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OPTIMIZATION OF CHASSIS GEOMETRY FOR INCREASING THE PRODUCTION CAPACITY OF 4X4 VEHICLE PLATFORM

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Abstract: *The optimization of chassis geometry represents a key step in the development of modern modular 4×4 vehicle platforms. The manufacturing of chassis with complex geometries requires the use of specialized tooling, involves potential deformations due to welding, and demands a complex logistical framework, all of which significantly increase production time and costs. These requirements further limit production flexibility and may slow down adaptation to diverse operational demands.*

In the military sector, where rapid response and adaptability to various missions are essential, modularity and shortened production cycles—along with minimal reliance on specialized tools—are of critical importance. For this reason, a chassis concept with simplified geometry and standardized structural elements has been developed, enabling rapid configuration of different superstructures. The entire assembly process is significantly simplified, as only a single type of longitudinal beam needs to be produced, while the wheelbase can be easily adjusted according to specific application requirements, owing to a dedicated connection method of the suspension subassembly. This approach enables more efficient production, easier maintenance, and greater operational flexibility of the vehicle.

Keywords: *vehicle modularity, increased production capacity, rapid assembly*

1. INTRODUCTION

Modern wheeled military vehicles are expected to provide high mobility, adaptability and operational flexibility while supporting a wide range of mission-specific configurations. To meet these demands, vehicle manufacturers are increasingly adopting modular platform concepts that enable multiple vehicle variants to be developed from a common structural base[1,2]. Such an approach can improve production flexibility [1,2], while modularity in military vehicle design may also provide benefits related to adaptability, life-cycle costs, maintenance and logistics [1].

The chassis is the primary load-bearing structure of a vehicle and has a significant influence on its structural performance, manufacturability and operational capabilities [3,4]. Conventional ladder-frame chassis remain the most widely used solution for military and off-road vehicles due to their robustness and versatility[3]. However, their production often involves complex frame geometries, numerous structural components, dedicated manufacturing fixtures and extensive welding operations. These factors increase production time and cost, reduce manufacturing flexibility and may introduce welding-induced distortions that require additional corrective operations[3,4].

Current trends in military vehicle development therefore focus on increasing modularity, component standardization and production simplification [1,3]. Reducing the number of unique structural components while enabling different vehicle configurations from a common chassis can significantly improve manufacturing efficiency and logistical support, particularly in low-volume military production[1,3].

This paper presents the development of a novel modular chassis concept for a multi-purpose 4×4 vehicle platform. The proposed design is based on simplified chassis geometry and standardized structural elements, aiming to reduce manufacturing complexity, minimize the need for dedicated tooling and improve production flexibility while maintaining the adaptability required for various military applications.

2. REVIEW OF CONVENTIONAL CHASSIS ARCHITECTURES

The chassis is the primary structural component of a vehicle, responsible for supporting the powertrain, suspension, body and payload while ensuring adequate strength and stiffness under various loading conditions. Over the years, several chassis architectures have been

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developed, each offering specific advantages depending on the intended vehicle application. The most commonly used structural concepts include ladder frame, backbone, monocoque and space frame chassis. Their design characteristics differ in terms of structural efficiency, manufacturing complexity, modularity and suitability for off-road and military applications[3].

2.1 Ladder frame chassis

The ladder frame is the most widely adopted chassis architecture for commercial trucks, off-road vehicles and military platforms. It consists of two longitudinal side members connected by a series of cross members, forming a robust load-bearing structure capable of supporting different body configurations. Its relatively simple construction, high load-carrying capacity, ease of maintenance and compatibility with various suspension systems have made it the preferred solution for low- and medium-volume production of military vehicles. Furthermore, the body-on-frame concept enables different mission-specific superstructures to be mounted on a common chassis platform, providing a certain degree of versatility. Despite these advantages, conventional ladder-frame chassis often require multiple frame variants, dedicated manufacturing fixtures and extensive welding operations, which increase production complexity and cost[3].

2.2 Backbone chassis

Backbone chassis utilize a central longitudinal structural member that carries the primary loads and connects the front and rear suspension assemblies. This architecture provides high torsional and bending stiffness, while drivetrain components can be enclosed and protected within the central structure [4]. Although less commonly used than conventional ladder-frame configurations, backbone chassis are still employed in certain specialized off-road and military vehicles. One notable example is the Tatra chassis concept, which combines a central backbone tube with independently suspended swinging half-axles [5].

2.3 Monocoque structure

In monocoque vehicles, the body itself serves as the primary load-bearing structure, eliminating the need for a separate frame. This concept offers significant weight reduction, improved crash performance and high structural efficiency, making it the dominant solution in passenger vehicle design[4]. Nevertheless, monocoque structures are less suitable for heavy-duty military applications, where high payload capacity, ease of repair and adaptability to multiple vehicle configurations are essential requirements[4].

2.4 Space frame structure

Space frame chassis consist of interconnected tubular or closed-section members arranged to achieve high stiffness with relatively low structural mass. Owing to their excellent strength-to-weight ratio, these structures are frequently used in racing vehicles and certain specialized military applications [6]. Recent studies have shown that space frame architectures can provide improved structural performance under high dynamic loading conditions [7] while offering greater design flexibility and modularity than conventional monocoque structures. However, their complex geometry, numerous joints, demanding fabrication processes and extensive welding requirements significantly increase manufacturing time and cost, limiting their suitability for cost-effective production of modular military vehicle platforms [4].

2.5 Limitations of conventional chassis designs

2.5.1 Manufacturing complexity

Conventional chassis architectures, particularly ladder-frame designs used in military vehicles, often require numerous structural components with different geometries and dimensions. Multiple longitudinal rails, cross members, reinforcement brackets and connection elements increase the number of manufacturing operations, assembly stages and quality control procedures. As vehicle families expand to include multiple wheelbase and payload variants, the number of unique structural components further increases, leading to greater production complexity and higher manufacturing costs [8].

2.5.2 Dedicated manufacturing tooling

Conventional chassis production frequently relies on dedicated manufacturing fixtures, positioning tools and welding jigs specifically designed for individual chassis variants [9]. The introduction of additional wheelbase configurations generally requires new tooling, increasing investment costs and extending production preparation time. Such an approach reduces manufacturing flexibility, particularly in low-volume military vehicle production where rapid adaptation to changing operational requirements is essential.

2.5.3 Welding and assembly challenges

The large number of welded joints required in conventional chassis structures increases manufacturing time and may introduce residual stresses and geometric distortions [10]. These effects often require additional inspection and corrective operations to ensure dimensional accuracy and structural integrity. Furthermore, extensive welding complicates repair and maintenance throughout the vehicle life cycle, particularly for vehicles operating under demanding field conditions.

2.5.4 Limited modularity

Although conventional ladder-frame chassis allow different vehicle bodies to be mounted on a common platform, their modularity is often limited by the need for different frame geometries and wheelbase-specific structural components. Consequently, each vehicle variant frequently requires modifications of the primary load-bearing structure, additional manufacturing documentation and dedicated production resources. These

limitations reduce production efficiency and increase logistical complexity throughout the vehicle life cycle[3]. A comparison of the main characteristics, advantages and limitations of conventional chassis architectures is presented in Table 1.

Table 1. Limitations of conventional chassis architectures

Limitation	Manufacturing impact	Operational impact
Multiple structural components	Higher production cost	More spare parts
Dedicated tooling	Longer production preparation	Reduced flexibility
Extensive welding	Distortion and longer assembly	More difficult maintenance
Wheelbase-specific designs	Additional chassis variants	Increased logistics complexity

These limitations highlight the need for a simplified and highly modular chassis concept capable of accommodating multiple vehicle configurations while minimizing structural complexity, production tooling and manufacturing effort.

3. DESIGN REQUIREMENTS

The design of a military vehicle chassis should satisfy both operational and manufacturing requirements. In addition to providing sufficient structural strength and reliability under various operating conditions, the chassis should enable efficient production, simplified maintenance and adaptability to different vehicle configurations. Based on the review of conventional chassis architectures and the requirements of modern military vehicle platforms, a set of operational and manufacturing requirements was established to guide the development of the proposed chassis concept [1,3].

3.1 Operational requirements

The proposed chassis concept was developed to satisfy the following operational requirements:

– adaptability to different mission profiles;
– compatibility with various mission-specific superstructures;
– accommodation of different wheelbase configurations;
– simplified maintenance and servicing throughout the vehicle life cycle.

3.2 Manufacturing requirements

In addition to operational performance, the proposed chassis should facilitate efficient and economical manufacturing. Therefore, the following manufacturing requirements were considered during the design process:

– simplified structural geometry;
– reduced dependence on dedicated manufacturing fixtures and tooling;
– shorter production and assembly time;
– reduced production and life-cycle costs.

4. PROPOSED MODULAR CHASSIS CONCEPT

The proposed chassis concept was developed to satisfy the operational and manufacturing requirements presented in the previous section while preserving the structural characteristics required for multi-purpose military vehicles. The development focused on simplifying the structural configuration, reducing the number of unique components and increasing manufacturing flexibility without compromising the adaptability of the platform.

Unlike conventional chassis designs, where different vehicle variants often require dedicated structural components and manufacturing tooling, the proposed concept is based on a modular architecture composed of standardized structural elements. The chassis was designed to enable straightforward manufacturing and assembly using conventional fabrication processes and widely available equipment, allowing production to be established with minimal dependence on specialized tooling. Such an approach is particularly suitable for low-volume military vehicle production and situations requiring rapid manufacturing or repair under field conditions.

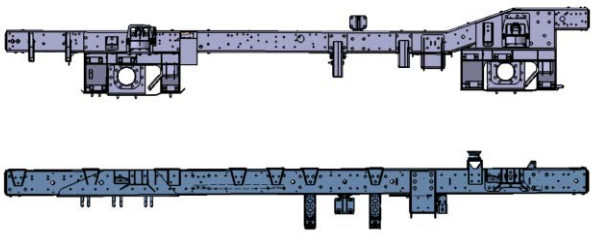


Figure 1 - Comparison of the baseline chassis and the proposed chassis concept

The proposed chassis concept incorporates several design features aimed at improving manufacturability and operational flexibility. These include a geometrically optimized chassis structure, modularly symmetrical longitudinal members, standardized cross members and an adjustable wheelbase concept. Each of these design features is described in the following sections.

4.1 Simplified structural design

The proposed chassis was developed with the objective of simplifying the structural configuration while preserving the strength, functionality and adaptability required for multi-purpose military vehicle platforms. The design process focused on reducing the number of structural components, simplifying manufacturing operations and improving assembly efficiency without compromising the structural performance of the chassis.

In addition to optimizing the geometry of the primary load-bearing structure, an important design decision was the selection of an independent suspension system from a different manufacturer incorporating an integrated suspension subframe. Compared to the previously used

solution, in which the suspension mounting structure consisted of multiple individual components assembled directly onto the chassis, the integrated subframe significantly simplified the overall structural configuration. This approach considerably reduced the number of structural components, assembly operations and manufacturing time required for chassis production.

Since a portion of these improvements results from the adoption of the integrated suspension subframe rather than solely from the redesigned chassis structure, the comparison presented in this study is performed at two levels. First, the primary chassis structures are compared independently of the suspension subframes in order to evaluate the influence of the proposed structural redesign itself. Subsequently, the complete chassis assemblies, including the suspension subframes, are compared to assess the overall manufacturing and assembly benefits of the proposed vehicle platform. This approach provides a balanced and objective evaluation by distinguishing improvements resulting from the chassis redesign from those associated with the selected suspension architecture.

The simplified structural design established the foundation for the remaining design features of the proposed chassis concept, including standardized longitudinal members, modular cross members and an adjustable wheelbase configuration, which are described in the following sections.

4.2 Symmetrical interchangeable longitudinal members

The longitudinal side members are the primary load-bearing elements of the chassis and therefore have a significant influence on manufacturing complexity, logistics and assembly. Conventional chassis designs typically employ separate left- and right-hand longitudinal members, resulting in a larger number of unique structural components and increasing the complexity of manufacturing, inventory management and production planning.

To simplify the production process and improve component standardization, the proposed chassis incorporates interchangeable longitudinal members. A single standardized component was developed that can be installed on either side of the chassis, eliminating the need for dedicated left- and right-hand parts. This approach reduces the number of unique structural components, simplifies inventory management and production planning and facilitates maintenance and replacement throughout the vehicle life cycle.

An additional advantage of the proposed design is the elimination of one of the most common manufacturing errors associated with chassis production. In conventional chassis manufacturing, separate left- and right-hand longitudinal members are produced from different unfolded geometries. Consequently, bending a component according to the drawing of the opposite side results in an unusable part, leading to material waste, additional manufacturing costs and production delays.

In the proposed design, both longitudinal members are manufactured from an identical, geometrically symmetrical unfolded geometry. Owing to this symmetry, the finished component remains suitable for installation regardless of the bending direction. Consequently, a correctly manufactured part cannot become unusable due to an incorrect interpretation of the left- or right-hand configuration, as shown in Figure 2. The possibility of producing an incorrect longitudinal member is therefore eliminated by the structural design itself rather than by manufacturing procedures or quality control.

Besides reducing the number of unique structural components, the proposed solution increases manufacturing reliability, simplifies quality control and inventory management, reduces material waste and minimizes the potential for human error during fabrication.

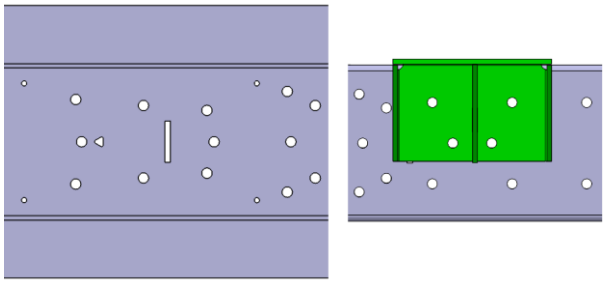


Figure 2 - Symmetrical interchangeable longitudinal member

The proposed symmetrical design results in several unused openings when the longitudinal member is installed on one side of the chassis, as these openings are intended for components that become active when the same member is installed on the opposite side, as shown in Figure 2. Although this represents a minor increase in the number of unused features, it is considered an acceptable design trade-off in view of the significant manufacturing and logistical benefits achieved.

The use of a single interchangeable longitudinal member enables identical spare parts to be used regardless of the installation side, eliminating the need to stock separate left- and right-hand components. Furthermore, in field conditions, replacement can be carried out without any structural modifications or additional machining. An additional advantage is that longitudinal members recovered from damaged or disabled vehicles can be directly reused as spare parts for other vehicles, providing valuable logistical support in emergency situations where replacement components may not be readily available.

4.3 Modular cross members

In order to increase the torsional stiffness of the chassis while preserving its modular character, a cross member manufactured by laser cutting and simple bending operations was developed. This solution enables a relatively simple production process and avoids the need for complex forming tools. Installed cross members are shown in Figure 3.

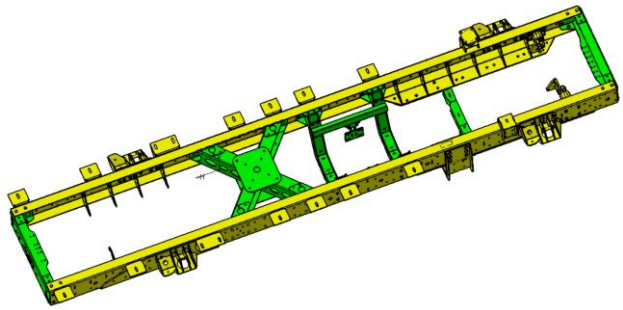


Figure 3 - Cross members

After fabrication, the cross member can be attached to the longitudinal members using either bolted joints or riveted joints, depending on manufacturing conditions and available equipment. Both joining methods can be used within the proposed concept. However, riveted joints are preferred where a permanent connection is required, since they reduce the possibility of loosening during vehicle operation. Bolted joints remain applicable in cases where easier disassembly or replacement of components is required.

In the area surrounding the transfer case, the cross members were additionally designed so that, with only minor modifications, they can also serve as supporting elements for a V-shaped blast protection structure, as shown in Figure 4. This solution provides the possibility of integrating an underbody mine protection system without requiring a complete redesign of the chassis structure, thereby preserving the modularity of the proposed concept.

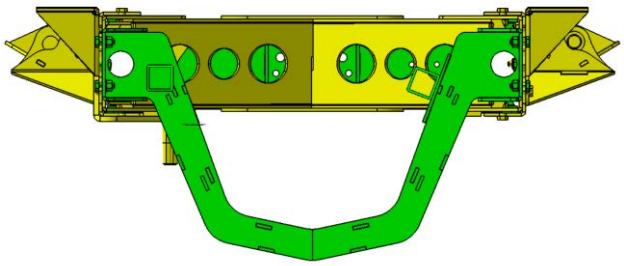


Figure 4 - Cross members around transfer case

The proposed cross member design contributes to improved torsional stiffness while maintaining manufacturing simplicity, assembly flexibility and the potential for future integration of additional structural and protective elements.

4.4 Adjustable wheelbase concept

One of the key features of the proposed chassis is the ability to modify the wheelbase without redesigning the primary load-bearing structure. In conventional chassis designs, changing the wheelbase generally requires the development of a new frame variant, resulting in additional manufacturing effort, dedicated tooling and increased logistical complexity.

In the proposed concept, the suspension subframes are mounted to a dedicated supporting structure that can be translated along the longitudinal members after loosening the corresponding fastening bolts. This arrangement enables straightforward adjustment of the wheelbase while preserving the same primary chassis structure and the majority of its structural components. Once the desired position is reached, the supporting structure, shown in Figure 5, is secured using the existing fastening points.

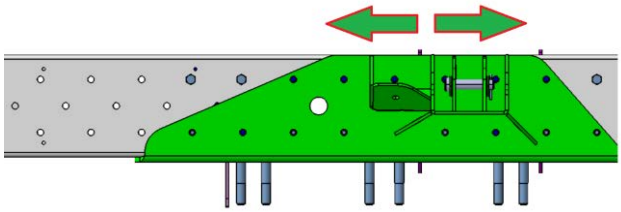


Figure 5 - Adjustable wheelbase concept

When a shorter wheelbase is required, the rear overhang can be reduced by shortening the longitudinal members to suit the new vehicle configuration. Conversely, if a longer wheelbase is required, the chassis can be extended without altering the basic structural concept. In practice, the maximum achievable chassis length is primarily limited by manufacturing constraints, such as the dimensions of the available sheet material and fabrication equipment.

Although changing the wheelbase requires corresponding modifications to the drive shaft, as well as portions of the electrical and pneumatic installations, these changes remain limited and straightforward. When the wheelbase is reduced, most of the existing components can be adapted to the new configuration without introducing additional parts. In cases where a longer wheelbase is required, only those components affected by the increased distance need to be replaced. Such components can be prepared as predefined conversion kits for each wheelbase configuration, enabling rapid vehicle reconfiguration without modifications to the primary chassis structure.

The proposed adjustable wheelbase concept significantly increases platform flexibility by enabling multiple vehicle configurations to be realized using the same basic chassis architecture. As a result, the number of dedicated chassis variants is reduced, while manufacturing, maintenance and logistical support are considerably simplified.

5. COMPARATIVE ANALYSIS

The design features presented in the previous section were developed with the objective of improving the manufacturability, modularity and operational flexibility of the proposed chassis concept. However, the practical value of these design solutions can only be assessed through a direct comparison with the existing chassis design. For this reason, a comparative analysis was performed to evaluate the influence of the proposed concept on manufacturing complexity, structural configuration and assembly.

Since the proposed vehicle platform incorporates both a redesigned chassis structure and an integrated suspension subframe, the comparison is carried out at two levels. First, the primary chassis structures are compared independently of the suspension subframes in order to isolate the effects of the structural redesign. Subsequently,

the complete chassis assemblies are compared to evaluate the overall benefits of the proposed vehicle platform from the standpoint of manufacturing, assembly and logistics.

5.1 Comparison of the primary chassis structure

The first stage of the comparative analysis focuses exclusively on the primary chassis structure, excluding the suspension subframes and associated mounting components. This approach enables an objective evaluation of the structural modifications introduced in the proposed chassis concept, independent of the influence of the selected suspension architecture.

A comparison of the existing and proposed chassis structures is presented in Figure 6. The comparison highlights the effects of the simplified structural design, interchangeable longitudinal members and standardized cross members on the overall chassis configuration.

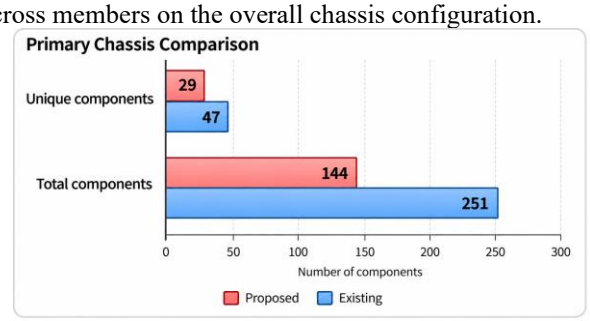


Figure 6 - Comparison of the primary chassis structure

The proposed chassis achieves a significant reduction in manufacturing complexity through a lower number of unique structural components and improved component standardization. In addition, the simplified structural layout facilitates manufacturing, assembly and maintenance while preserving the functionality required for different vehicle configurations.

5.2 Comparison of the complete chassis assembly

While the previous comparison focused exclusively on the primary chassis structure, the second stage of the analysis considers the complete chassis assembly, including the suspension subframes and all structural components directly associated with the chassis. This comparison provides a more realistic assessment of the manufacturing and assembly benefits achieved by the proposed concept.

As discussed in Section 4.2, the proposed chassis incorporates an integrated suspension subframe, which contributes to a further reduction in the number of structural components and assembly operations. To ensure an objective evaluation, the influence of this design decision was separated from the comparison of the primary chassis structure and is considered only in the complete chassis assembly, as shown in Figure 7.

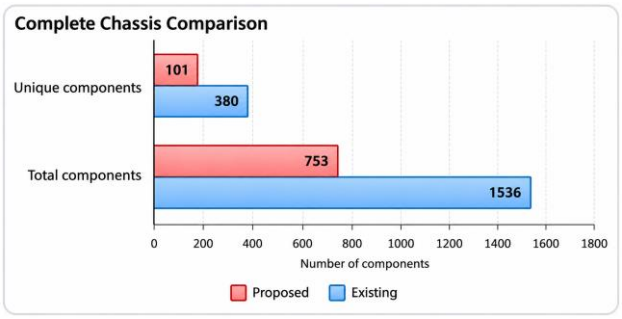


Figure 7 - Comparison of the complete chassis assembly

The complete chassis assembly of the existing vehicle consists of 1536 components, whereas the proposed concept reduces this number to 753. Components common to both vehicle concepts, such as the powertrain and other shared vehicle systems, were excluded from the comparison in order to evaluate only those components affected by the structural redesign. The reduction in the number of components simplifies assembly, inventory management, spare parts logistics and maintenance while supporting a more efficient manufacturing process.

5.3 Manufacturing and logistical benefits

The proposed chassis concept provides several manufacturing and logistical advantages compared to the existing design. The reduced number of structural components, together with the use of interchangeable longitudinal members and standardized cross members, simplifies production, assembly, inventory management and maintenance.

The adjustable wheelbase concept further increases platform flexibility by enabling different vehicle configurations to be realized using the same primary chassis structure. In cases where the wheelbase is increased, only the components directly affected by the modification need to be replaced using predefined conversion kits, while the primary chassis structure remains unchanged.

Overall, the proposed concept reduces manufacturing complexity, improves component standardization and simplifies logistical support while preserving the modularity required for modern military vehicle platforms. The reduction achieved by the proposed chassis concept is shown in Figure 8.

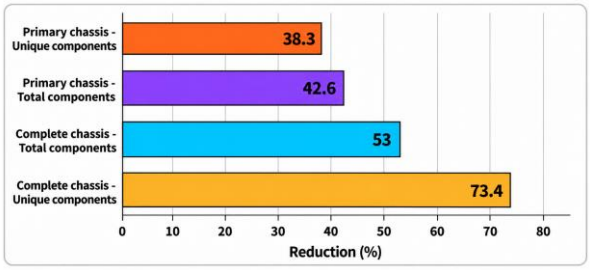


Figure 8 – The reduction achieved by the proposed chassis concept

6. CONCLUSION

This paper presented the development of a modular chassis concept intended to simplify the production and increase the operational flexibility of multi-purpose military vehicle platforms. The proposed design was developed with emphasis on simplified structural geometry, component standardization and the ability to adapt the wheelbase without redesigning the primary chassis structure.

Several design solutions were introduced to achieve these objectives, including interchangeable longitudinal members, standardized cross members and a movable suspension supporting structure enabling straightforward wheelbase adjustment. In addition to improving manufacturing flexibility, the proposed concept eliminates one of the common manufacturing errors associated with the production of left- and right-hand longitudinal members through the structural design itself.

A comparative analysis of the existing and proposed chassis concepts demonstrated a significant reduction in the number of structural components at both the primary chassis level and the complete chassis assembly level. The results indicate that the proposed concept can simplify manufacturing and assembly, reduce inventory requirements, facilitate maintenance and improve logistical support while preserving the modularity required for different vehicle configurations.

The proposed chassis concept represents a practical approach to the development of modular military vehicle platforms and provides a foundation for further structural verification, numerical analyses and experimental validation.

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