.

This study did not examine ballistic components with advanced materials such as ceramics or high-strength steel parts. These materials have high production costs and are more applied in military vehicles with higher protection levels against powerful weapons. The other limitation of this work is the number of valid interviews at the AASPs. Therefore, the authors cannot generalize the results for the entire sector, such as to ballistic protection suppliers or logistic companies involved. On the other hand, due to the lack of armoring reference procedures, the authors considered the research sample representative. Furthermore, they guaranteed the reliability of the results obtained by the AASPs interviewed because they acquire significant experience over the 20 years in armor operations and added automotive knowledge in disassembly operations and reassembly of original vehicle parts. Therefore, besides the low number of interviews, the information collected was considered relevant and helped the authors to analyze, discuss and present the best practices for armoring procedure operations.

It is essential to point out that the research objective was exploratory in evaluating the significant difficulties in civil vehicle armoring operations performed at AASPs in Brazil. Therefore, the work presented the practices, guidelines, and literature references that generate the most challenges and the most used tools to mitigate them. Hence, a suggestion for future research is to extend the questionnaire to AASPs in other regions in Latin America or even the Middle East based on the detailed armoring operation flow. Second, this study could include interviews with OEM engineering managers focusing on automotive, quality, and ballistic protection requirements to increase technological partnerships with AASPs in armoring vehicle operations. Finally, in future work, it is suggested to present a detailed development of an armoring project in specific vehicle subsystems, such as a vehicle door assembly. This subsystem receives ballistic protection parts, glasses, stainless steel parts, and aramid plates, considered in the armoring procedure guidelines presented in this paper.

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Abbreviations

AASP	Automotive Armoring Service Provider
ABNT	*Associação Brasileira de Normas Técnicas* [Brazilian Association of Technical Standards]
ABRABLIN	*Associação Brasileira de Blindagem* [Brazilian Armoring Association]
ANFAVEA	*Associação Nacional dos Fabricantes de Veículos Automotores* [Brazilian National Association of Motor Vehicle Manufacturers]
CAV	Civilian Armored Vehicle
DFA	Design for Assembly
DFD	Design for Disassembly
DFMA	Design for Manufacturing and Assembly
DFR	Design for Recyclability
DFS	Design for Service
DFX	Design for Excellence
IATF	International Automotive Task Force
ISO	International Organization for Standardization
NIJ	National Institute of Justice
NVH	Noise, Vibration and Harshness
OEM	Original Equipment Manufacturer
PDP	Product Development Process
PU	Polyurethane
RC	Research Clarification
SUV	Sport Utility Vehicle

巴西的民用装甲车辆操作 - 挑战和生产过程的改进：一项定性调查

關鍵詞
汽车行业
防弹保护操作
DFMA，制造和装配设计
生产流程改进

摘要
装甲民用车辆需要专业的知识和经验，但许多装甲公司缺乏这些知识和经验，因为它们不是车辆制造商的直接或间接供应商。这限制了它们获取汽车质量和制造认证或详细车辆设计的机会，这可能会导致在装甲过程中失去或损坏汽车组件。因此，本研究旨在调查巴西民用装甲公司面临的挑战，并确定其生产过程的改进机会。使用针对巴西八家专业公司的问卷调查以及与DFMA、制造和装配设计、质量、汽车和弹道相关的文献进行了定性研究。研究结果包括详细的装甲操作步骤、定性调查报告以及有助于装甲从业人员为不同车型生成标准装甲程序的有用文献参考。遵循在调查答复中收集的汽车和装甲程序的最佳实践可以标准化和增强弹道保护操作，同时保留原始车辆系统的功能和保修。这项工作为装甲公司提供了有价值的信息，以改进其与汽车系统的操作和接口，并遵循汽车和弹道参考。