

## QUALITY ASSESSMENT OF HIGH MOBILITY MULTI-PURPOSE VEHICLES IN BALLISTIC ARMOUR DESIGN

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*In the article the quality assessment method of the mechanical design of a Mine Resistant Ambush Protected Vehicle is presented. Based on the research of the High Mobility Multipurpose Wheeled Vehicle already in operation, the new design of a MRAP vehicle is evaluated in the context of the quality assessment of the designing process. The research assumption was the provision of safety, which was taken into consideration as the primary designing requirement. This principal focus includes the experimental research of shooting and explosions of an IED blowing charge. In the paper a new mechanical design method named the Design for Optimal Sigma is presented as an application of the new armour design.*

**Keywords:** *designing, quality assessment, light ballistic vehicle, armours, MRAP (mine-resistant ambush protected vehicles)*

### INTRODUCTION

Personal field vehicles of high mobility derive their origins from personal field vehicles in military applications. One of the first vehicles applied to the vehicle design for military use was the High Mobility Multipurpose Wheeled Vehicle (HMMWV). The basic design structure was re-designed and employed successfully in operations by such services as patrol crews, observers, journalists and others. The new design and the fact that it can be easily assembled in accordance with operational requirements makes it suitable for special purposes in military actions. This vehicle has become the most popular in the countries where international military actions are needed. Apart from this, popular vehicles which were adapted to special vehicles as basic equipment are efficiently produced in the civilian sector. Apart from the HMMWV, there are three most popular manufactures producing vehicles designed for special purposes: Land Rover Defender, Toyota Land Cruiser and Mercedes-Benz class G. The design quality of these vehicles would offer mobility as the main design characteristic. Nevertheless, an ability to satisfy the potential user in extremely difficult conditions is complicated.

Therefore, a new design methodology was applied to designing in accordance with direct special condition requirements. The requirements have been described in selected publications [1, 2]. Leading producers have noticed the need of drawing a new vehicle structure. The new design comes from the family of personal field vehicles, but it should be characterized by much better protecting parameters [3, 4], especially to protect the crew and people staying in vehicles from the most dangerous explosion effects. The first project which meets this requirement is the Mine Resistant Ambush Protected vehicle (MRAP). Nowadays, this program is prioritized as a new solution to terrorist problem [5, 6]. Therefore, in the MRAP program there are many construction offices involved. So far the most popular vehicles have been and are still produced by American and South African companies (Fig. 1). On the whole, in the MRAP vehicles design the main assumption is the fulfillment of Mine Resistance Requirements. (Fig. 2).



Fig. 1. View of a MRAP vehicle in a military operation

*Source: Own elaboration*



Fig. 2. View of a MRAP vehicle following a non-controlled explosion of an IED blowing charge

*Source: Own elaboration*

In order to determine the levels of ballistic resistance, the armour research including welding and screwed connections has to be taken into consideration. Based on the standards, connections must be designed to protect over 90% of the general protection area. The main problem of ballistic shield development is the structure of connections, which are the crucial elements of the armour. Therefore, to minimize the quantity of safety defects, the quality assessment of the armour designing process is necessary.

The new design concepts of High Mobility Multi-Purpose Vehicles in the MRAP program are presented in Fig. 3.

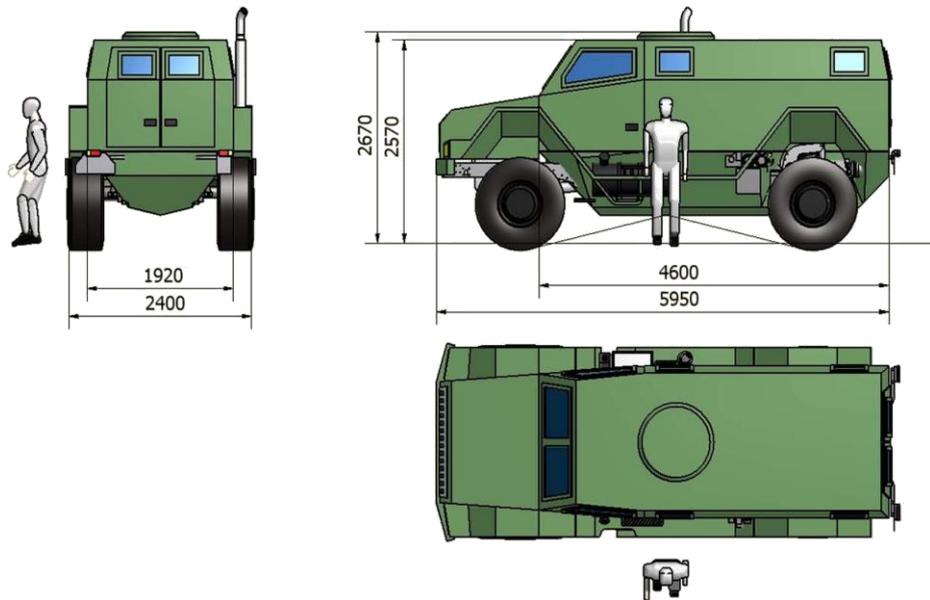


Fig. 3. A new concept of a Mine Resistant Ambush Protected vehicle with regard to construction defects

*Source: [7]*

## 1. QUALITY ASSESSMENT METHODOLOGY

The quality of the structure being the final outcome of the designing process of vehicle and machine structures depends on a number of factors, primarily on the expertise of engineers, their familiarity with and availability of the cutting-edge construction solutions, familiarity with applicable standards and other regulations, and with modern design tools and methods.

The first stage of the quality assessment methodology is the importance determination of qualitative criteria which are assigned to three basic groups defined as criteria with particular – X, essential – Y and moderate – Z of the influence on the quality of object [8]. Input data to the importance determination comes from operators, investors and independent expert requirements as to the operation process and selected market sensitivity to the types of defects. The factor determining the plan of the improvement of quality is an equally significant parameter, necessary for the classification of the qualitative criteria of the object [1, 2]. The relative importance and the evaluation of the mechanical object examinations obtained in the research of the clients satisfaction [8, 9] are the basis for calculating the rates evaluations of the importance of criteria [8]. The

most important issue coming from the quality assessment of the armour are welded connections (Fig. 4).

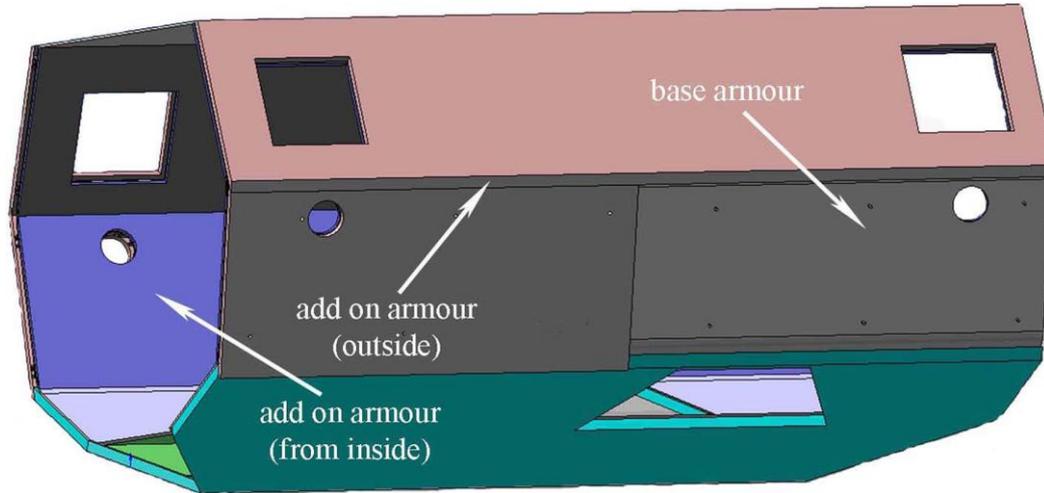


Fig. 4. Crucial connections of armour structure at the pre-study designing phase

Source: [7]

These rates in the initial phase are set according to drawn up object features, in order to get in the next stage the importance level of ( $q_{0i}$ ) and quality object evaluation ( $p_i$ ) in accordance with the qualitative criteria [8]. The importance of every single qualitative criterion is an arithmetic mean of the importance rates of the object features representing the criterion – equation (1). The importance rate of qualitative criteria also depends on marketing evaluation that determines the sensitivity of the market to the sudden and accumulated appearance of defects of the incompatible production. In consequence, it causes fall in sales of the product, even though most of the customers till the moment of announcing the incompatibility were satisfied with the product. This kind of customer reaction usually causes grave financial losses of manufacturers; therefore, also marketing evaluation ( $s_i$ ) is being taken into consideration in the assessment of the designing process according to the method of the Design for Optimal Sigma (DFOS) [8].

$$d_i = \frac{\sum_{j=1}^m d_{ij}}{m}; \quad p_i = \frac{\sum_{j=1}^m p_{ij}}{m}; \quad f_i = \frac{\sum_{j=1}^m f_{ij}}{m} \quad (1)$$

where:

$d_i$  – relative importance of the customer for the criterion  $K_i$ ,

$p_i$  – evaluation of the product by the customer for the criterion  $K_i$ ,

$f_i$  – target of the evaluation of the product for the criterion  $K_i$ ,

$m$  – number of polled customers,

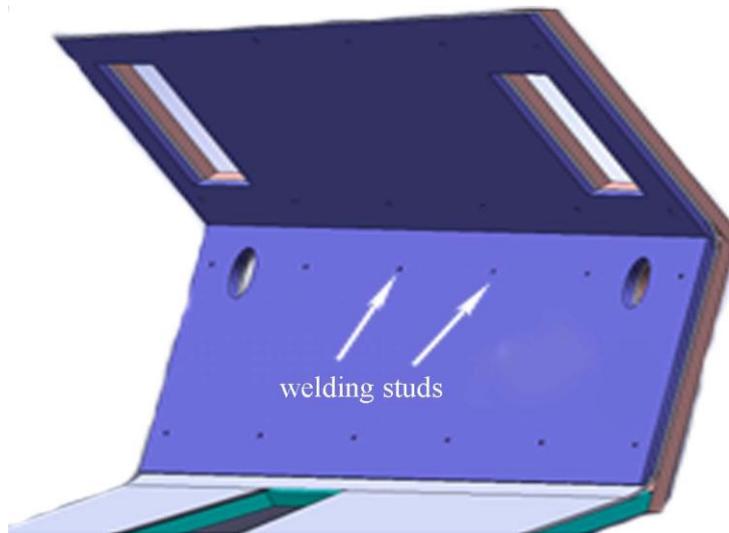
$j$  – number of mechanical object features representing to the criterion  $K_i$ .

## 2. IMPORTANCE FACTORS OF CRITERIA IN QUALITATIVE ASSESSMENT OF ARMOUR

At the first stage of the designing process the behaviour functions analysis allowed one to assume the parametric specification limits that must be fulfilled in the armour. In this

parametric range optimization was directed to increase ballistic resistance and protection of the crew area in the vehicle against mine explosion. In the analysed structure of the armoured vehicle, the main goal of optimization was the maximum reduction of the first grade defects. Quality of the armour structure connections are ones of the factors representing the most important qualitative group. In addition, it is very difficult to design an add-on armour kit without ballistic windows from the practical (including handling, designing, weight etc.) and economical point of view, for example the mounting of spall liner (Fig. 5).

a)



b)

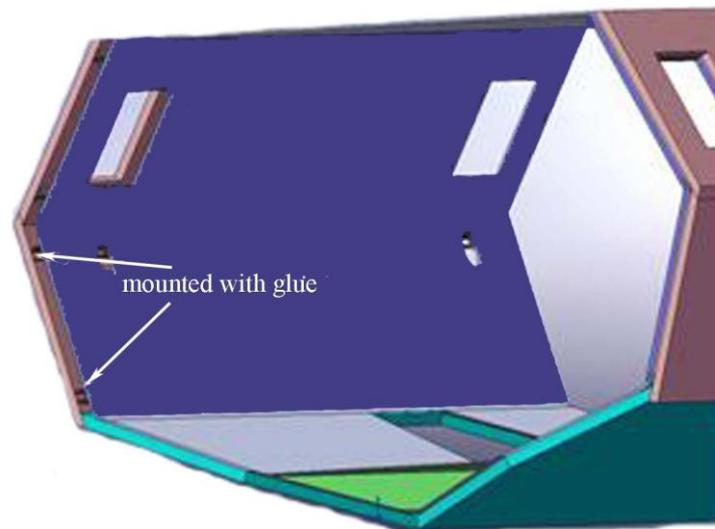


Fig. 5. View of spall linear assembly

Source: [7]

So the classification of importance of 1st, 2nd and 3rd grade criteria groups are described in Table 1.

Table 1. Classification of structure assessment criteria to particular importance groups

Criterion	$q_i$	Criterion group	Importance level of $q_{oi}$ for $K_i$
$K_i$	$q_i \geq \frac{\sum_{i=1}^n q_i}{n}$	X	$q_{Xi}$
$K_i$	$\frac{\sum_{i=1}^n q_i}{n} > q_i \geq \frac{2 \sum_{i=1}^n q_i}{3 \cdot n}$	Y	$q_{Yi}$
$K_i$	$q_i < \frac{2 \sum_{i=1}^n q_i}{3 \cdot n}$	Z	$q_{Zi}$

where: n – number of criteria

Source: [10]

### 3. METHODOLOGY OF THE EVALUATION CRITERIA IMPORTANCE SELECTION OF THE ARMoured STRUCTURE

The prototype of the Mine Resistant Ambush Protected Vehicle (Fig. 6) was a new design of the research object for military use. The technical specification that was used as the input to the designing process was determined in cooperation with Polish drivers and service engineers operating HMMWVs and RG-31 vehicles during military operations under combat conditions.



Fig. 6. The prototype of the Mine Resistant Ambush Protected Vehicle

Source: Own elaboration

The evaluation criteria importance selection was conducted in accordance with the Kano Model [10, 11] Attributes and the importance of features are the results of the analysis. Questions for respondents were formulated in the context of the qualitative

criteria. The questionnaire contained questions separately for drivers, investors, crew and service representatives.

The results of the evaluation criteria importance selection are presented in Tables 2 and 3.

Table 2. Importance factors of qualitative criteria for HMMWV

Qualitative criteria	Importance group	Importance factor ( $q_0$ )
Safety	X	12,05
Probability	X	9,84
Mass	Y	8,50
Reliability	Y	8,15
Operation and economics	Y	8,00
Ecology	Y	8,00
Ergonomic and design	Z	6,03

*Source: [9]*

Table 3. Importance factors of qualitative criteria for RG-31

Qualitative criteria	Importance group	Importance factor ( $q_0$ )
Safety	X	24,94
Mass	X	17,80
Probability	X	15,39
Reliability	Y	13,61
Ecology	Y	11,66
Ergonomic and design	Z	9,44
Operation and economics	Z	7,27

*Source: [9]*

The determination of criteria importance allowed one to calculate the defect influence factors on the object structure (Table 4). In the next step based on the factors, the designing process quality is assessed highlighting crucial designing space as the area for improvement with the use of O-DFSS [8].

The application of the Optimal Design for Six Sigma allows one to determine the direction of optimization, especially selecting the upper specification limit of armour entire mass as a crucial parameter responsible for the mobility and ballistic protection and mine resistance of the vehicle (Fig. 7).



Fig. 7. Chassis adopted to the design project of a MRAP vehicle

*Source: Own elaboration*

Table 4. Influence of the factors of defects on the designing process of a RG-31 and a HMMWV

Factor	RG-31	HMMWV	
	Value of factor	Value of factor	
a	1st grade influence factors of defects	19,4	10,9
b	2nd grade influence factors of defects	12,6	8,16
c	3rd grade influence factors of defects	8,35	6,03

*Source: Own elaboration*

## CONCLUSIONS

The discussed issues of the quality assessment of the armoured shell are considered in the context of the research of two vehicles operated under combat conditions by Polish soldiers.

The implementation of the O-DFSS methodology allowed one to achieve the following results:

- the importance factors of criteria in the qualitative assessment of the innovative armour;
- the factors of defect influence on the designing process;
- the optimization of armour according to the determined crucial specification limits based on the most important qualitative criteria;

- the modulation of construction (recommendation based on customer satisfaction research).

Nowadays, the modern design of mechanical objects, especially vehicles dedicated for military purposes, should be managed and developed based on advanced qualitative assessment methods. These prevention actions in the designing phase allow one to reduce the possibility of manufacturing a defected object that could be operated under combat conditions. Besides, the presented methodology is closely connected with crew observations providing new data of combat conditions and the crucial points of a vehicle.

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## **OCENA JAKOŚCIOWO-KONSTRUKCYJNA POJAZDÓW OSOBOWO-TERENOWYCH WYSOKIEJ MOBILNOŚCI W KSZTAŁTOWANIU ODPORNOŚCI BALISTYCZNEJ**

### **Streszczenie**

*W artykule omówiono metodykę założeń projektowo-konstrukcyjnych pojazdu minoodpornego typu Mine Resistant Ambush Protected Vehicle. Bazując na badaniach już eksploatowanego pojazdu High Mobility Multipurpose Wheeled Vehicle przeprowadzono prace projektowo-konstrukcyjne nowo budowanego pojazdu MRAP. W założeniach główny nacisk położono na bezpieczeństwo pancerza przed ostrzałem amunicji strzeleckiej i wybuchami ładunków typu IED. Na podstawie wypracowanej metody Design for Optimal Sigma starano się przeprowadzić ocenę jakościowo-konstrukcyjną nowo projektowanego opancerzenia tego pojazdu.*

**Słowa kluczowe:** projektowanie, ocena jakościowo-konstrukcyjna, lekka ochrona balistyczna pojazdów, pancerze, MRAP (pojazdy minoodporne)