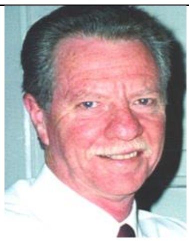
SUSTAINABLE TRANSPORT LEGISLATION USING PBS & COMPARATIVE METHODOLOGIES FOR BRIDGE ACCESS. PROJECT VAD URUGUAY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		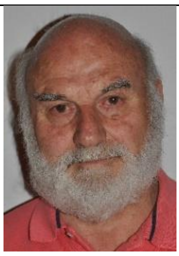	
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Summary: The feasibility study performed in Uruguay for the Ministry of Transport & Public Works and the regulations which emerged from its recommendations provides an ideal opportunity to discuss novel ways to regulate the introduction and implementation of High Performance Vehicles (VAD in Spanish). The new regulations place Uruguay at the forefront of Road Heavy Vehicle legislation in the region and show how the combination of independent consultants with proven international experience in PBS and prescriptive legislation, local knowledgeable authorities, a socially responsible business sector and strong political will are crucial for the development and implementation of a sustainable transport legislation where all stakeholders benefit.

Keywords: PBS, Regulations, High Performance Vehicles, Infrastructure Access, Uruguay

1. Introduction

The implementation of sustainable transport policies (which balance economic, environmental and social interests) requires coordinated work to face challenges and barriers that are independent of the geography or level of economic development of a country or region. The legislation sought is one that increases the productivity of the country's road transport fleet safely, but at the same time is easy to understand, certify, comply with, monitor and control. Sustainable legislation that, by distributing costs and responsibilities between the State and private companies, benefits the community in general. The challenge for the authorities when implementing the legislation is to find the right balance between the arguments of the various actors, in a changing political environment.

The Project VAD Uruguay (High Performance Vehicles are referred to as VAD in Spanish) began to take shape in 2017 when the Uruguayan Ministry of Transportation and Public Works (MTOP) received a request from the private forestry sector to study the possibility of authorizing the circulation of vehicle configurations larger than conventional ones, such as a B-triple of 30m and 74t. The request responded to the logistics plan for the sector, which included other means of transport, such as the railroad and a modern deep-water port terminal. The MTOP saw the potential benefits for the country's economy of using VADs, both for the sector that had requested them and for other Uruguayan productive sectors. With the collaboration of the Inter-American Development Bank (IADB), the MTOP hired a group of consultants with vast local and international experience in the implementation of VAD, to study the feasibility of designing a sustainable regulation that would allow its circulation, taking into account of the country's road reality both in terms of safety and infrastructure.

The VAD project was divided into two phases. A first phase of two months at the end of 2017 included a reconnaissance trip to Uruguay through various Uruguayan routes by two of the authors together with MTOP engineers, and the delivery of a report with an initial diagnosis based on the experience of the consultants. The report, which can be summarized in the phrase *"what is proposed will not be worse than what is currently circulating"*, confirmed the reasonableness of continuing with a second, more exhaustive phase of study. The second phase would use Performance Based Standards (PBS) as in other countries and regions of diverse geographies and economies like Australia, Canada, New Zealand, South Africa, Sweden and the European Union. Each of these countries have implemented or seek to implement VAD in different ways, showing the degree of flexibility open to regulatory authorities with respect to the creation of regulatory instruments supported by PBS.

The comparative studies allow the authorities to measure the positive or negative impact the introduction of VAD configurations would have on safety and road infrastructure compared to the existing fleet and recommend the conditions under which they could be approved. Over the years, evidence shows using PBS has significantly improved transport efficiency and safety as well as reductions in road maintenance costs (Nordengen et al. 2018; Australian National Transport Commission (NTC) 2018). The PBS scheme is briefly described in the next section.

Taking the experience of the feasibility study carried out in Uruguay, the intention of this paper is to generate discussion on various ways to regulate the introduction and implementation of VAD and other new configurations. This paper focuses more on the study methodology and the discussion of the results that led to the regulation, rather than the detailed description of the study results, which are specific to the VAD Uruguay project.

2. PBS scheme: a brief description

The literature regarding Performance Based Standards (PBS) is vast and therefore this section is only a brief summary of it. The PBS schemes are innovative heavy vehicle regulatory scheme that provide a pathway for heavy vehicles that do not meet the prescriptive regulations to gain access to the road network as long as they meet certain safety and infrastructure requirements. The schemes focus on "*how a vehicle performs, rather than how it looks*", and represent an alternative to the more prevalent prescriptive regulation of mass and dimension limits. The PBS schemes include standards examining acceleration capability, vehicle stability, high-speed dynamic performance, low-speed manoeuvrability as well as the impact on infrastructure.

To provide a few examples, the Tracking Ability on a Straight Path (TASP) standard measures lateral movement when travelling at high speed on straight roads with uneven surfaces, and whether the proposed vehicle remains within its traffic lane’s width. The Static Rollover Threshold (SRT) standard is measured at speed and is very useful to avoid rollover when a cargo vehicle enters roundabouts or curves, at higher or even at the authorized speed limit. Rollover stability is a significant safety issue and arguably the most important performance measure for heavy vehicles because it has been strongly linked to rollover crashes. The Load Transfer Ratio (LTR) standard characterizes the extent to which a vehicle approaches rollover condition in a sharp manoeuvre while traveling at speed in a straight line, such as when the driver "swerves" abruptly to avoid an obstacle.

The PBS are currently used in Australia and New Zealand, in South Africa under the Smart Truck initiative, and have also been used in international studies benchmarking vehicle performance, such as the Moving Freight with Better Trucks project (OECD, 2011) undertaken by ARRB for the International Freight Forum (ITF)/Organisation for Economic Co-operation and Development (OECD) and the European Union FALCON Project (De Saxe et al. 2018).

Evaluation of the performance of vehicle configurations and their payloads according to PBS is currently done by computer simulation, which is advantageous to interested manufacturers and operators because it allows design changes to be made for approval prior to building the configuration. There are a variety of commercial and even free software available, however their use by people without accreditation and experience in PBS evaluation does not guarantee the accuracy of the results.

Corridors approved by PBS legislation are classified by Access Levels so that there is a match between the performance of the configuration and the routes through which they circulate. The FALCON Project (De Saxe et al., 2018) for example, recommended a new route classification for VADs to adjust them to European infrastructure and geography, removing Australian Level 4 for remote areas and creating a Level 0 for restrictive city access.

3. Research Methodology

The comparative methodology enables the measuring of road safety impact of new configurations with respect to the existing fleet, comparing the dynamics and stability of the vehicle, as well as its interaction with the infrastructure. The different parts of the second phase of the study took approximately 9 months and were executed during 2019.

	Part of Study	Comments & Suggestions
1	Revision and comparison of Uruguayan legislation with that of countries using VADs with PBS	Compare with countries of similar characteristics. For this Project, it was decided to compare with Australia, South Africa, New Zealand and Canada
2	Definition of configurations and their parameters for the simulation. Definition of the PBS to include in the study	Include at least one authorized vehicle and others considered of potential use in the country and the region. Consult with local tractor and trailer operators, manufacturers, and dealers
3	Field evaluation of vehicles' dynamics and manoeuvrability in real operating conditions in predetermined routes.	Results of field tests under research conditions with test pilots have been published in the region for more than 10 years. Real conditions enable behaviour observation of road users and VADs
4	PBS computer simulation and analysis of the chosen configurations and their payloads	These simulations must be performed by an accredited organization with proven international experience with government entities and industry, to guarantee the accuracy of the evaluation.
5	Road geometry analysis in existing or potential corridors for VAD	Review of junctions, roundabouts, entrances and exits to route by satellite map, together with drones and go-pro cameras when doing field observations
6	Bridge Analysis by comparative simulation of the diverse impacts of VAD bridge access against a set of authorized reference vehicles	Modern and cost-efficient way to define the weight limits (total and per axles) allowed on the different bridges of a network according to their load action effect (positive, negative, shear and pier reaction)
7	Analysis of available Weigh in Motion (WIM) data of the road network	Enables to understand the reality of current heavy vehicles' behaviour (frequency and degree of overload by type of vehicle in time, for example) and give context to the Bridge Analysis
8	Analysis and discussion of all the results	Evaluation of PBS appropriate for inclusion in the legislation and levels of access to the network
9	Recommendation of a legislative approach to initially implement VAD, appropriate for Uruguay	Defines the criteria and process for approval and disapproval of VAD requests, responsibility for controlling the VAD operation and elements, penalties for non-compliance, among other issues.

4. Results: Summary and Discussion

This section summarises the results from the consultancy report the authors consider are needed to understand the recommendations and conclusions of this paper.

4.1. Vehicle Evaluation – Computer Simulation

The performance of a vehicle, representative of the Uruguayan fleet, was compared with new VAD configurations with different types of payload and with the forestry bitrain, authorized to circulate since 2011 in two exclusive corridors. Uruguayan operators and Argentine truck and trailer manufacturers were consulted so that the configurations and parameters to be simulated were real in the regional market. The forestry company provided the parameters of one of their bitrains, and a South African manufacturer's design for the forestry B-triple.

In Uruguay the 20m bitrain must have a 6x4 powertrain, while a similar configuration approved for 60t in neighbouring Argentina, requires a minimum 6x2 powertrain and a lower power-to-weight ratio (6.75 in Argentina, 7.3 in Uruguay). The forestry bitrain was simulated then with the same horsepower (450HP) but comparing its performance as a 6x4 and a 6x2.

In total, 6 VAD configurations and a reference vehicle were simulated according to 12 PBS for vehicles used in the Australian regulatory scheme and the LTR standard for:

- Different loading heights, to understand vehicle dynamic performance at high speed and stability performance.
- Different type of loads (with different centre of gravity): containers, general load, grain in bulk and logs.
- Different speeds (90km/h and 110km/h), to understand the effect of increased speed on the dynamic performance and stability of the configurations
- Increases in suspension stiffness, to understand the impact on roll stability.
- Tractors 6x2 and 6x4, to understand the impact of drive axles on the startability and the gradeability, which are key for crossings or to maintain speed uphill.

In Figure 1 two of the simulated VAD are shown, currently circulating in Argentina.

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Bitrain with two 40’’containers, length 30.1m Simulated for 71t for Uruguay, in Argentina is allowed a total GWT of 75t.

Bulk Grain Hopper, length 22.3m Simulated for a GWT of 57t, in Argentina it is allowed a GWT of 60t

Figure 1: Configurations simulated in the Project VAD Uruguay, currently circulating in neighbouring country Argentina. Source: Vulcano Semitrailers

The Reference Vehicle (C12R11) chosen was a truck and trailer of 20m total length, 45t GWT and 5 axles, currently circulating in the Uruguayan roads. It was simulated with a mechanical suspension, as it would circulate in real conditions, but attributed better parameters than it usually has, such as 60% higher power than the regulations request. The 2011 regulation for bitrains requests air suspension, so for all VADs, the same type of air suspension was used, in order to eliminate the effect of suspension stiffness in the comparison between configurations. The manoeuvres are executed without the influence of advanced stability systems which could mask the performance results. In operation however, these systems can improve safety by significantly reducing the risk of rollover, acting as a kind of “double safety net”. It should be noted that the vehicle combinations in Uruguay are wider (2.6m) than those allowed in Australia (2.5m). Due to this discrepancy, an extra 100 mm allowance could be reasonably applied to requirements for each PBS Level when assessing the performance of vehicles.

As anticipated by the consultants in their report in 2017, the reference vehicle was the poorest performing in terms of high-speed dynamic performance. The reference vehicle was the only vehicle to fail a high-speed dynamic PBS standard (RA) at the simulated speed of 90km/h, as well as exceeding the recommended 0.6 limit for LTR. This indicates that the VAD combinations do not pose a greater threat in terms of high-speed dynamic performance than the reference vehicle. Moreover, when modelled at 110 km/h, the reference vehicle performed the equal worst against the TASP standard, achieving performance equal to the considerably longer 30.1 m B-double and B-triple combinations. And while each of the VAD combinations remained under the recommended 0.6 limit for LTR at both speeds, the reference vehicle experienced wheel lift-off at 88 km/h and, at 110 km/h, rolled over during the manoeuvre.

The results obtained showed that inappropriate speed reduces the dynamic performance of the configurations and increases the risk of rollover. Speed limiters are a technology sometimes objected to by some operators as unsafe, however its mandatory use in road heavy vehicles has shown a significant reduction in accidents and CO_{2e} emissions since the 1990s (Hanowski et al, 2012). Speed limiters are mandatory in countries like Australia, Canada and the European Union (Directive EC 2004/11). In Argentina, speed limiters were included in a phased manner for new and used vehicles (Provision 500-E/2017), with the approval of transport operators as they saw their fuel efficiency improve. In Argentina, as in Uruguay, the maximum speed for freight vehicles is 80km/h, and the limiters are set at 90km/h.

Vehicle performance in terms of rollover resistance was highly dependent on the type of payload. The results indicated that the SRT in the different VADs studied did not reach the minimum value of 0.35g required by the standard when they were simulated uniformly loaded with logs, regardless of the loading height. The same vehicles, uniformly loaded with other types of cargo with a lower Center of Gravity, such as general cargo or containers, reached or exceeded an SRT of 0.35g. That is, the results of the standards cannot be generalized for a VAD configuration, but rather depend on the type of payload, its way of being loaded, and if it is uniformly loaded, its total height.

Regarding driveline performance, all of the VAD combinations with two driven axles performed better than the reference truck and trailer (which was simulated with an engine 60% more powerful engine than the regulatory minimum) in the gradeability standard, as the increased friction available from the extra axle enabled these combinations to maintain speed on a steeper grade. The result for the 20m bitrain, simulated with the same payload but with 6x2 and 6x4 traction, confirmed the need for two driven axles. Low speed vehicle performance results were varied, but all VADs were at satisfactory levels. The reference vehicle displayed the lowest Low speed Swept Path (LSSP) performance, with the extra points of articulation providing a benefit to its manoeuvrability. The swept path performance of the VAD combinations increased with increasing overall length. The reference vehicle was the only vehicle to fail the Frontal Swing standard and showed the poorest Tail Swing performance of the vehicles simulated.

Not reaching the PBS values considered safe for a certain type of payload does not always mean that the configuration itself should be discarded, because perhaps, by varying payload or configuration design parameters, satisfactory results can be achieved. An experienced accredited PBS assessor can guide towards this objective.

4.2. VAD dynamics and road geometry: Evaluation in real operating conditions

To evaluate the configurations during their normal operation required the collaboration of governments, shippers and transport companies. In Uruguay, the consultants visited, together with the MTOP engineers, a plantation of the forestry company where the vehicles are loaded with logs. The three vehicles were a tractor and semi-trailer loaded according to the authorized weight of 45t, the bitrain and the prototype B-triple loaded with a total gross weight of 74t. The consultants travelled in the bitrain and in the B-triple prototype in order to observe their interaction with the road geometry and other road users. As some of the configurations were not found in Uruguay, the alternative proposed was to execute the observations in a location with roads of similar characteristics to Uruguayan network. The place chosen was the province of San Luis, Argentina, where the operation of nine 25m bitrains were observed.

20m bitrain and 30m B-triple loaded, Young Roundabout Uruguay.

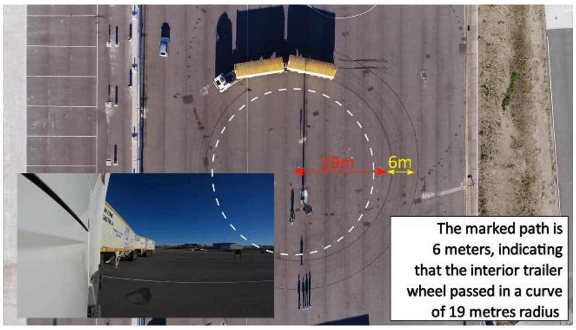
25m/ 75t bitrains entering the road from a field. San Luis, Argentina.

Figure 2: Observations in everyday operating conditions. Source: Authors, 2019

The three vehicles observed in Uruguay stayed inside their lane, with no significant tail swing, regardless of the road conditions. All three performed the exit of the roundabout in a similar manner, as it can be seen in Figure 2. Other road users treated them just as another heavy vehicle. In San Luis, it was noticed a significant variation in the measurements taken of times and distances in three of the manoeuvres performed (times of entry from intersection and lane clearance, acceleration distances to reach 45km/h and slow speed 90 degrees turn at an intersection). For example, when entering the concrete road from the perpendicular dirt intersection, the opposite lane clearance times ranged from 12 to 35 seconds. The total distance travelled until reaching 45 km/h from zero varied from 95 meters to 405 meters, and it was not always linked with the opposite lane clearance values. That is, one driver returned to his lane quickly and accelerated slowly, another took more time to return to his lane, but with marked acceleration. In the 90-degree turns, faced with the same obstacles, three of the five observed bitrains used the extra width of the road and two did not, but then a conventional 20m truck and trailer truck behaved like the first three 25m bitrains.

The 9 bitrains where of the same type, same payload, same parameters, belonged to the same transport company and were driven by drivers trained at the EMaBi School for Bitrain Driving. The authors conclude the observed differences are more due to the driving style of each driver and the circulating traffic at the moment of manoeuvring.

Because in San Luis the bitrains did not go through any roundabout during their operation, a typical Uruguayan roundabout was drawn on the pavement of the La Pedrera Stadium and one of the owners of the bitrain drove following the internal radius and the external. The results of the test were highly satisfactory, according to the MTOP engineers who were present.



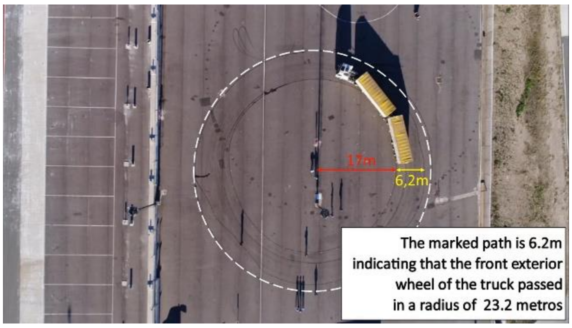


Figure 3: Test in Uruguayan type of roundabouts, Source: Authors, Final Report 2019

The results of both computer simulations and field observations suggest that the VADs studied adapt without difficulty to the current road geometry, and that if any modifications were to be made to the road network, these should be made for the benefit of all types of heavy vehicles. and not specifically for the VAD.

4.3. Infrastructure: Comparative simulation of the impacts on bridge access

While the MTOP realised the potential benefits of using VADs for the economy, they acknowledged that factors such as safety and infrastructure costs needed to be carefully weighed up before agreeing to allow wider VAD access. International practice formed an important input into the project so that experiences and learnings from other countries that have introduced VADs were incorporated into the considerations.

The line model comparative analysis of vertical loads is a modern and efficient way to assess the load limits allowed on the road network or a particular corridor. It allows for many critical factors such as total load, load concentration and axle group configurations to be considered in a fair and appropriate manner. The comparative analysis is the starting point to examine bridges on routes slated for assessment for VAD access, determining maximum line model load action effects based on historical design eras and associated design loads. This helps to defined appropriate reference vehicles that represent the current “bridge capability” of each bridge and ultimately the network as a whole.

Initial assessment of the bridge stock using the line model comparative analysis allows for more targeted evaluation of those bridges and/or specific bridge spans within a road corridor that require more detailed assessment. This allows better focusing of resources for the assessment and approval of vehicles requesting access.

For the Uruguay VAD project, 686 bridges were studied, of which there was data for at least one span, from a total number of bridges in the road network (751), with an estimate of 5,357 spans. The Uruguayan bridge network includes those built in the indefinite era, pre-1959 (with vehicle of unknown design), to those built in 1959-72 (HS20), 1973-92 (36t DIN), 1993-2017 (45t DIN) and 2018-today (45t DIN + Acc. Veh.). Maximum load actions effects calculated were sagging moment, shear, pier reaction, and hogging moment if the bridge was a continuous structure. The maximum effects for each configuration were calculated for span lengths ranging from 5 to 60 meters, using span increments of half a meter.

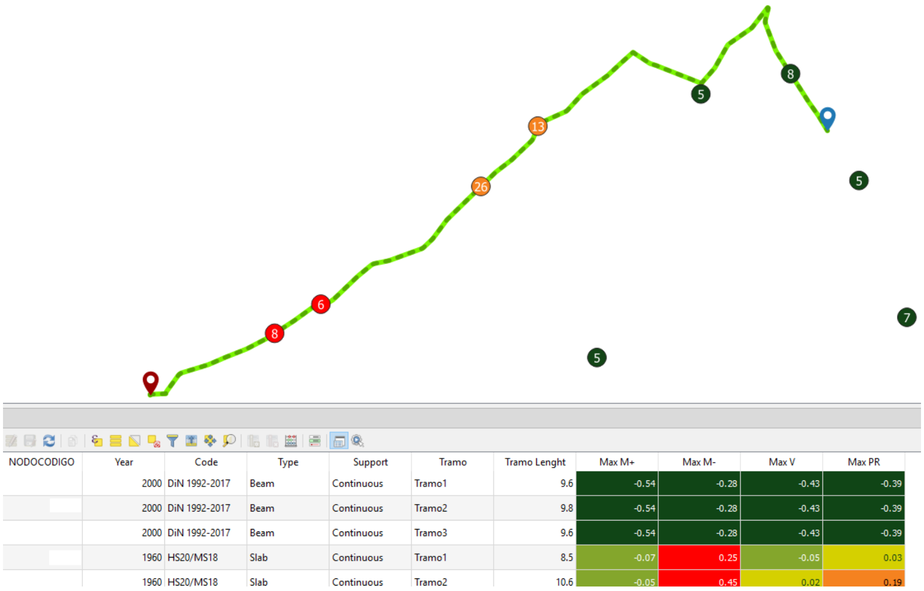
In general, the analysis provided in the vertical load analysis is not definitive and the findings need to be considered within the limitations and simplifying assumptions of the methodology.

Some of the findings suggest for example, that for the bridge stock designed to the DIN loadings since 1972 (roughly 30% of the total bridge stock), while they appear to be suitable based on the line model action effects of the primary vehicle, they were designed without suitable consideration of multiple presence of vehicles until 2017. In order to fully understand the ramifications of this oversight of past codes, a line model calibration exercise was undertaken to address the multiple presence issue. Pier reactions appear to be a significant issue for HS20 bridges, but then this finding is similar to most studies from around the world that have considered pier reaction and it is not surprising because VAD are significantly heavier than the HS20 design loads. Many countries throughout the world have introduced VADs despite this shortcoming based on the reasoning the substructures are usually over designed and in particular, piers are typical a blade style configuration. A key recommendation was to use the finding to identify bridges on routes under consideration for VAD vehicles that have substructure detailing that may be susceptible to significant increases in loads.

To ensure VAD vehicles access is undertaken in a safe manner in the early stages of their introduction, it was recommended to evaluate VAD access on a “route by route” basis, as requested by interested parties. If these additional studies, which employ more detailed assessment, are used to continuously update the initial “bridge capability” as defined by historical design vehicles, it will allow the progressive improvement of understanding of bridge capability and may lead to improvements in access outcomes. This is achieved by updating the bridge capabilities with new reference vehicles as they are assessed, effectively forming a database of comparative action effects that will allow accurate line model assessment of vehicles wanting to access the network or designated routes.

In order to implement this approach, the development of a line model comparison tool which can calculate maximum line moments, shears and pier reactions will be necessary. A data base of bridges with corresponding maximum line model actions “bridge capability” will also be needed to be maintained for comparison to any application vehicle. This style of analytical tool can also form the basis for effective permitting which requires minimum administration if set up correctly.

A Heat Map allows the data to be visual for better decision making in the prioritisation of those bridge spans to evaluate, together with the specific load action effect to assess. Figure 4 shows an example of how a corridor requested by an interested party could be analysed. The circles in red show those bridges where there are spans that need to be studied, and the number inside the circle indicates the number of spans that bridge has. The table provides information that allows identifying individual sections and focusing on those vertical loads according to their level of adequacy.



NODOCODIGO	Year	Code	Type	Support	Tramo	Tramo Lenght	Max M+	Max M-	Max V	Max PR
	2000	DiN 1992-2017	Beam	Continuous	Tramo1	9.6	-0.54	-0.28	-0.43	-0.39
	2000	DiN 1992-2017	Beam	Continuous	Tramo2	9.8	-0.54	-0.28	-0.43	-0.39
	2000	DiN 1992-2017	Beam	Continuous	Tramo3	9.6	-0.54	-0.28	-0.43	-0.39
	1960	HS20/MS18	Slab	Continuous	Tramo1	8.5	-0.07	0.25	-0.05	0.03
	1960	HS20/MS18	Slab	Continuous	Tramo2	10.6	-0.05	0.45	0.02	0.19

Figure 4: Screenshot of the Vehicle Access Comparison Tool. Source: Authors, Final Consultancy Report 2019. Not published.

Studying Overloading

When deciding on an appropriate level of access for the requested VADs, it is necessary to know and understand the overloading behaviour of heavy vehicles. If this behaviour cannot be controlled and/or mitigated in some way, it may be replicated for VADs. To understand the current overload characteristics in Uruguay, an analysis was performed of available Weigh in Motion (WIM) data from weighing stations and traffic counting stations, some of which have piezoelectric scales that, when calibrated, can reach an accuracy between ±15% and ±5% (values that did not reach this precision were discarded). Two parameters were analysed: The **rate** of overloading, i.e. the percentage of vehicles that are over their configuration's maximum allowable GWT, and the **degree** of overloading, i.e. the percentage by which each configuration was overloaded with respect to their configuration's maximum allowable GWT.

The analysis of WIM records showed that the rate of overloading in fixed weighing stations was less than 1%, suggesting that the implementation of strategically positioned fixed stations has been effective. On the contrary, there is a significant overloading issue in regions where there are no fixed WIM stations, between 15% and 30%, this overloading was prevalent in vehicles like the one used as the reference vehicle in the study, and the T12S3 tractor and triaxle semi-trailer configuration. Both configurations are the most used by Uruguayan transport companies and if this behaviour of overloading was to transfer to VAD vehicles, there may be significant issues related to structure performance and safety. Discussion with industry on how overloading behaviour can be controlled needs to be a key focus of the consideration to introduce VAD vehicles.

Figure 5 and Figure 6 represents the annual degree and rate of overloading in piezoelectric scales by type of configuration for the past 9 years, however it is important to note that these are averages, not peak overloads. An increase in the rate and degree of overloading can be appreciated since 2016, especially for those mostly used configurations C12R11 and T12S3. It is worth noting that bitrains do not exhibit overloading, even without anticipated controls. Additional features such as onboard weighing scales would help ensure VADs would not exhibit the overloading that is endemic in the other configurations.

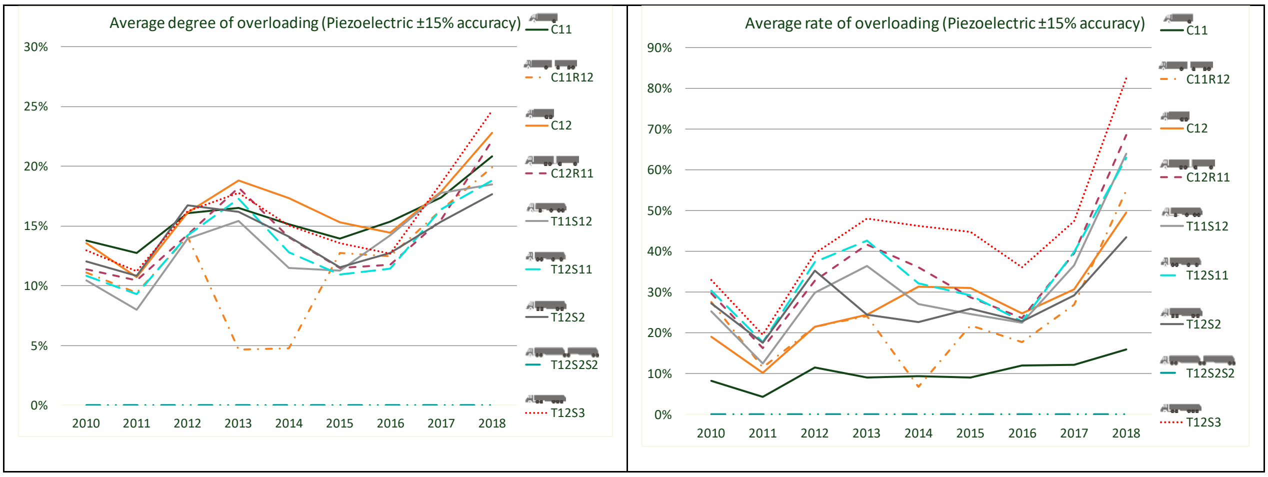


Figure 5 : Average rate and degree of overloading by type of vehicle, piezoelectric stations, 2010 to 2018. Source: Authors, 2019. Final report. Unpublished.

Figure 6 is a geographic visualization of the degree and rate of overloading in the different locations where there are weight stations (fix, piezoelectric, border).

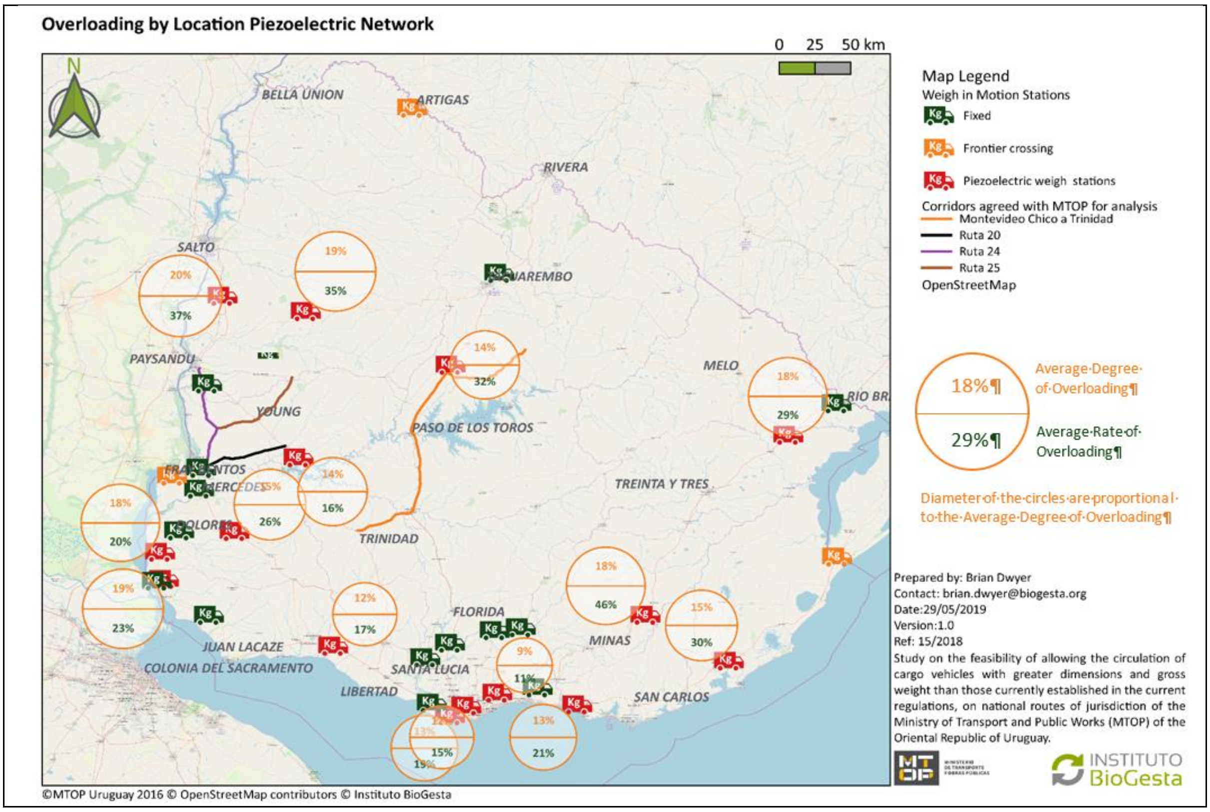


Figure 6: Overloading by location, piezoelectric network. Source: Authors, 2019

The overload factor used by the MTOP for bridge access analysis was indicated as 1.5, and it was the one applied in the analysis to design vehicles, conventional vehicles and the new proposed VAD configurations. Comparative simulations were also made considering an overload limited to 15% and 8% for the VADs, in the event that the legislation was modified to apply control mechanisms (physical and/or administrative) to guarantee that the VADs are not overloaded, or rewarding schemes such as those used in Australia for harvesting (Grain Harvest Management Schemes).

5. Development of a Sustainable Road Heavy Transport Legislation for Uruguay

The feasibility study together with discussion meetings between consultants and authorities led to three types of regulations for road heavy vehicles in Uruguay:

5.1. Regulation for current conventional vehicles up to 20m and 45 GWT: The current Uruguayan regulations and requirements for road heavy vehicles would continue to apply since they present a reasonable representation for these conventional vehicles.

5.2. Tractor and triaxle semitrailer, 18.5 m and 48t GTW. Resolutions s/n MTOP, January and July 2020.

The balance between the different stakeholders to achieve a sustainable legislation mentioned in the introduction can be seen in this regulation. Just before starting the second phase of the VAD project, the MTOP received a request from the transport operators to increase the weight of the T12S3 configuration, 18.5m triaxle semi-trailer, from 45t to 48t. The MTOP authorities decided to include this configuration in the feasibility study and decide how it would be regulated at the end of the study. The results of the comparative simulations of both the vehicle performance by PBS and bridge access including degree and rate of overloading for this particular configuration showed the negative impact on road safety that inappropriate speed and loading would have on vehicle performance and infrastructure if the T12S3 configuration with 48t was included in the legislation for conventional vehicles.

For the PBS simulation, for example, the configuration was evaluated for two types payloads, containers and logs, starting with a total height of 4.0m which was then increased to 4.1m, 4.2m and 4.3m. The latter is the maximum legally authorized height for heavy vehicles in Uruguay. The configuration with logs did not reach the minimum SRT at 4m, and its LRT become unstable as it passed 4.10m of loading height. A sensitivity study was performed which highlighted the effect that modifying the payload centre-of-gravity height in 5% increments between 30% and 50% of the total payload height, and the effect on the SRT performance measured. The configuration loaded with containers up to 48t worsened its LTR value with increasing height and, when the speed was increased to 110 km/h for 4.3m height, the LRT value reached the maximum allowed limit, 0.6. The configuration performed worse than the reference vehicle in both driveline standards. The impact of its authorised 25.5t triaxle on the effects produced by this vehicle was simulated for bridge access.

The study results showed the need to include stability control devices, mass control devices as well as speed limiters for this configuration, to name a few prescriptive requisites which are not mandatory in the existing legislation for conventional vehicles. The configuration could have been regulated then as a VAD or left as a conventional vehicle. It was agreed between the parties that this configuration, when loaded with 48t of GWT would have its own regulation, an intermediate between the existing one for conventional and the one that would be imposed on VADs. The regulation does not distinguish by type of payload and does not require a PBS report for the T12S3 as for the VAD, but requests more road safety technology devices than conventional vehicles and circulation is only permitted through corridors detailed in the regulation, or a corridor requested from the National Roads Authority.

5.3. **High Performance Vehicles (VAD)**. National Decree N°303/2020**:** For the new VAD, a combined prescriptive and PBS legislation was adopted, taking the most beneficial aspects from regulations from Australia, Canada and New Zealand but taking the particularities of local road infrastructure and legislation, as in the European FALCON (de Saxe et al, 2018).

The 13 prescriptive measures reduce the number of PBS to simulate and guarantee the associated benefits. Some of these prescriptive measures include minimum power to weight ratio of 7.3HP per ton and a 6x4 powertrain, and in all elements (truck and trailers) air suspension, originally installed electronic braking systems, Electronic Stability Control Systems (ESC), speed limiters and on-board scales systems. The five PBS are specific for Uruguay and were recommended as long as the recommended prescriptive measures and other existing Uruguayan regulations are maintained. The first PBS are referred to high-speed dynamic performance (TASP, LTR and YDC), the fourth to configuration roll-over stability (SRT) and the fifth one to low-speed swept path performance (LSSP). The Dynamic Load Transfer Coefficient LTR is used by Canada and recommended by the European Falcon Project but is not required in Australia.

The various certificates supplied to the vehicle owner by the manufacturers, importers or installers, help to control several of the prescriptive technological elements. Accredited and reliable local or international organizations provide the certification of those required devices, as well as the evaluation report by PBS standards. In this way, legal responsibility falls on who provides the certificates. It is requested that all certificates are in legally translated into Spanish.

For road infrastructure, an easy-to-use Route Selection Guideline that does not require special training of resources and/or hiring specialist consultants was recommended. Regarding bridge infrastructure, the analysis of vertical loads and for horizontal braking forces indicated that access to bridges need to be evaluated on a "route by route" basis for the proposed VADs as requested by stakeholders. The procedure can be found in the National Decree N°303/2020.

6. Conclusions, recommendations, and discussion

Consultants with professional independence and proven international experience in both PBS and prescriptive legislation, local authorities with technical and legislative knowledge, a responsible business sector and political will are crucial for the development and implementation of sustainable transport legislation. The regulations obtained following the methodology described in this paper place Uruguay at the forefront of Road Heavy Vehicle legislation in the region, surpassing previous regulatory strategies explained by Efrón & Corvalán (2016).

The authors wish to highlight that, although the study methodology can be replicated in other countries, the results and regulations generated are specific to Uruguay. The feasibility study using PBS and other comparative simulation tools should be considered as the first stage in the process of evaluating the convenience of allowing VAD configurations to access the road network. To successfully introduce and implement new VAD-type configurations, there must be an agreement for the development of a long-term investment plan that focuses on the strategic development of specific corridors that make economic sense for the country. This agreement requires a long-term financial commitment to ensure that adequate resources are available to improve and update the legislation.

Bridges should be a key focus of this investment strategy. The development of a linear Vehicle Access Comparison Tool and an adequate bridge performance assessment database are necessary if VAD access is considered a priority. This tool has the potential to form the basis for an effective Automated Permit System in the future. Opening the tool to the provincial and municipal authorities would enable visibility throughout the requested route, so that they are able to understand and explain results to those who requested access to the corridor and the community.

The implementation of a combined legislation, following the Canadian approach of "envelope" vehicle requires a greater number of simulations of vehicle configurations and payloads. Reaching the current legislative frameworks for VADs in Canada, Australia and New Zealand has taken years of experience and a large number of simulations with different dimensional variations. Initially then, it is suggested to evaluate each VAD for a specific payload, according to the different requests and needs of the interested parties (carriers, shippers, associations).

The vehicle dynamic characteristics of the conventional 20m truck and trailer were found to be highly undesirable, however not many transport companies have the possibility to operate new VADs. The combined PBS/prescriptive approach can be used to upgrade existing configurations. A study focussing on trailer layout redesign leaving the truck largely unchanged in recognition of the high capital cost of trucks compared to trailers is advisable. The study could involve a computer simulation based parametric sensitivity analysis of the truck and trailer combination to understand what parameters are contributing to undesirable vehicle response and how the parameters can be changed to improve vehicle dynamic stability. Once this is understood, the study team would work with the vehicle regulatory body and industry representatives to produce a final vehicle version that is both stable, road friendly and compatible with Uruguayan infrastructure and the needs of industry. In Canada, for example, some configurations that were circulating before the 1987 legislation were made safer and more financially attractive (for example, in the total allowable weight). The weight limits (total and per axle) in Australia, Canada and New Zealand are lower than those allowed in Uruguay and the region, so the comparison between countries by type of vehicle only on "*how it looks*" is not valid. The comparative simulations must be performed between the new configurations and the existing ones within the same country or region. This is especially important for bridge access analysis.

Training on the correct use of the technologies and devices included in the vehicles is crucial, since their correct use returns economically both to the private sector, the society and the State, while incorrect use translates into greater fuel consumption, increased tire wear and damage to road infrastructure, coupled with an increase in road insecurity (Efrón & Corvalán, 2018). Technological elements on their own do not always improve productivity and road safety.

Uruguay has already implemented the VAD legislation at the start of 2021 in a simple but thorough way. From the start of the feasibility study to the recommendations, development of the regulation and its implementation, less than two years have passed. At the time of the writing of this paper, only 3 B-triples carrying logs have acquired the permit, over 500 applications for the 48t truck and semi have been requested.

6.1. Use of control devices information. Incentives and Sanctions.

The legislation seeks to enforce regulations but guaranteeing fair competition among transport operators. Unfair competition between transport operators has been the subject of study in many parts of the world, where for example operators that overload can gain a substantial competitive advantage over other operators that comply with the rules. The motivation for not meeting the requirements of the regulation is affected by a large number of factors, some outweighing others. In a market where the contract is awarded to the lowest bidder, overloading can be an attractive way to cut costs and thus win contracts. In addition, social control and the possibility of being reported for overloading are low. Improper loading requires efficient enforcement policies and enforcement practices that prevent infringement without obstructing compliant vehicles. The relationship between compliance activities and the level of compliance largely depends on the subjective risk of being controlled and sanctioned.

The traditional way to use overload information is to penalize the operator when overloading is detected. South Africa and Australia have self-managed accreditation systems, in which weight represents only part of the management. These accreditation schemes require periodic external audits, during which the external auditor will verify the policies and processes of the company and will verify if said policies and processes are being complied with. In the event of non-compliance, there must be evidence of corrective actions.

Some penalties that discourage overloading include schemes whereby the receiver of the overloaded truck refuses to pay for the overload. Another sanction to continuous overloading can lead to the banning of the operator for increasing periods of time, up to the revocation of the registration certificate, as in Canada. The Insurance Companies can play an important role, refusing to cover the configuration if at the time of an incident it was found that it was overloaded and / or with any of the mandatory devices altered. Other methods used in Australia to generate competitive advantages offer incentives, such as Harvest Management Programs (GHMS), which allow participants flexibility (i.e. greater tolerances) in weight limits for products that vary in moisture content and density. The penalties for exceeding the weight limit and tolerance are imposed on who receives the overload.

7. A final word…

In the countries analysed, the legislation for VADs through the PBS scheme has shown that PBS can be part of the solution to protect the infrastructure, reducing transport costs in line with the objectives of social responsibility. New vehicles must coexist with the dimensions, weights and behaviours of other road users. Particularly for heavy vehicles, inappropriate speed leads to them being less stable, influencing both the risk of a road accident and the severity of injuries resulting from road accidents. Inadequate loading affects both vehicle performance and the driver's ability to control their unit, increasing the probability of accidents, coupled with increased maintenance costs for the operator and public infrastructure.Community involvement is ideal to successfully implement this sustainable legislation, so that the social costs generated by inappropriate loading and speed are known and which are the prescriptive measures included in the legislation to help avoid them. A tour of independent consultants to municipalities and community associations to explain and answer questions in non-technical language can be a way to disseminate the regulation.

***Acknowledgments**: The authors wish to thank all the people, companies and government authorities for their invaluable contribution throughout the project. In particular to the San Luis Province Government, the owners and drivers Transport Operator TSA, Vulcano Semitrailers, Roque DiGiglio and team, who answered questions on safety and stability devices; John DePont, from Ternz, who contributed with his knowledge on the history of VAD in New Zealand; to Graeme Elphinstone, who offered his experience on speed limiters and stability of bitrains and B-triples in Australia, and the UPM forestry company (together with its transport operator and drivers) for their participation in the observations in Uruguay.*

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