Courses of Action for Improving the Safety of the Powered Cycle

Luc Vinckx and Huw Davies

Abstract This paper explores the possibility to include a number of safety features from passenger cars in powered cycles with three or four wheels, whilst complying with the legal definitions and requirements, and also the legal conditions to use the bicycle lanes. The differences between technical specifications contained within EU law for pedal cycle with pedal assistance, powered cycles, quadricycles and passenger cars will be explained. Further, examples of traffic code rules with respect to the use of bicycle lanes in different countries will be discussed. Finally, the need for new safety criteria for powered cycles, replacing the existing power limit, is highlighted. In addition to the above, the need for a different technical approach to deal with the stability of 1 m wide e-bikes with a vehicle height similar to a mainstream passenger car will be discussed.

Keywords Safety · Regulation · Powered cycle

1 How to Increase Bicycle Use and at the Same Time Reduce Casualties and Injuries Resulting from Bicycle Accidents

A modal shift from passenger cars to the increased use of bicycles, e-bikes and powered cycles will help to improve air quality and at the same time reduce congestion resulting from passenger car use. The provision of a dedicated infrastructure, for example bicycle lanes, has an important role to play in this evolution. However, even with aggressive growth in infrastructure provision, it is likely that

L. Vinckx (✉)
Elephant Consult BVBA, Olmenstraat 31/1, 3080 Tervuren, Belgium
e-mail: luc.vinckx@telenet.be

H. Davies
Automotive Systems Engineering, Research Institute for Future Transport and Cities, Coventry University, Coventry, UK
e-mail: ac2616@coventry.ac.uk

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there will be no dedicated bicycle lane for part of a given trip. On one hand, such situations lead to the so-called “black spots”, where there is an increase in conflict with other road users that would result in accidents with the potential for higher injury outcome (e.g. collisions with passenger cars). On the other hand, a number of travellers, upon realising this situation and in order to avoid the risk, prefer to use their car for the entire trip. If a modal shift away from passenger cars is to be realised, then there is need to respond to these safety concerns.

At present, road safety policy—the courses of action, regulatory measures, laws, etc.—is restrictive in terms of providing appropriate solutions to the above problems. In this paper, a simple solution is proposed that will support OEMs to include a number of safety features from passenger cars in powered cycles with three or four wheels, whilst complying with the legal definitions and requirements, and also the legal conditions to use bicycle lanes. This further leverages the existing opportunity for powered cycles with three or four wheels to be driven on bicycle lanes and provides a similar safety level as other vehicle types (quadricycles, tricycles, passenger cars) allowing them to safely use existing road space used by passenger cars.

This paper is structured as follows: Sect. 2 discusses the present EU system of vehicle classification, highlighting the difference between passenger car classification and the classification of lightweight vehicles (L-category and assisted pedal cycles). Section 3 summarises the present situation regarding access to dedicate bicycle infrastructure across a number of EU member-states. Section 4 brings together vehicle classification and infrastructure access requirements to develop a new proposal that would support the goal of modal shift from passenger cars. Section 5 then concludes.

2 EU Classification of Vehicles

The EU Regulation 168/2013 [1] defines two different types of vehicles with pedals and a small electric motor. These are highlighted below:

- ‘Pedal cycles with pedal assistance’ which are equipped with an auxiliary electric motor having a maximum continuous rated power of less than or equal to 250 W, where the output of the motor is cut off when the cyclist stops pedalling and is otherwise progressively reduced and finally cut off before the vehicle speed reaches 25 km/h;
- ‘Powered cycle (L1e-A)’ as a vehicle designed to pedal, equipped with an auxiliary propulsion with the primary aim to aid pedalling with a maximum power of 1 kW and a maximum width of 1 m. The output of the auxiliary propulsion is cut off at a vehicle speed ≤ 25 km/h.

The pedal cycle with pedal assistance is excluded from vehicle type approval according to (EU) 168/2013, but it is subject to the machinery directive 2006/42/EC

[2]. Compliance with the objectives of the machinery directive can be proven by complying with a number of EN standards. The powered cycle is subject to European type approval laid down in (EU) 168/2013 and a number of “delegated acts”. Further, to the above, both the ‘pedal cycles with pedal assistance’ and the ‘powered cycle’ can have two, three or four wheels.

Examples of four-wheel ‘pedal cycles with pedal assistance’ are the Podbike [3] (Fig. 1) and the Bio-Hybrid [4]. The Podbike is designed in accordance with EU regulations for pedal cycles with pedal assistance, and it is only slightly wider than a regular bicycle trailer. The Bio-Hybrid startup describes its vehicle as the ideal combination of a bike and a car. Essentially, it is a weather-protected four-wheel bike that can be powered by battery or pedalling. For both the Podbike and Bio-Hybrid, the electric traction motor assists the operator—as in the case of a pedelec—up to a speed of 25 km/h. As a result, both the Podbike and Bio-Hybrid are permitted to ride wherever regular bicycles are allowed.

The Podbike and the Bio-Hybrid therefore offer a unique modality. They provide the user with a small lightweight vehicle with which they can legally access bicycle infrastructure. The question is: Why has this particular modality not found the success of other modalities that have restriction on where they can be used?

Since the ‘powered cycle’ as well as the ‘pedal cycle with pedal assistance’ [1] can be built in a four-wheel version, it can be useful to compare these vehicle categories with other, more powerful vehicle categories. A comparison is made with the light quadricycle (L6e-B), the heavy quadricycle (L7e-C and L7e-A2) and the passenger car (M1). Requirements for M1 have been published by regulations 2018/858 [5]. Table 1 shows key legal parameters between five different vehicle categories for four-wheeled vehicles.

A quick review of the key legal requirements for the different vehicle categories suggests that it would be theoretically possible to create a vehicle that crosses the different categories; i.e., a vehicle could be categorised as both L6e-B and at the same time L1e-A. Indeed, it is not unknown for manufactures to develop a vehicle and to classify the vehicle in multiple categories. Examples include:

Fig. 1 Podbike (Norway) pedal cycle with pedal assistance (250 W) is announced for 2020 [3]

Table 1 Comparison of key legal parameters between different vehicle categories for four-wheeled vehicles

	Pedal cycle with pedal assistance	L1e-A	L6e-B	L7e-C/ L7e-A2	M1
		Powered cycle	Light quadricycle light quadrimobile	Heavy quadricycle heavy quadrimobile	Passenger car
EU Regulation	Excluded from (EU) 168/2013	(EU) 168/2013	(EU) 168/ 2013	(EU) 168/ 2013	(EU) 2018/858
Number of wheels	2, 3 or 4	2, 3 or 4	4	4	4
Max. length (m)		4	3	3.7/4	12
Min. length (m)		None	None	None	None
Max. width (m)		1	1.5	1.5/2	2.55
Min. width (m)		None	None	None	None
Max. mass (kg)		None	425	450[a]	None
Min. mass (kg)		None	None	None	None
Max. number of seats			2	4/2	9
Min. number of seats		(1)	1	1	1
Min. top speed (km/h)		6	6	6	25
Max. top speed (km/h)		25	45	90/None	None
Max. motor power (kW)	0.25	1	6	15	None

[a]The maximum vehicle mass in (EU) 168/2013 is based on the mass in running order without the battery for electrical propulsion. Mass in running order does not include the mass of the driver, but it includes all the liquids necessary to put the vehicle in traffic [1]

- The Renault Twizy has been on the market since 2012 and is certified as an L6e-B and L7e-C. The mass in running order is about 450 kg [6].
- The Lumeneo Smera was proposed as a small M1 with a maximum weight of 450 kg, and a vehicle width below 1 m [7].
- The Colibri from the German company Innovative Mobility Automobile (IMA), 540 kg and 1.1 m width, was presented at the Geneva motor show in 2013. The vehicle was announced to be launched in 2016, but has not yet reached the market [8].

However, classifying a vehicle into multiple categories is not that simple. If a vehicle is to be classified in different categories in additional to the requirement to comply with the physical requirements listed in Table 1 (weight, size, seats, etc.), there are additional legal requirements, mostly relating to safety or environmental performance. For classification as M1, a vehicle needs to be certified, according to UN ECE Regulation 94 on “protection of the occupants in the event of a frontal collision”, UN ECE Regulation 95 on “the protection of the occupants in the event of a lateral collision” and UN ECE Regulation 127 on “pedestrian safety performance”. These three regulations are considered as “defining” a vehicle platform. This means that if an existing vehicle is not compliant with the three regulations, it is almost impossible to adapt the existing platform accordingly. In this regard, it seems difficult to comply with these regulations for vehicles respecting the maximum weight for the L6e-B and L7e-C categories, especially for two-seaters in the side-by-side format, with standard side doors and a roof.

For reasons of completeness, it has to be mentioned that one-seater vehicles without a roof or standards side doors (with vertical hinges) can be certified as L6e, L7e and M1. However, even as an L-category vehicle (L6e and L7e) consideration of crashworthiness is an essential for success in the market place—for example, a number of OEMs in the L6e and L7e market space subject their product on a voluntary basis to crash testing to provide confidence to the consumer [9].

Many other regulations apply on a mandatory basis to the different vehicle categories mentioned in this article, but they do not impact the basic mechanical structure of the vehicle platform. Of course, they might add weight and therefore adding or mandating these technologies might lead to a non-compliance of the maximum weight for L6e-B and L7e-C.

The requirement to consider crashworthiness has a penalty in terms of vehicle mass. Energy absorbing structures, safety equipment and the need to design a vehicle to include crush space all increase vehicle mass. Further, the inclusion of crashworthiness considerations in light and heavy quadricycles leads to a requirement for higher motor power in order to overcome the increase in mass.

The Renault Twizy, Lumeneo Smera and Colibri represent market acceptable solutions in the light and heavy quadricycle categories. The Podbike and Schaeffler Bio-Hybrid represent solutions in the ‘pedal cycles with pedal assistance’ category. When looking at these five vehicles or prototypes, belonging to two different “families”, it appears that a common bodywork, with a width not more than 1 m could be used in both groups. For the L1e-A, the overall maximum width is 1 m, for L6e-B and L7e-C the maximum width is 1.5 m and for M1 the maximum width is 2.55 m.

From the argumentation above, it becomes clear that a car based on an e-bike powertrain is possible.

The concern is that three- or four-wheel e-bikes are not yet being promoted as vehicles allowed to be used on bicycle lanes. This could be seen as a new modality: They can use bicycle lanes wherever present, but are forced to use the car lanes when there is no bicycle lane. The latter is a concern to users and can be a reason for not using a bike, but a car. A solution would be to include the safety elements of the light and heavy quadricycles in an L1e-A vehicle. It is possible to develop a family of vehicles, using the same bodywork with a maximum width of one metre. Different variants of this vehicle could be certified in different vehicle classes.

Different track widths could be used for L1e-A, L6e-B/L7e-C and M versions, in line with the different maximum widths for these categories.

Assuming that an L1e-A vehicle could be developed sharing many of the safety elements of vehicles certified in the L6e-B, L7e-C category or M1 class, it is important:

– To investigate whether that vehicle (the improved L1e-A category vehicle) would still be allowed to be driven on a bicycle lane (addressed in Sect. 3)
– To determine the maximum weight possible for an L1e-A variant and hence if the extent to which the safety of the L6e/L7e/M1 can be kept (addressed in Sect. 4).

3 Use of the Bicycle Lane: Differences Between Countries

Within the EU, technical regulations have been harmonized. For the traffic rules, there has not been the same level of harmonisation. The only elements of the traffic rules harmonised at EU level, known to the authors, are the driving licence and minimum age, defined in EU Directive 2006/126/EC [10].

When it comes to the rules with respect to the use of the bicycle lane, some differences can be detected between member-states. Examples are:

– Germany: L1e-A are not allowed the standard bicycle lanes. But there are some “special” bicycle lanes where they are allowed (“E-Bikes allowed” or “Mofas allowed”) [11]
– Belgium: L1eA are allowed on all bicycle lanes [12]
– Netherlands: Electric bikes with top speed up to 25 km/h are allowed to be driven on bicycle lanes; therefore, this includes L1eA [13]
– UK: With more than 250 W auxiliary power, a bicycle is not allowed on bicycle lanes [14].

Further, markets outside of the EU that still share the same vehicle classification requirements can be considered:

– Norway (not part of EU): All bicycles, e-bikes with power assistance up to 250 W can drive on the bicycle lanes [15].

The observation from the above is that ‘pedal cycles with pedal assistance’ and ‘powered cycles’ are treated differently depending on the market. This causes significant complications in the promotion and development of new modalities.

As a first step, harmonisation of traffic rules, e.g., concerning the use of bicycle lanes, would be helpful for market development of new vehicle concepts, e.g., based on the L1e-A regulatory framework. Second, the adaption of traffic rules to facilitate and promote the adoption of new modalities that support the move to cleaner and more sustainability mobility would be beneficial. At this point, the question arises how these requirements/rules should look like.

4 Calculation of the Maximum Mass of a Powered Cycle

In order to estimate the total vehicle weight that still allows an L1e-A vehicle to be driven at a speed of 25 km/h with an electric motor power of 1 kW, we made some basic calculation of the instantaneous power as a function of the aerodynamic resistance, vehicle dimensions, total vehicle weight, road friction, vehicle speed and the slope of the street.

The formula to calculate the instantaneous power to propel a road vehicle can be derived by combining the definition of mechanical power and the specific formula's for aerodynamic force F_a, the rolling resistance force F_r and the component of vehicle weight alongside the slope of the road, F_w.

P = Instantaneous power at the wheels

v = Instantaneous vehicle speed

Definition of power: P = (sum of the forces exerted on the vehicle), v

$$P = (F_a + F_r + F_w).v \tag{1}$$

When a vehicle is driving on a slope with constant speed (no acceleration), three forces are active in the direction of motion of the vehicle:

– The aerodynamic resistance force F_a is proportional to the frontal surface area A, to the square of the vehicle speed, to the aerodynamic coefficient (C_x), to the air density ρ (normally 1.2 kg/dm^3) and to the square of the vehicle speed:

$$F_a = \frac{1}{2}.\rho.C_x.A.v^2 \tag{2}$$

– The rolling resistance force F_r is proportional to the vehicle mass m, the gravitational acceleration g and the rolling resistance coefficient μ. A normal value for μ on wet road surfaces is 0.015.

$$F_r = \mu.m.g \tag{3}$$

– The component of the vehicle weight is parallel to the road surface, F_w For small values (e.g., 0.05) of the slope θ: $tg(\theta)$ = sin(θ) = θ. So, the formula can be simplified into:

$$F_w = m.g.\theta \tag{4}$$

Combining the expressions for the three forces (2), (3) and (4) in formula (1) for the power, we find the following expression:

$$P = (F_a + F_r + F_w) = F_a = \frac{1}{2}.\rho.C_x.A.v^3 + \mu.m.g.v + \theta.m.g.v \tag{5}$$

Another way to write the formula could be:

$$P = P_a + P_r + P_w \tag{6}$$

This formula reads as follows: The instantaneous mechanical power is the sum of:

- The power necessary to compensate the aerodynamic resistance,
- plus the power necessary to compensate the rolling resistance,
- plus the power to compensate the weight component in case of a slope.

The final power output of the electric motor needs to take into account the parasitic losses in the powertrain. With p the parasitic losses and P_{em} the power of the electric motor, our aim is:

$$P < (1 - p).P_{\text{em}} \tag{7}$$

This formula can be easily implemented in a spreadsheet. In Table 2, one particular set of input values is proposed. The calculation is done with a total mass of 500 kg, assuming that with this mass, sufficient safety technology can be integrated to guarantee a "safety level" similar to the quadricycles and small cars. The corresponding output results are given in Table 3. The output shows that the "heavy" version of the powered cycle L1e-A is able to drive at 25 km/h on a slope of 5% with a total mass of 550 kg.

The conclusion from the calculation: If a narrow vehicle (vehicle width <1 m) can be certified as an L6e, L7e or M1, the bodywork can be used as the basis for an L1e-A vehicle.

Table 2 Some reasonable estimates to calculate the power need for an L1eA at top speed

Parameter	Estimate	Units
Vehicle speed v	7	m/s
	25	km/h
Frontal surface A	1.5	m^2
Aerodynamic coefficient C_x	0.4	–
Total mass (vehicle, passenger, luggage) m	550	kg
Rolling resistance μ	0.015	–
Gravitational acceleration g	9.81	m/s^2
Slope θ	0.05	(rad)
Parasitic losses p	0.15	–

Table 3 Output of the calculation (based on the input from Table 2)

Power to compensate the aerodynamic resistance	123 W
Power to compensate the friction	567 W
Power to compensate the slope	270 W
Total mechanical power needed (P)	960 W
Legal maximum power for electric motor L1e-A (EU)	1000 W
+Human power, modest estimate	200 W
Total power available	1200 W
Total power available after parasitic losses ($(1-p).P_{em}$)	1020 W

5 Conclusion

Small electric vehicles (SEVs) provide an opportunity to respond to environment and mobility concerns. The limitation is safety. Dedicated infrastructure, for example bicycle lanes, support the market acceptance of SEVs by providing an environment that reduces risk to the user by removing conflict with larger, more aggressive, collision partners such as passenger vehicles.

However, for end-to-end journeys, an SEV user will be required to use a mix of dedicated and shared infrastructure. This creates a conflict. When SEVs are used in a mixed infrastructure, consumers require safety features that increase mass and hence power. If they are to be allowed access to the dedicated infrastructure, the vehicle power and hence mass must be limited.

In Chap. 3, it was shown that some countries allow the powered cycle on a bicycle lane, but in many countries, the right to be driven on the bicycle lane is reserved to power-assisted e-bikes with a maximum power of 250 W. At this juncture, it is uncertain what is the origin and the meaning of this 250 W limitation. Furthermore, this limitation on power removes an opportunity for creating cost-effective mobility solutions. In Chap. 4, it was shown that there is an interesting opportunity to develop a variant of the powered cycle that can share a lot of components with quadricycles and cars. Because of the positive effect of economies of scale, this could be a route to improve the economics of SEVs.

The authors therefore question whether it is appropriate to exclude narrow vehicles (<1 m) from the bicycle lanes irrespective of maximum power providing that they that do not drive faster than 25 km/h.

In short, we conclude and propose:

- Component and/or platform sharing between L1e-A, L6e, L7e and M1 is possible
- International harmonisation of rules with respect to the use of bicycle lanes for narrow vehicles restricted at 25 km/h, but with power >250 W, furthermore, approx. 1 or 2 kW, should be considered in this regard.

- The power limit of 250 W as a safety criterion should be replaced by a different criterion. More research is needed to identify the need and eventually to develop such a criterion.

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