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GENERAL CONSIDERATIONS ON REGULATIONS AND SAFETY REQUIREMENTS FOR QUADRICYCLES

Abstract: *In recent years, a new class of compact vehicles has been emerging and wide-spreading all around Europe: the quadricycle. These four-wheeled motor vehicles, originally derived from motorcycles, are a small and fuel-efficient mean of transportation used in rural or urban areas as an alternative to motorbikes or city cars. In some countries, they are also endorsed by local authorities and institutions which support small and environmentally-friendly vehicles. In this paper, several general considerations on quadricycles will be provided including the vehicle classification, evolution of regulations (as homologation, driver licence, emissions, etc), technical characteristics, safety requirements, most relevant investigations, and other additional useful information (e.g. references, links). It represents an important and actual topic of investigation for designers and manufacturers considering that the new EU regulation on the approval and market surveillance of quadricycles will soon enter in force providing conclusive requirements for functional safety environmental protection of these promising vehicles.*

Keywords: *city car, four-wheeled motor vehicle, homologation, Euro NCAP, safety, crash test*

1. Introduction

Quadricycles are a relatively new class of small fuel-efficient vehicles used in rural or urban areas. Popular in mainland Europe, quadricycles may be seen as an ecological and flexible alternative to motorbikes or city

Far from representing a totally new class of vehicles, they can be considered a deep transformation of an historical mean of transportation accordingly to new needs and functionalities. In fact, a quadricycle was the first vehicle ever developed, designed and produced by Henry Ford. Ford's “first car” was a simple frame with an ethanol-powered engine and four bicycle wheels mounted on it. These earliest cars were hand built, one by one, and very expensive. The peculiar machines were seen as toys for the rich. In the 1890s, the "horseless carriage" was a relatively new idea, with no one having a fixed, universal idea of what a car should look like or how it should work. Most of the first car builders were inventors, rather than businessmen, working with their imaginations and the parts they had on hand. Thus, the invention of the quadricycle marks an important innovation as a proto-automobile that would lay the foundation for future, with more practical designs to follow.

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An fascinating collection of quadricycles and other strange vehicles are reported in (Doeden, 2007) where the trajectory of evolution for mean of transport can be recognized and traced.

Nowadays, in general terms, “quadricycle” or, less frequently, “quadracycle”, “quadcycle”, “quadrocycle”, can be referred to every vehicle with four wheels. From this perspective, this group is rather large and multifarious, also including, for instance, all-terrain vehicles (also known as a "quad"), low-speed vehicles (LSV), velomobiles (human-powered vehicles with a fairing), rickshaws (a four-wheeled style of cycle) and other strange four wheeled vehicles (Figure 1). Somewhere (e.g. Australia), these small vehicles, when motorized, are often referred as Alternative Vehicles (AVs) highlighting how these wheeled vehicles, used for personal transport, are differ in construction from conventional vehicles such as cars, motorcycles and bicycles. And do not comply with applicable vehicle regulation for cars or motorcycles.

Figure 1. Large variety of four wheeled vehicles on the market

But, more appropriate lines of demarcation have to be defined with the aim at creating categories of homogeneous vehicles. The definition and classification of vehicles is a first, but fundamental step of the regulation activity to be implemented before alternative vehicles can be properly used. In fact, in connection with these categories, several regulations can be established as, for instance, homologation, safety, driving licences, emissions, etc.. How to consider a quadricycle has been an issue widely discussed in the recent years. A review of international practices suggests that jurisdictions are having difficulty catering for alternative vehicles. At the moment there are no International vehicle standards that can be applied in their entirety to cover all concerns about the safety and operation of alternative vehicles

The European Union, limiting its interest to “motorised quadricycle”, proposes a classifications of these four-wheeled microcars based on weight, power and speed. The Directive 92/61/ECC concerning the reception of a two or three wheel vehicles – later recast in framework Directive 2002/24/EC – gives a legal basis to the manufacturing and licensing of quadricycles. However, a very recent Directive, the N. 168/2013, which will be fully implemented in few months, provides general requirements for functional safety environmental protection of these vehicles and repeal the above Directives.

2. EU classification of motor vehicles

In Europe, the classifications for vehicle category are based in UN Regulations, also known as UNECE standards. The United Nations Economic Commission for Europe, was established in 1947 to encourage economic cooperation among its member states. It is one of five regional commissions under the administrative direction of United Nations headquarters. It has 56 member states. Besides countries in Europe, it also includes Canada, the Central Asian republics, Israel and the United States of America. The regulations are based on the principles of type-approval and of reciprocal recognition of approval among participating countries. The legal framework for the reciprocal recognition of UN Regulations is set out in the "1958 Agreement". This coordination body permits to widespread standards all over the world.

The unification between UN and EU regulations is obtained by the Directive 2007/46/EC (the Framework Directive), applied to powered four-wheel vehicles including passenger cars, goods vehicles and trailers. The Framework Directive lists more than 40 separate EU Directives that the vehicle must comply with in order to gain type-approval (more details in Table 1). These specify performance requirements and tests for various aspects of the vehicle ranging from tyres through to exhaust emissions and braking systems. The Framework Directive also lists United Nations (UN) Regulations that are considered to be acceptable alternatives to certain EU directives.

Table 1. Technical requirements and directives for category L vehicles

Subject	**Directive number**
Maximum torque and maximum net power of engine	95/1/EC
Anti-tampering measures	97/24/EC Chapter 7
Fuel tank	97/24/EC Chapter 6
Maximum design speed	95/1/EC
Masses and dimensions	93/93/EEC
Coupling devices and their attachment	97/24/EC Chapter 10
Anti-air pollution measures	97/24/EC Chapter 5
Tyres	97/24/EC Chapter 1
Braking systems	93/14/EEC
Installation of lighting and light-signalling devices on the vehicle	93/92/EEC
Lighting and light-signalling devices on the vehicle	97/27/EC Chapter 2
Audible warning device	93/30/EEC
Position for the mounting of rear registration plate	93/94/EEC
Electromagnetic compatibilità	97/24//EC Chapter 8
Sound level and exhaust system	97/24//EC Chapter 9
Rear-view mirror(s)	97/24//EC Chapter 4
External projections	97/24//EC Chapter 3
Stand (except in case of vehicles having three or more wheels)	93/31/EEC
Devices to prevent unauthorised use of the vehicle	93/33/EEC
Windows; windscreen wipers; windscreen washers; devices for de-icing and demisting	97/24//EC Chapter 12
Passenger hand-hold for two-wheel vehicles	93/32/EEC
Anchorage points for safety belts and safety belts	97/24//EC Chapter 11
Speedometer	2000/7/EC
Identification of controls, tell-tales and indicators	93/29/EEC
Statutory inscriptions (content, location and method of affixing)	93/34/EEC

An useful simplification of the EU classification of motor vehicles with at least four wheels is:

- Category G: off-road vehicles
- Category L: light motor vehicles
- Category M: vehicles having at least four wheels and used for the carriage of passengers
- Category N: used for the carriage of goods (trucks):
- Category O: trailers (including semi-trailers)

Quadricycles were traditionally included inside the *Category L: light motor vehicles*, together with motorized bikes, tricycles and quad, but also with moped and motorbikes. Additional details for Category L are available in Table 2.

Table 2. Typology of vehicles inside in the "L" category

Category		Subcategory		Example
L1e	Light two-wheel vehicle	L1e-A	Powered cycles	
		L1e-B	Moped	
L2e	Three wheel moped			
L3e	Motorcycle	A1, A2, A3		
L4e	Motorcycle with side car			
L5e	Tricycle	L5e-A	Tricycles	
		L5e-B	Commercial Tricycles	

L6e	Light quadricycle	L6e-A	Light quad	
		L6e-B	Light mini car	
L7e	Heavy quadricycle	L7e-A1 L7e-A1	On road quad	
		L7e-B1	Heavy all terrain quad	
		L7e-B2	Heavy all terrain quad side-by-side buggy	
		L7eC	Heavy Quadri-mobile	

Besides, according to UNECE standards, the framework Directive 2002/24/EEC strengthened quadricycles definition by introducing a distinction between light quadricycles and heavy quadricycles, creating the two sub-categories, knowingly:

- light quadricycles (L6e)
- heavy quadricycles (L7e)

This framework became mandatory for all category L vehicles sold in the European Union from 9th May 2003.

3. Definition of light and heavy quadricycles

Entering in technical details of L6e and L7e sub-categories (Figure 2), as defined by Framework Directive 2002/24/EC:

Light quadricycles (L6e) are:

- motor vehicles with four wheels
- whose unladen mass is not more than 350 kg, not including the mass of the batteries in case of electric vehicles
- whose maximum design speed is not more than 45 km/h
- whose engine cylinder capacity does not exceed 50 cm^3 for spark ignition engines
- whose maximum net power output does not exceed 4 kW in the case of other internal combustion engines (e.g. diesel fuelled)

- whose maximum continuous rated power does not exceed 4 kW in the case of an electric motor

Adding, these vehicles shall also fulfil the technical requirements applicable to three-wheel mopeds of category L2e unless specified differently in any of the separate Directives

Heavy quadricycles (L7e) are:

- motor vehicles with four wheels other than those referred to as light quadricycles
- whose unladen mass is not more than 400 kg (or 550 kg for vehicles intended for carrying goods), not including the mass of batteries in the case of electric vehicles
- with a design payload not more than 200 kg (passenger) or 1000 kg (goods)
- whose maximum net engine power does not exceed 15 kW.

Adding, these vehicles shall also fulfil the technical requirements as previously reported in Commission Directive 2001/116/EC of 20 December 2001, adapting to technical progress Council Directive 70/156/EEC on the approximation of the laws of the Member States relating to the type-approval of motor vehicles and their trailers. In practices, these vehicles shall be also considered to be equal to motor tricycles and shall also fulfil the technical requirements applicable to motor tricycles of category L5e (unless specified differently in any of the separate Directives).

4. Evolution of EU classification of quadricycles

This categorisation is related to an evolution of rules.

In 1992, the European Union published Directive 92/61/EEC which considered that quadricycles fell into the same category as mopeds. Framework Directive 2002/24/EC then refined this definition by distinguishing between light and heavy quadricycles (L6e and L7e categories). Furthermore, Directive 2006/126 (3rd Driving Licence Directive), later described in details, establishes a common framework for light quadricycles driving licences. For more than twenty years, these directives represented the complete framework for every aspect related to quadricycles in Europe.

But, as quadricycles look set to become more and more popular, also leading tragic accidents all over the World, several doubts about the real level of safety offered by this innovative mean of transportation emerged.

Consequently, as already mentioned, a new regulation was approved on 15 January 2013. This Directive, known as n. 168/2013, refers to the approval and market surveillance of two- or three-wheel vehicles and quadricycles. To be fully implemented on 1st January 2016, it will provide general requirements for functional safety environmental protection of these vehicles and repeal all the above Directives.

5. Permission for driving

As briefly anticipated, the Third European Driving Licence Directive, also known as 2006/126/EC, represents the main EU directives for use of quadricycles. This Directive specifically refers to the minimum requirements for driving quadricycles, including the category of authorized streets and speed. It imposes, for instance, the same requirements for light quadricycles as for mopeds, including the driving age, for which it recommends 16 years as a minimum. The transposition deadline of the directive was 19 January 2011, but several delays occurred at the national level.

Figure 2. Heavy quadricycles (L7e category) for transportation of persons (left) and goods (right)

Largely adopted in Europe not before 2013, it can present relevant distinguishes in consideration of the specific regulation approved by each EU Members. Limiting this analysis to the most important and promising markets for quadricycles (as France, Italy, UK), the national laws currently establish that for driving a:

- light quadricycle (L6e), a full A category licence is needed
- heavy quadricycle (L7e), a full B category licence is needed.

Instead to be considered as marginal, the specificity of licence to be used for driving quadricycle is probably the most relevant single aspect in all this matter. For instance, the L6e, limited to a maximum speed of 45 kilometres per hour (equivalent to 28mph) and having a maximum weight of no more than 350 kg (excluding battery pack), lightweight quadricycles can be driven in many European countries without a driving license, or just on a moped license in others.

Adding, the permission of driving selects the age of driver and, sometimes, limits the way to use the vehicle. For instance, in a large number of EU countries, a full B category licence is obtainable only when the driver is over 18-year old. The same age is also legally requested for transportation of other people. Furthermore, a limit in permission of driving, as an A category licence, limits the user to light quadricycle (L6e) and a 45 km/h maximum speed. But, beyond the marginal restraint of a decreased speed, the real limitation consists in the streets a light quadricycles can run. Highways, bypasses and other main streets around cities could be forbidden. Consequently, designers, manufactures, customers and potential markets are directly involved in the application of 2006/126/EC, together with all technical requirements referred from conceptual design (e.g. engine power, maximal speed) to manufacturing choices (e.g. target costs).

6. Market and costumers

Referring to the current market, the fleet of quadricycles, updated to 2012, counts about 340.000 drivers in Europe, with 17.000 new registrations per year, mainly in France (10614) and Italy (2351). This market is growing fast, with an estimated growth of +10% per year. Outside Europe an estimations is more complex since information from quadricycles is merged with data referred to other categories of light vehicles (e.g. United States).

Market studies and practical observations show that there are two different kinds of quadricycle users: an elderly population, with or without driving licence, living in the countryside, accessing to limited resources and interested to low-priced products. At the moment, this demographic segment counts for the majority of users, with a large quantity of vehicle for transportation of goods in rural areas. These customers are traditionally interested to vehicle characterized by low level of innovation and performances.

On the contrary, it is evident how a well-off, young and urban population is growing fast as end-users for quadricycle. It is also evident by a recent investigation in United Kingdom. Although quadricycles were not particularly popular in this country, the number of them increased from 223 to around 600 over between 2010 e half of 2014. Adding, during this period around 40% of quadricycles are licensed in the City of London and this part is progressively increasing. In these and similar cases, quadricycles offer many technical advantages that make these mini-cars the best choice as urban vehicle:

- small dimensions making narrow accesses and parking easier;
- a reduced speed of 45 kph (in the case of L6e) which is better adapted to urban driving;
- entry level graduated driving which encourages better driver awareness;
- easy to operate continuously variable transmission (CVT);
- fuel efficiency (approx 40km/l);
- low CO2 emissions reducing the environmental impact.

Even if characterized by relevant benefits, the world-wide market access for quadricycles is not so obvious. As demonstrated by recent researches (Gilke *et al.*, 2013) a successful implementation of Mass Customization can result in a challenging manufacturing environment with both high volume production and high product mix, where the customers expect individualized products at the same price they are paying for mass-produced items. Meeting this challenge requires changes in the manufacturing strategies, increase in the flexibility of the production equipments and the most importantly are the adaptable computer systems which make this possible in the manufacturing enterprise. The major requirement is to develop a system which can adapt quickly in order to start new production or to react quickly in failure scenario. Thus the system should have the ability of self improving, self-adaptable and self healing. Thus there is a need for technical migration from a well established flexible manufacturing system (FMS) to intelligent and reconfigurable manufacturing system. Nothing of these is already implemented in the case of quadricycles where nor the production chains, or the supply chain are fully engineered, yet.

7. Environmental aspects and norms

These benefits on environment permit to present quadricycles as a sustainable solution for transportation. Lightness, high efficiency, hybrid power train, reduced speeds lead to low energy consumption. Several investigations already report business models for the introduction and operation of electric car or market penetration scenarios for electric vehicles (Hacker *et al.*, 2009) including, as fundamental parts, quadricycles and similar minicars in their considerations (Varma *et al.*, 2011). A new vision for transportation, including uncommon vehicles, seems to represent the compulsory strategy toward a significant reduction of greenhouse gas emission.

There is also lobbying to allow these vehicles to be used on public paths, cycleways or reserved roads (Paine, 2011). The argument is often put forward that these vehicles will be used instead of cars and so will result in reduced pollution and less traffic congestion. Even if nothing has ever established in that sense, these considerations are reinforcing the general interests on the vehicles all over the world (King, 2007).

Specifically referring to the antipollution requirements or other standards for environmental protection, in line with the whole L category, the European Union already planned a transition for quadricycles to:

- Euro 3 since 1 July 2014;
- Euro 4 since 1 January 2017 for L6 and 1 January 2016 for L7;
- Euro 5 since 1 January 2020 for both L6 and L7.

Vehicle and Engine manufacturers confirmed the transition to Euro 3 and ensured the capability to obtain the Euro 4 standards as originally scheduled. At the same time, taking into account financial and technical resources, quadricycle manufacturers are concerned with the process of transition to Euro 5 standard (planned for 1st January 2020). Insofar as it is difficult from a technical point of view for manufacturers to comply with the requirements induced by Euro 5 standard for quadricycles, additional steps between the passage of Euro 4 and Euro 5 have been proposed.

Interested evaluations and assessments on a new way for a sustainable management organisation have been already proposed in several recent investigations (Afgan, 2009), but they are often limited to conventional internal combustion engine cars. At the same time, it is already evident that a real jump over is possible only considering electrical motorization and light vehicles.

8. Safe and dangerous

Experts from Euro NCAP (New Car Assessment Program), the European crash test agency declared that quadricycles show a level of safety that is way below that of cars since crash safety tests are not required by law (Figure 3). According to this opinion, even though they meet legislative standards, these vehicles lack the minimum safety equipment which has become commonplace on passenger cars sold in Europe. This criticality has to be considered particularly relevant in the case of heavy quadricycles. Like lightweight quadricycles (L6e), heavy quadricycle are not required by law to undergo the same strict crash tests as full-size cars, yet both types of vehicle share the same roads as far more powerful, far safer cars.

Figure 3. A light quadricycle, a golf cart fared really badly in a crash test (EURO NCAP courtesy)

Up to the most recent years, the general opinion was that in a collision the occupants of a heavy vehicle would, on average, suffer fewer and less serious injuries than the occupants of a lighter vehicle (IIHS Status report, 2011). For instance, it was found that a 100 kg increase in mass decreases the risk of injury to the driver in a two-car injury accident by 3 % (Talouei and Titheridge, 2009). Adding, preliminary research carried out by the Highway Loss Data Institute in the United States found that the odds of being injured in a crash are 25 percent lower for people in hybrids than people travelling in non-hybrid models (IIHS Status report, 2011). All these confirmations seem to converge to the same outcome: heavy quadricycle are safe vehicles.

Unfortunately, this reassuring outlook can be considered totally out-of-date, overtaken by rationality and practical evidences. Heavy quadricycles (L7e) are defined in law by maximum weight (400 kg excluding battery pack) and a power output (15 kilowatts), but not limited in speed (as L6e). It is an evident nonsense considering that some of the micro-cars available on the market are able to reach relevant speeds (Figure 4). And higher speed means larger impact energy in the case of accident. Adding, as usually happens, a heavier vehicle will also be more “aggressive” and hence increasing the mass of a particular vehicle could increase the risks to occupants of other vehicles. Finally, quadricycles are not required by law to carry airbags, crumple zones, or assistive safety technologies like ABS or traction control. And while quadricycles must meet certain basic safety requirements, like seatbelt, lights and efficient brakes, they are no match against heavier, better protected vehicles in an impact.

Figure 4. Some models of heavy quadricycles in Europe with maximum speed

According to a recent report provided by ACI - Automobile Club Italiana, during the triennial period 2010/12 in Italy, 2.152 accidents involved (at least) a quadricycle happened, procuring 2.922 injured and 40 dead peoples. During the previous year, the

2009, a maximum of 18 deaths occurred. Considering that about 80.000 mini cars are present in Italy and that quadricycles caused less than 1% of all death events for car accidents, the intrinsic risk of driving can be considered quite low. But addition considerations changes this perspective. Firstly, 18 deaths of 682 accidents means a death index of 2.63 for this kind of vehicle, three time the average (approx. 0.9) and higher than all other categories, even motorbikes. Also considering the ratio between the values of injured people (558) and accidents (682), it is possible to find an index for injury, around 81.8, very high, almost comparable to moped (99.1) and motorbike (100.0). Finally, it is important to consider that 40% of drivers were between 14 and 16 years old, a weak category of population to be specifically protected.

9. Outside Europe

In the North America, life for quadricycles is not easy. In the USA, there are regulations to allow Low Speed Vehicles, including quadricycle, on some specific roads. But, in general their circulation is forbidden. In Canada, the Agency of Transport and the Insurance Institute for Highway Safety have each conducted crash tests of quadricycles and have expressed strong concerns about the lack of crashworthiness and the risk to occupants in relatively low speed collisions with cars.

In Australia, quadricycles are considered as Alternative Vehicles (AVs), wheeled vehicles used for personal transport, differ in construction from conventional vehicles. Since they do not comply with applicable vehicle regulation for cars or motorcycles, strong limitations in circulation are active. Australian AVs are similar to rickshaws, golf cart and power-assisted bicycles, appropriate for public paths and cycleways, very different from European quadricycles. Consequently, it is not amazing that a remarkable limitation in maximum speed (down to 25 km/h) was proposed in Australia, according to experimental evidences on the fatality risk for pedestrians and cyclists at collision with AVs. (Wramborg, 2005; Paine, 2003). This interesting investigation estimates a negligible risk of a fatal accident for a pedestrian up to 10-12km/h of impact velocity for the quadricycle, and less than 3% for 30km/h. But this risk increases very fast with speed, up to 10% at 40km/h and 40% at 60 km/h.

In New Zealand, the vehicle classifications make no discrimination on power source. The classifications and associated rules for safety are solely designed to reduce the likelihood of a vehicle being involved in a crash and protect the occupants in the event of a crash. As New Zealand does not have vehicle manufacturing or assembly industries, nor require purpose made vehicles, our safety standards are taken directly from the jurisdictions we buy our vehicles from. At the same time, New Zealand recognizes that standards to protects, at least, from frontal impacts are vitally important for crashes with large vehicles at any speed. As a large number of trucks can effectively travel on almost any section of New Zealand roads, they consider the circulation of quadricycles totally unsafe (King, 2007) even if they endorse the use of little cars, better is powered by electricity. In any case, all these countries are only marginal interested in the L6&L7 categories.

A different situation is present in the overcrowded India. Statesmen officially declared that quadricycles could well change the landscape of urban and semi-rural commuting in India. According to the technical requirements of Indian models, this four-wheeler is weighs less than half the weight of a small car, has about a tenth of a car's horse power and has a maximum top speed of anywhere between 70-80 km an hour. A quadricycle is considered much more comfortable and safe than three-wheelers and rickshaws, largely spread in India. For all these motivations, since 1st October 2015, quadricycles are allowed to ply in cities across the country and, even, encouraged. But, it is clear that quadricycles have to be considered for their own merits rather than in the context of cars. And sellers of quadricycles are not allowed to sell them as replacements to cars. A recent disposition of law clarify all these aspects. Every new vehicles, for the first time in India, have to satisfy crash tests for homologation, but not quadricycles. For them, it is enough to adopt specific solutions for safety (as rigid doors and roof, belts, etc.). At the same time, quadricycles are not allowed to ply on highways, but limited to city and village streets, while their top speed is reduced to 70 kmph.

10. A critical choice

In a consolidated investigation on motor vehicle safety realized throughout Europe (ETSC, 2007), motorcycles accounted for 2% of distance travelled, but accounted for 16% of road deaths in the EU-25. Indeed, the fatality rate per million kilometres travelled is, on average, 18 times greater than passenger cars (ETSC, 2007). Furthermore, while other vehicle modes have shown significant decreases in fatalities and serious injuries over time, those for motorcycles have exhibited much lower decreases or remained static. Referring to the case of quadricycle (and not motorcycle), in another European investigation (Robinson *et al.*, 2009), accident data concerning L6 and L7 quadricycles and off-road quadricycles was very limited, although available data indicated that the fatality risk per 100,000 vehicle kilometres was between 10 and 14 times that of passenger cars, and lay between the risk for M1 vehicles and mopeds.

Even if not definitive, these preliminary results can provide a clear idea of how crucial the situation on quadricycle is. No institution desires to transform, by an under evaluation of risks, Le6 and Le7 categories in what is now represented by motorcycles. At the same time, every ineffective rule is going to negatively impact on an emerging market. For instance, reducing quadricycle size and unladen mass limits has the potential to improve safety, although most current quadricycles exceed the proposed limits and therefore this may result in significant manufacturer development cost to meet new requirements. Industry was in favour of this option in principle, since it differentiates quadricycles for other vehicles, although the criteria suggested by industry were larger than the limits proposed by the EC and more consistent with current quadricycle dimensions (Robinson *et al.*, 2009). And, it does not represent a solution the hypothesis to leave every EU Member State free to choose its own regulation. In fact, stakeholders indicated that reverting to national approvals has the potential to negatively influence the industry, because approving at a national level (potentially to different country specific requirements) may inhibit the market and would ultimately increase the costs to manufactures and consumers (Robinson *et al.*, 2009). Finally, it should be noted that designing a vehicle that does not have to pass Frontal Impact tests is significantly cheaper for the manufacturer. Lower production costs are a large reason these vehicles are made to a lesser standard.

11. Safety tests campaign

To verify the level of safety offered by quadricycles, in June 2014 Euro NCAP took four vehicles currently on the market in Europe and put them through the same crash tests normally reserved for full-size, highway-capable cars. The vehicles were tested in front and side impacts (Figure 5). In the frontal test, the full width of the vehicle is impacted at 50km/h into a honeycomb element attached to a concrete block. On the road, if quadricycles are struck by other vehicles, the change of velocity or ‘severity’ of the collision can be much greater than the maximum speeds they themselves are capable of. In the side impact, a honeycomb barrier is driven at 50km/h into the side of the vehicle. Together, these tests represent the sorts of accidents that quadricycles might be involved in when driven on public roads. Even if these tests were performed in less severe conditions respect to traditional crash-tests, no vehicle was able to reach 50% of the potential score for safety.

Figure 5. The first crash test campaign on quadricycles (EURO NCAP courtesy)

This test campaign confirmed, when all is said and done, that quadricycles generally provide a much lower level of safety than regular passenger cars. All of the quadricycles tested by Euro NCAP showed critical safety problems, although some fared better than others. The vehicles tested are type-approved and meet the minimal safety requirements set by European legislation for L7e heavy quadricycles. Analogues results were obtained by authors with Finite Element simulations of crash tests (Pavlovic *et al.*, 2012, 2014).

As quadricycles look set to become more and more popular, risky situations are going to increase very fast. On the contrary, consumers are not properly informed regarding the authentic level of protection currently offered by these vehicles. Consumers should note that quadricycles in general offer a significantly lower level of occupant protection than is offered by cars.

12. Crash test for all

As solution, Euro NCAP invited European legislators and automakers alike to create a mandated minimum crash test standard for a class of vehicle which to date has avoided the tough crash test standards required by law for all full-size vehicles.

Directive 96/79/EC and UN Regulation 94 set the minimum requirements for the frontal impact performance of cars (M1 category). They both specify a frontal impact test in which the car is propelled into an offset, deformable barrier at 56 km/h. Similarly, Directive 96/27/EC and UN Regulation 95 set the minimum requirements for side impact performance. They specify an impact test in which a mobile deformable barrier is propelled into the side of the car at 50 km/h. There are no specific provisions for electric vehicles in the EU Directives for frontal and side impact. The test procedures and occupant safety requirements could be applied to any vehicle, regardless of power train type.

In 2009, a group of interested experts on post-crash provisions for electric vehicles was formed. The aim of the group was to derive amendments to UN Regulations 94 and 95 so that they are appropriate for the assessment of electric vehicles. The group was formed mainly of experts in electrical safety from the UN informal working group on electrical safety and experts in crash safety from the UN informal working group on frontal impact. Although the amendments have been prepared by experts, they have not been validated experimentally. Performing a series of crash tests (and/or obtaining data from manufacturers) would help to confirm that the amendments are appropriate and consider all the hazards (Visvikis, 2012).

According to a recent investigation (Robinson *et al.*, 2009), aligning the quadricycle requirements with M1 vehicles was estimated to result in significant cost increases to meet front and side crashworthiness requirements. Manufacturer cost would be significantly increased in materials, design, development, and testing (e.g. airbag development). Significant societal and environmental benefits may result from this investment, but the effects and magnitude of these were uncertain. Reducing quadricycle size and mass was estimated to require lower investment, but with smaller resulting benefits. The environmental impacts were assessed as low negative for all options, apart from improving the requirements towards that of M1 vehicles, where low positive benefits for noise and emissions might be possible.

The recent Directive n. 168/2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles, moved in the direction to generally improve the attention on vehicle functional protection and occupational safety. The safeguard is not limited to users, but also involves pedestrians and environment.

Even if without obliging the adoption of crash tests, the Directive is not going to exclude this hypothesis. Everywhere is stated that, in order to ensure that a high level of functional safety is attained, the Commission shall adopt delegated acts regarding the functional safety of vehicles. The first one of such acts was planned for 31 December 2014, but several others will follow till 2020.

As a direct consequence of this new legislative interest, on June 2014 Euro NCAP launched the N.2 crash testing protocols for L7e category, in the case of frontal and side impacts. These protocols were arranged considering a minor severity of conditions of tests respect to the traditional ones. For instance, the impact speed was reduce from 64 km/h to 50km/h ± 1km/h in consideration of the urban use of these vehicles. Additionally, both protocols consider an impact against a deformable barrier, not a rigid one. And, finally, the full width frontal impact has been preferred respect to the more severe half width frontal impact.

13. Modality of adoption for new rules

The EU Regulations typically follow a "split-level" approach, comprising two-parts:

- Fundamental provisions are set out in an EU Regulation laid down by the European Parliament and Council and adopted through the ordinary legislative procedure;
- Technical specifications that implement the fundamental provisions are laid down in one or more separate EU Regulations adopted by the Commission with the assistance of a regulatory committee (typically comprising representatives of EU member states, the automotive industry,

component manufacturers and other stakeholders).

European Union Directives are generally kept up to date, but several EU Directives have started to lag behind their corresponding UN Regulation, particularly on the subject of electric vehicles.

UN Regulations generally provide for the approval of vehicle systems and components, or for specific aspects of a vehicle, but there is no “whole vehicle” approval mechanism. Several UN Regulations have been amended to include specific provisions for electric vehicles. These include UN Regulation 12 (protective steering), UN Regulation 13 and 13-H (braking), UN Regulation 51 (noise), UN Regulation 83 (emissions), UN Regulation 85 (engine power) and UN Regulation 101 (CO2 emissions). In addition, proposals to amend UN Regulation 94 (frontal impact), UN Regulation 95 (side impact) have now been adopted. UN Regulation 100 sets out specific provisions for electrical power trains and was recently made mandatory for EU type-approval (Visvikis, 2012).

14. Conclusion

World people are simultaneously dealing with the air pollution, global warming and increasing energy demand. The automobile electrification is expected to be a promising solution in major countries to overcome the worldwide stringent regulation of the fuel saving after 2020. Their ambitious goals of the electric vehicles on roads in 2020 are five million in China, two million in Japan, one million in Germany, and one million in USA in 2015 (Higuchi, 2014). Heavy quadricycles could represent a prominent solution, especially for small mobility used in residential area. But the low level of safety of these vehicles are reducing the possibility to widespread their benefits in several potential markets. Outside Europe and part of Asia, a large confusion was caused by the introduction of quadricycles, since they were and are perceived as urban electric passenger vehicles. Consequently, these vehicles are considered as designed for very limited operating environments. And they are currently prohibited from entry in several countries because they do not provide evidence to pass minimum safety requirements. The idea is that allowing these vehicles on roads, it will come at the expense of safety standards without a better interest for citizens. In contrast there are several models of fully electric car that have similar environmental benefits to electric quadricycles but are designed to meet car crashworthiness standards. Designers and manufacturers of heavy quadricycles have to change the general approach to these vehicles or they will lose a great opportunity in a very short of time. A recent EU directive, adopting warnings from international institutions or experts, moved toward this direction requiring more safety specification for heavy quadricycles. Euro New Car Assessment Program (NCAP) already proposed its protocols for crash tests. At the same time, it is evident that this modification, if not supported by an appropriate strategy for product development and optimisation, will simply increase the costs of these already high-priced vehicles. Several solution to minimize the costs of testing and maximize the benefits can be adopted. For instance, finite element (FE) computer simulations of a NCAP full scale crash tests (Marzougui *et al.* or, recently, in Pavlovic *et al.*, 2014) can be used with success. In fact, computer simulations of vehicle collisions have improved significantly over the past few years. With advances in computer technology and non-linear finite element codes, full scale models and simulations of such sophisticated phenomena are becoming ever more possible. Recently, refined FE models of airbags and dummies have been added to the simulations. This allows direct evaluation of occupant risks and injuries using simulation data reducing, as possible, the expensive and disruptive NCAP tests.

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