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Race Car Crash and Occupant Protection

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1 Introduction

The aim of this report is to assess the crash performance of a BMW 130i E87 (2005) that has been converted for road and gravel rally use. The car has undergone extensive modifications to its structure, safety systems, and interior, which are examined in terms of both crashworthiness and occupant protection. Particular attention is given to how these changes alter the original road-car safety concept, including the removal of standard equipment such as airbags and interior trim and the addition of components such as a roll cage, harnesses, and lightweight body parts.

The report first outlines the original crash and occupant protection features of the BMW 130i as a road car, then describes the key modifications carried out for rally competition. These modifications are evaluated using engineering principles, hand calculations, and relevant regulations to determine their impact on energy absorption, structural integrity, and driver safety in different impact scenarios. Where direct measurements, such as an updated vehicle mass, are not available, reasoned estimates are used and clearly identified as such, ensuring the analysis remains transparent and technically justified.



Figure 1 UWTSD rally car in action from university website

2 Original BMW 130i Crashworthiness and Occupant Protection

The stock 2005 BMW 1 Series, on which the 130i is based, is equipped as standard with dual front airbags, side airbags and head-protecting inflatable side tubes, seatbelt pretensioners, ISOFIX mountings, and a safety battery terminal designed to disconnect in the event of a crash. Additional active safety systems include anti-lock braking (ABS) and electronic stability control (ESC), which contribute to maintaining vehicle stability and avoiding loss-of-control events that might otherwise lead to an impact. According to ANCAP, the BMW 1 Series achieved an overall score of 33.37 out of 37 points and a five-star safety rating in combined frontal offset, side-impact and head-protecting tests, indicating a generally high level of occupant protection in its original road-car configuration.

In the 64 km/h frontal offset test, the passenger compartment of the BMW 1 Series maintained its shape well, with only moderate movement of the A-pillar and door aperture and good protection recorded for the head and upper legs. The chest and lower legs showed a slight risk of serious injury, reflected in reduced chest and lower-leg scores, but no structural penalties were applied, suggesting a robust underlying front structure. In the 50 km/h side-impact and optional pole tests, the car scored highly, particularly for head protection, which is consistent with the presence of head-protecting side airbags.

((1350) Euro NCAP | BMW 1 Series | 2004 | Crash test - YouTube, no date)

(BMW 1 Series | Safety Rating & Report | ANCAP, 01/2004; The new BMW 130i, 08/2005)



Figure 2 from ANCAP crash test of the BMW 1 series

3 Overview of Race Conversion

The BMW 130i has been extensively modified from its original road-going specification in order to compete in road and gravel rally events. These changes affect both the vehicle's mass distribution and the way crash loads are managed, so the car can no longer be expected to behave like a standard BMW 130i in an impact. The main modifications are summarised in Table 1, grouped by system (engine, drivetrain, brakes, exhaust, body and safety equipment).

Many of the changes are aimed at reducing mass and improving performance, for example fitting a lightweight flywheel, smaller rally battery, fibreglass bonnet and plexiglass windows, as well as removing interior trim, carpets and the boot floor. Other modifications, such as the installation of a roll cage, harnesses and upgraded braking system, add weight but are intended to increase structural stiffness and improve occupant protection and control. Taken together, the data in Table 1 and 2 show a significant net reduction in vehicle mass alongside substantial changes to the structure and safety systems, which are analysed in detail in the following sections.

Table 1 Modifications made to the BMW 130i
Modifications (kg)

Engine	Gearbox and Drivetrain	Wheels and Brakes	Exhaust	Mapping	Body	Total weight change (kg)
K&N Performance Air Filter	Coolerworx Short Shifter	Braid Fullrace A Alloy Wheels	Simpson 421 Stainless Steel Exhaust Manifold	Saxon Motorsport	Fibre glass bonnet	
TTV Lightweight Single Mass Flywheel	M3 E92 Differential	BMW M-Performance F20 Brake System	Simpson 2.5" Exhaust System		plexi-glass windows	
Davies Craig Electric Water Pump	M3 E92 Driveshafts	Ferodo DS3000 Brake Pads			drilled holes for weight reduction	
smaller battery		Goodridge Braided Brake Lines				
		Motul RBF700 Brake Fluid				
-16	5	2	-5		-22	-36

4 Structural modifications and Crashworthiness

The structural modifications to the BMW 130i – including a multi-point roll cage, removal of interior panels and floor sections, and replacement of glass with plexiglass – mean its crashworthiness philosophy is now very different from the original five-star ANCAP-tested road car. The factory configuration relied on controlled deformation of the bodyshell together with airbags and seatbelt pretensioners to absorb energy and limit deceleration for occupants without a helmet. In rally trim, many of these systems have been removed and replaced by a rigid safety cell formed by the cage, bucket seat and harnesses.

The interior has been heavily lightened by removing carpets, rear seats, the boot floor and sound-deadening, and by drilling non-structural panels. This substantially reduces total mass and therefore the kinetic energy at a given speed, which is beneficial, but the paths through which the remaining energy is carried into the structure are now dominated by the cage rather than by controlled crumple zones. The roll cage ties the front and rear of the shell together and increases stiffness around the occupant cell, improving survival space in rollovers and lateral impacts but shortening the effective crush distance in some frontal impacts, which can raise average deceleration if not compensated by the restraint system.

Removing the OEM airbags changes how loads are managed on the occupant: in the ANCAP tests, frontal and head-protecting airbags spread contact forces and reduced head and chest deceleration, whereas the rally car relies on the harness, seat and HANS device to control the driver's motion. The plexiglass side and rear windows contribute less to global stiffness than laminated or tempered glass but reduce the risk from flying debris and shattering on gravel stages. Overall, the structural changes trade some of the controlled crumple and airbag-based protection of the stock 130i for a lighter, stiffer shell and a defined safety cage more suited to severe rally accidents and rollovers, so the original ANCAP rating is no longer directly applicable to the modified car.

(Championship Regulations 2026 – 2026 Protyre MUK Asphalt Rally Championship, no date; BMW 1 Series | Safety Rating & Report | ANCAP, 2026)

5 Occupant Protection Modifications

In terms of occupant protection, the BMW 130i in its original road-car form was very well equipped, scoring highly in ANCAP and Euro NCAP tests with good protection for the head and legs thanks to a combination of airbags, energy-absorbing dashboard structures and seatbelt pretensioners. In the rally-prepared configuration many of these systems have been removed or disabled, including the frontal and side airbags, some cushioned interior impact zones and the pretensioner road-car belts, so the original passive-safety strategy is no longer present. However, occupant protection has not been ignored; instead it has been re-engineered around motorsport safety equipment such as the roll cage, multi-point harnesses, HANS device and on-board fire extinguishers, which are required under the relevant rally regulations.

With the airbag system dismantled, the harness and seat now carry almost all of the deceleration loads into the driver's torso and pelvis, so the load path runs from the body, through the belts and seat shell, into the cage and floor structure. The tensile force in each harness strap can be approximated by $F \approx \frac{m_{\text{torso}} a}{n}$, where m_{torso} is the mass of the upper body, a is the vehicle deceleration and n is the number of straps sharing the load. For example, if a 40 kg upper body experiences 25 g (about 245 m/s²) and the load is distributed between four shoulder and lap straps, each strap may see a force on the order of $F \approx \frac{40 \times 245}{4} \approx 2450$ N. This illustrates why strong, well-designed anchorages and clear, direct load paths into the roll cage and bodyshell are essential if the modified car is to provide a level of occupant protection appropriate for rally crashes, even though the original airbag-based system has been removed.

6 Mass Changes and Weight Distribution

There has been a substantial reduction in vehicle mass, with most of the removable items coming from the interior and the rear of the car where many components are not required for rally use. The stock BMW 130i has a kerb mass of roughly 1450 kg, whereas the rally-prepared car is recorded at about 1250 kg in the team's weight tracker, giving an overall reduction of around 200 kg. This saving is achieved mainly by stripping the rear seats, boot floor, trim, sound deadening and ancillary systems such as air conditioning, and by fitting lighter components including a smaller battery and composite body parts.

Despite these reductions, the car remains front-heavy because it retains a large 3.0-litre inline-six engine, which, even with a magnesium block, is significantly heavier than the 2.0–2.5-litre four-cylinder engines used by many rivals in the same rally class. As a result, the front axle still carries a high proportion of the total mass, while the rear has lost more weight due to the removal of interior and boot components, so the overall weight distribution is biased towards the front. This front-heavy distribution influences both handling and crash performance: it tends to increase front-axle loading and understeer in normal driving, and in a frontal impact it means a larger share of the vehicle's reduced kinetic energy is transmitted through the front structure and roll cage into the occupant cell.

Table 2 Weight added and removed to the BMW 130i

Removed Weight (-Kg)			Added Weight (+Kg)		
Parts	Est. Weight (kg)	Total	Parts	Est. weight (kg)	
Door cards		7	Roll Cage		45
headling		2	Foot plates		5
carpets		9	4 point harness x2	3kg-per harness	
holes drilled (boot,doors)		2	fire extinguisher		2
boot floor		10			
lights and wiring for non essential syste		2			
Carpets		9			
sound deadning		12.5			
Heater matrix and heater core		5.65			
rear seats		20			
dash board		25			
miscellaneous trim		7			
Airbag system		12			
spare wheel and toolkit		15			
Rear Doors		10			
seat bracket		5			
Total (Kg)					58
Total Weight difference (kg)=			-153.15	Total (kg)	
			-131.15		

7 Regulatory Context

The original BMW 130i as a road car was designed to meet road-vehicle type-approval and consumer crash-test requirements such as Euro NCAP and ANCAP, which emphasise controlled deformation of the bodyshell, airbag deployment and belt pretensioners to protect occupants without a helmet in standardised frontal and side impacts. The rally-prepared car no longer operates under this framework; instead it must comply with the safety and technical regulations for special stage rallies set out by Motorsport UK, which are adopted by the Protyre Motorsport UK Asphalt Rally Championship.

Under these rally regulations the priority shifts from protecting multiple occupants in everyday collisions to preserving a rigid survival cell in high-energy, multi-impact accidents. Cars are required to be fitted with an approved roll-over protection system (ROPS), competition seats and multi-point harnesses, fire-resistant clothing and an on-board fire extinguisher system, all installed in accordance with Motorsport UK Section K requirements. For this BMW 130i, compliance is visible in the full roll cage, harnesses, fixed-back seat and fire extinguisher installation, while systems such as airbags and interior padding have been removed. As a result, the original ANCAP five-star rating is no longer applicable: the vehicle now satisfies a different set of safety standards tailored to rallying, relying on structural reinforcement, specialised restraint systems and personal protective equipment rather than airbags and interior trim to manage crash loads. (01/2026; Championship Regulations 2026 – 2026 Protyre MUK Asphalt Rally Championship, no date)

8 Hand calculations and Engineering Analysis

8.1 Change in crash energy due to mass reduction

Kinetic energy is related to the mass of the vehicle, the stock mass of 1450kg is considerably heavier than the 1250kg weight of the rally car, therefore if we can use $Ek = \frac{1}{2}mv^2$ to calculate the crash energy at a speed of 72km/h = 20m/s:

Stock car weight = 1450Kg:

$$E_{stock} = 0.5 \times 1450 \times 20^2 = 290000J = 290Kj$$

Modified rally car weight = 1250Kg:

$$E_{rally} = 0.5 \times 1250 \times 20^2 = 250000J = 250Kj$$

With a 40Kj difference in weight there is a substantial difference in load that the car has to deal with in the event of an accident, meaning, despite the change in where the load is distributed, the vehicle structure has a lot less energy to absorb, making it safer for the occupants.

8.2 Average Deceleration and Crush Distance

The relationship between the crush distance and the deceleration is very important, as this considerably helps the deceleration of the vehicle by slowing down the speed of deceleration:

$$a = \frac{v^2}{2s}$$

With no published deformation zones available, lets say stock deformation is 0.6m in a frontal impact at the same 20 m/s:

$$a_{stock} = \frac{20^2}{2 \times 0.6} = 333 m/s^2 = 34g$$

With the roll making the cabin more rigid, the effective crush distance reduces e.g. to 0.4m at the same speed of 20m/s:

$$a_{rally} = \frac{20^2}{2 \times 0.4} = 500 m/s^2 = 51g$$

Even though the modified car is lighter and dealing with less energy the force acting on the occupants is increased by 17g due to the decreased crush distance.

8.3 Harness Strap Load Estimate

The force on the harness straps is important, as this is the force applied directly to the chest area/upper-body.

$$F = \frac{m_{torso} a}{n}$$

Using the average weight of a human torso = 40kg, and a severe crash with $25g = 245 m/s^2$, and with a 4 point harness $n = 4$ (shoulder and lap) :

$$F = \frac{40 \times 245}{4} = 2450 N = 2.5 KN$$

This shows that the harness experiences 2.5KN in the event of a severe crash, enforcing the fact that strong harness straps are needed and reinforced anchorage points e.g. the roll cage and reinforced floor mounts.

(2005 BMW 130i E87: detailed specifications, performance and economy data, 2026)

9 Critical Discussion

The modifications to the BMW 130i significantly change its crash performance compared with the original five-star ANCAP-tested road car, bringing both clear benefits and new risks. The 200 kg reduction in mass from approximately 1450 kg to 1250 kg lowers the car's kinetic energy by around 14% at a given speed, so the structure and restraints have less energy to absorb in a crash, while the roll cage greatly improves preservation of the survival space in severe rollovers and side impacts, in line with Motorsport UK rally safety requirements. However, the cage also stiffens the shell and reduces effective crush distance, and the equations above show that this can increase average deceleration for the same impact speed, placing greater demand on the harness, seat and HANS device to manage occupant loads. The removal of airbags, interior padding and pretensioners means the original NCAP-based passive-safety concept for normal road users no longer applies; instead, the car now relies on competition seats, multi-point harnesses, personal protective equipment and fire-safety systems to meet rally regulations. Overall, the rally configuration can offer better protection for a correctly equipped and belted driver in high-energy stage-rally accidents, but it is likely to provide less protection than the stock 130i for occupants without a helmet in everyday road collisions, so the notion of "safety" depends strongly on the intended operating environment.

10 Conclusion

In its original form the BMW 130i offered strong occupant protection, with six airbags, ESC and ABS, an automatic battery disconnect and a well-engineered deformable structure that achieved a five-star NCAP rating in frontal and side-impact tests. These systems were designed to protect occupants in everyday crashes by allowing the bodyshell to deform in a controlled way while airbags and pretensioners managed head and chest deceleration. After conversion for rally use, many of these features have been removed, and the interior has been stripped, but this loss is partly offset by the addition of a full roll cage, competition seat, multi-point harness and HANS device, which create a rigid safety cockpit around the driver.

The hand calculations show that reducing the mass from roughly 1450 kg to about 1250 kg lowers the car's kinetic energy by around 40 kJ at 72 km/h, which means the structure has less energy to absorb in a given impact. At the same time, a stiffer cage and shorter crush distance can increase average deceleration in a severe frontal crash, so the loads transmitted into the torso and harness rise even though the total energy is lower. This makes correct

installation and use of the harness, seat and HANS device is critical for keeping chest and neck loads within acceptable limits. Overall, the modified BMW 130i is likely to offer better protection than the stock car for a fully belted, helmeted rally driver in high-energy rollovers and stage-rally accidents, but worse protection than the original road car for occupants without a helmet in typical road collisions, because the airbag-based protection strategy and much of the interior padding have been removed and the ANCAP rating no longer directly applies.

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