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RESEARCH ARTICLE

Is the power-to-weight ratio related to safety?

¿La relación potencia-peso tiene que ver con la seguridad?

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Abstract

Through Decree 779/95 (regulating Traffic Law 24449), Argentine regulations have established an improvement in the power-to-weight ratio of units used for freight transport. The implementation process requires a huge investment from the private sector to renew older units for modern and powerful trucks. This article looks at the strengths of having a better power-to-weight ratio.

Resumen

La normativa argentina ha establecido, a partir del Decreto 779/95 (reglamentario de la Ley de Tránsito 24449), una mejora en la relación potencia-peso en las unidades afectadas al transporte de cargas. La implementación es un proceso que requiere una ingente inversión del sector privado para renovar las unidades más antiguas por camiones modernos y potentes. Este artículo analiza las fortalezas de contar con una mejor relación potencia-peso.

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In general, the power-to-weight ratio reminds us of a useful indicator for evaluating sports cars or motorcycles, and consequently, we think of brilliant accelerations or high-top speeds.

In the realm of light vehicles, the engine power is chosen freely by manufacturers and generally ensures that all modern cars have a high power-to-weight ratio, allowing them to circulate with acceptable performance, most of the time, without utilizing all the available engine power.

"The speed difference between vehicles traveling on a route is an important factor in accidents."

Let's say that in this segment, the power-to-weight ratio is not linked to safety, except for the driver who uses that power availability for reckless driving. In such a scenario, the problem lies not with the vehicle but with the driver's behavior.

However, in the realm of freight transport, the power-to-weight ratio has a direct connection to various aspects of road safety, greenhouse gas emissions, pollutant emissions, the reliability of vehicles, and even the productivity of road infrastructure.

Firstly, it's interesting to evaluate different modes of road transport and observe the power-to-weight ratio each of them possesses.

As we can see, the power-to-weight ratio varies significantly from one mode of transport to another. Many of the listed vehicles in Table 1 can legally operate on public roads.

The power-to-weight ratio directly impacts the following vehicle variables:

- Ability to ascend inclines
- Acceleration
- Maximum speed
- Ability to maintain a reasonable speed on a given incline

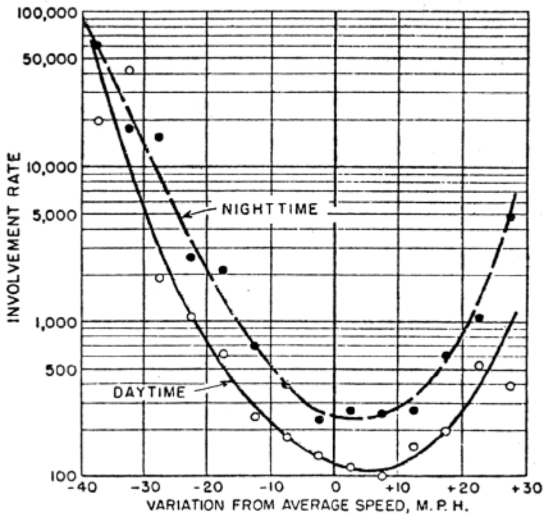
Road Safety Conditions

The speed difference between vehicles traveling on a route is a significant factor in accidents. Indeed, this phenomenon has been studied by road safety researchers such as Salomon and Cirillo, who have observed variations in accident rates based on the speed difference between the involved vehicles and the route's average speed.

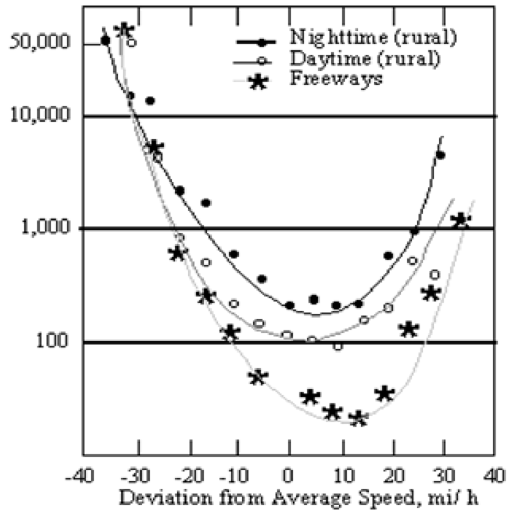
Table 1. Power-weight ratio in various means of transport

Transport unit	Power [hp]	Total or total gross weight combined [t]	Power-to-weight ratio [cv/t]
Cart with ox team	1,8	3	0,6
Passenger carriage	0,8	0,8	1,0
Amateur cyclist	0,2	0,08	2,5
Truck MB L1114	135	45	3,0
Ford cargo 1719	192	45	4,3
B-train 75 tn	506	75	6,7
Low floor bus (11 m)	210	16	13,1
Long-distance double-decker bus	400	24	16,7
4 tn light truck	160	8,3	19,3
Citroën 3 CV	32	1	32,0
Modern van 15 m3	150	5	30,0
Motorcycle 150 cm3	15	0,3	50,0
Std double cab pickup	180	3	60,0
Midsize sedan std.	100	1,5	66,7
Premium midsize sedan	140	1,8	77,8

Figure 1. Accident involvement rates are based on speed variation.



Accident involvement rate by variation in average speed, by section, day, and night (Salomon, 1964[1])".



Crash involvement rate by deviation from average travel speed (Salomon, 1964 & Cirillo, 1968).

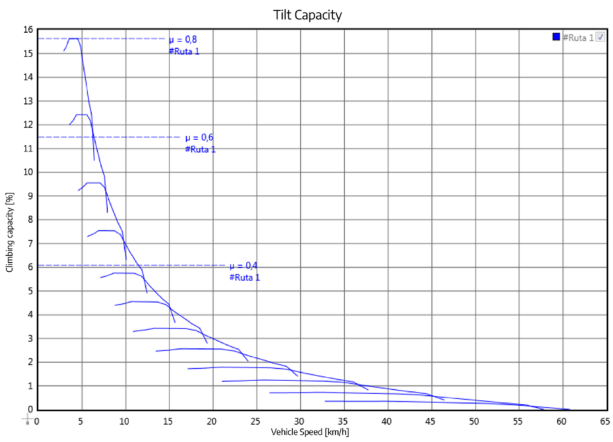
This analysis presents a 'U' shaped curve, where vehicles traveling below or above the average speed of a particular road increase their probability of accidents.

This study confirms a subjective perception that is generally held by motorists regarding road safety.

Figure 1 indicates that a vehicle traveling at 20 mph (32 km/h), below the average speed on a rural road during the day, increases the accident rate nearly tenfold.

Next (Figure 2), we present the performance curve at different speeds for an older tractor-trailer truck carrying approximately 45 tons with a 150 hp engine.

Figure 2. Performance curve of tractor-trailer truck (45 tons, 150 hp).

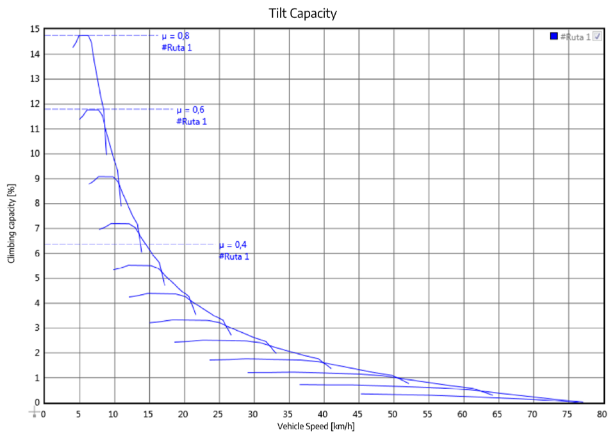


The graph shows that at full power, the truck reaches a little over 60 km/h, but if it must travel on a road with a modest 1% incline, for example, the speed will be 38 km/h, and the driver will need to downshift three gears to maintain the maximum possible speed. Additionally, headwinds or crosswinds can significantly affect the traveling speed.

As we can see, under these conditions, this tractor-trailer truck operates on a highway or a route where the normal flow of commercial vehicles travels at around 80 km/h, and cars travel at 100 km/h or more.

Now, let's analyze, in Figure 3, the behavior of a conventional truck, which has a power-to-weight ratio of 4.25 hp/t.

Figure 3. Performance curve of conventional truck



1. Solomon D. 1964. Accidents on main rural highways related to speed, driver and vehicle. Washington, DC: US Department of Commerce & Bureau of Public Roads

As observed, in this case, the maximum speed is 80 km/h, and when faced with a 1% incline, the truck will be able to maintain a speed of 52 km/h.

Clearly, it's not optimal, but considering that Argentina is a predominantly flat country in the areas where cargo transportation is extensive, it represents a reasonable ratio.

For a transportunit with these characteristics, if it operates in mountainous terrain, its performance will be poor, and it will achieve very low, unsafe, and uneconomical commercial speeds.

In Argentina, there are some equipment configurations authorized to carry larger loads, reaching a Gross Combination Weight (GCW) of up to 55 tons.

To illustrate, let's consider an example: a tractor-trailer truck with a 3.80-meter-high Side semi-trailer, similar to new hopper grain carriers, with a roof and side deflector, a 6x2 tractor axle configuration, with a 1+2 trailer.

Image 1. Semi-trailer with a GCW of 52.5 tons and a power-to-weight ratio of 6 hp/t

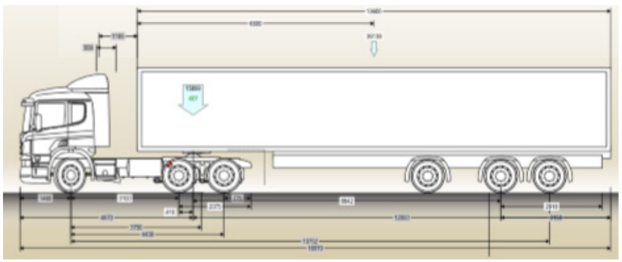
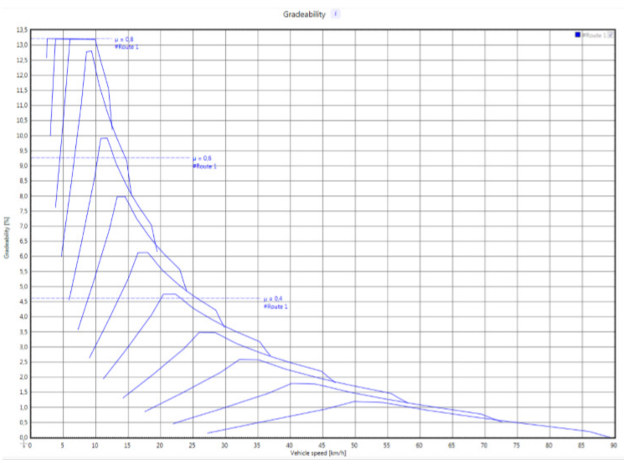


Figure 4. Performance of the described semi-trailer as an example



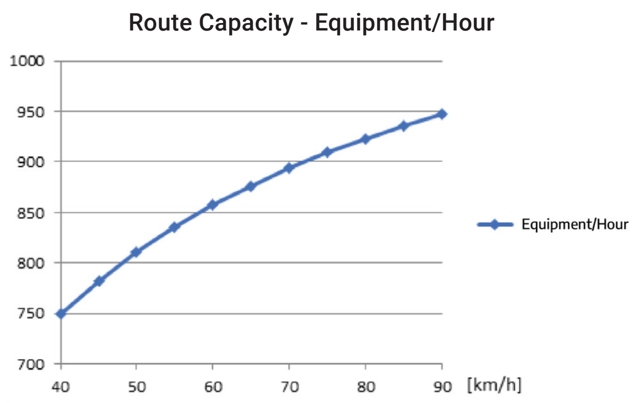
In this case, we can see that the transportation unit is capable of reaching a maximum speed of 90 km/h, meaning it can travel at the legal speed limit (80 km/h) even when the road gradient reaches 0.5%. With a 1% incline, it can maintain a speed of 65 km/h.

In summary, this unit can maintain its legal speed without pushing the engine to its maximum power.

Economic Performance Conditions on the Roads

Each roadway has a traffic capacity, and this capacity is reduced by vehicles traveling at low speeds. Let's assume, theoretically, a single-lane road where only tractor-trailer trucks circulate. In this case, the traffic flow will depend directly on the travel speed. Let's look at a graph calculated based on a 20-meter unit and a 3-second following distance between one unit and the next.

Figure 5. Relationship between vehicular traffic capacity and speed on a road



Source: Author's own work.

As we can see in the previous figure, if all the units were traveling at 80 km/h, the theoretical flow would reach approximately 923 units per hour. However, if the speed were reduced to 50 km/h, this number would decrease to 811 units, representing a 12% reduction in the theoretical capacity of the road. It's evident that the productivity of road infrastructure is impacted by the average speed of the vehicles in circulation. It's important to note that even if most of the units could travel at the maximum commercial speed set by the road, a few slower-moving trucks would significantly affect the pace and productivity of the road, leading to numerous overtaking maneuvers, which increase the risk of accidents.

Ultimately, this translates into longer travel times, less capital turnover, increased labor hours, and, in the end, higher transportation costs.

As an example, a theoretical calculation exercise is presented to assess the parameters required for transporting the soybean harvest at two different commercial speeds on the road segments. The exercise considers an average trip distance of 260 km, a unit's load capacity of 30 tons, and a soybean harvest of 59,374,021 tons for the year 2017.

Table 2. Example of variation according to commercial speed

Commercial speed [km/h]	50	70
Average distance [km]	260	260
Circulation hours [h]	5,20	3,71
Trips to move the soybean harvest	3.958.268	3.958.268
Hours to move the soybean crop	20.582.994	14.702.139
Equipment/hour per roadway	811	894
Tons per hour [t/h]	24.330	26.820
Hours of route use to move the harvest	2.440	2.214

Source: author's elaboration, 2023.

While the example has its limitations, it clearly illustrates the importance of providing cargo transportation services at an appropriate commercial speed.

Limiting Greenhouse Gases and Environmental Pollution

Engines have characteristic curves that allow us to understand their performance based on the load they are subjected to (how much we press the accelerator) and the revolutions per minute (rpm) at which they operate. Let's take a look at one of these curves for a 9-liter diesel engine.

As we can observe in Figure 6, this unit can generate a maximum of approximately 310 kW at 2,300 rpm (blue point). In this situation, the engine consumes about 220 g/kWh.

Let's assume that we must operate under this condition at full power to allow our transport unit to travel at a certain speed. As a result, our engine will be operating far from its optimal point of maximum efficiency.

Now, let's consider, using the same curve, that to cruise at a certain speed, I need 230 kW, which is 74% of the engine's maximum power.

In this case, I can work along the 230 kW curve (orange line), and depending on the gearbox and differential ratio applied, I can obtain those 230 kW between 1,350 rpm and 2,300 rpm. Clearly, gear ratios are finite, and the final gear will provide the optimum. Suppose in our hypothetical case, the engine operates at 1,600 rpm to achieve the desired speed. In that case, the equilibrium condition is achieved with a fuel consumption of 193 g/kWh, which is 12% lower than when operating at its maximum power.

Indeed, these curves explain why it is advantageous to work with engines that have greater power than the maximum required for traveling at commercial speed. This allows the engine/transmission to operate at a lower rpm range and with significantly lower fuel consumption.

It's also worth noting that when the power train operates at partial power, it is subjected to less stress, which increases its lifespan.

Argentina has a fleet (stock) of cargo units, and modernizing it is neither an easy nor a quick task. However, from the perspective of efficiency, safety, and environmental impact, if the country aims for a modern transport system, policies should be implemented to facilitate the modernization of the fleet of motor vehicle cargo transportation units.

Figure 6. Illustration of a diesel engine curve case