#### ASSESMENT OF DUTCH LONGER AND HEAVIER VEHICLES WITH A PERFORMANCE BASED APPROACH AND ITS APPLICABILITY TO EUROPE



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#### Abstract

The volume of goods transported as well as the number of commercial vehicles in Europe has increased substantially over the past decade. The sixteen years old European directive on vehicle weights and dimensions does not fully reflect on these circumstances and allows commercial vehicles up to 18.75m of length and weight of 44t for international transport. As the Dutch experience reveals, the legalization of longer and heavier vehicles (LHV) on highways makes transportation of goods more efficient, sustainable and is applicable even in highly populated regions. This paper is benchmarking the performance of all currently used Dutch LHV combinations, two potential LHV concepts satisfying the logistic needs, and conventional European combinations using the Australian performance based approach. Furthermore it discusses applicability of performance based standards to Europe as an alternative to current prescriptive legislation and shows that performance of LHV's can differ very much.

Keywords: High Productivity Vehicles, Performance Based Standards, Modeling, Testing

## 1. Introduction

After the crisis in 2009, it is evident that economic development and transport are inextricably linked. Just as development increases transport demand so. Conversely the availability and flexibility of transport stimulates further development by enabling trade. However, both public and freight transport-sector  $CO_2$  emissions represent according to nowadays estimates 23% of overall  $CO_2$  emissions from fossil fuel combustion. The freight transport sector itself accounts for approximately 15% of the overall greenhouse gas emissions [1]. With emissions predicted to increase by two thirds over the next thirty years any credible and coherent future strategy must emphasize innovative thinking and cooperation across the full range of stakeholders aimed at improving the environmental performance of the transport sector, without compromising the mobility and access on which economic growth and development largely depend.

The impact of emissions aside, one should also consider that the amount of transported goods is almost directly related to the GDP (gross domestic product) of a country. In Europe, transport of goods has grown by 30% between 1995 and 2006. From this portion about 75% of transport was done over the inland public roads or highways [2]. In the future it is foreseen [1] that the growth of the freight transport between years 2000 and 2020 will be 55%.

The above mentioned growth forecasts of future transport automatically imply issues like growing emissions, increased infrastructure usage and traffic congestion, and further increase of demands from logistic perspective.

Based on this point of view and positive experience with usage of LHV's from Scandinavia a research project involving co-operation of academic institutes (HAN and TU/e) and major heavy truck industry players has started. The project is aiming at the investigation of new commercial vehicle concepts for the years 2020+ which reduce CO<sub>2</sub> emissions, meet the future needs of logistics companies, are compatible with existing infrastructure and facilitate inter-modal cross border transport within Europe (i.e. concepts will be based on existing modules used in road-rail-water-air).

It is envisioned that these future concepts will be beyond the European directive 96/53 EC. This regulation prescribes both maximum weight and length limit which in fact results in 3 types of configuration that can legally operate within Europe having total length 16.5m for L1, 18.5m for L2 as well as for L3 as shown in Figure 1. The weight limit cannot exceed 40 tons for L2 and L3 and 44t for L1.



Figure 1. Legal European commercial vehicle configuration

To increase the productivity, reduce operating costs and generally investigate the applicability of Longer and Heavier Vehicles (LHV) in highly populated European conditions, the Dutch government has started originally a small scale experiment (involving 4 vehicles) in December 2000 to investigate the potential of LHV's. Over the years this experiment has grown with 162 vehicles at the end of 2006. In 2010 the experiment ended with very positive overall reactions from both road authorities and fleet operators. During the period from 2000-2010 there have been only 19 road accidents, fully documented in [3], involving LHV's. The accidents were mainly of light character without casualties and were not caused by the LHV in most cases. The national policy makers have legalized LHV operation in 2011 and 5 types of combinations (A-E), as depicted on Figure 2, are allowed to operate on highways and roads leading to distributions centers, obviously outside of city areas.



Figure 2. Current Dutch LHV's

The maximum weight limit of the combination has been set up to 60 tons, maximal length to 25.25 m and only two articulation points are allowed. Even though the Netherlands is not the only one in the European Union (EU) who authorized operation of LHV's (e.g. Sweden, Finland) cross border transport between EU member states is still not permitted due to the 96/53EC. It can lead to situations where the LHV must be disassembled and subsequently assembled when crossing the state border. This legal obstacle represents clearly one of the important challenges for European transport policy makers as it limits the usage of LHV's in cross border long haul transport.

Beside the legal issues one has to also consider trends and future needs in logistics. A recent study among the main Dutch logistics companies reveals [4], that the most used container size in future accounted to be 45ft (13.7m), based on Euro-pallet dimensions, and 48ft (14.6m) which is currently the most selling one worldwide.

To meet these future requirements, two potential configurations will also be analyzed, note however these configurations are not legal in any European country. The combination H has a modular size up to 53ft (16.2m) container with a total vehicle weight of 50t, and configuration I is composed from 30ft (9.15m) + 45ft (13.7m) container with a total vehicle weight of 60t, as shown in Figure 3.



Figure 3. Potential future LHV's

Both combinations have only one gap between towing and towed vehicle (resulting from one articulation point) which also accounts for decreased air drag [8], being one of the significant factors linked with fuel efficient operation of LHV's. Combination H has one rear driven axle whereas combination I two driven axles.

### 2. Research Method

The future modular commercial vehicle concepts will most likely develop from existing LHV's. Although the legalization of LHV's was certainly innovative step forward, especially with respect to high population density in Netherlands, the full potential of LHV's is however not fully exploited as the regulation is still prescriptive. An alternative approach in policy making has been successfully implemented in Australia. The approach assesses the performance of the vehicle with respect to the safety and infrastructure load and it is commonly known as performance based standards (PBS) [5]. It is a practically oriented set of rules enabling to rank the performance of LHV's from different perspectives. Generally speaking it does not matter what the vehicle looks like but how the vehicle performs in a number of different scenarios.

The Australian PBS scheme [5] is divided in two parts. Firstly the infrastructure loading is judged by 4 standards:

- Pavement vertical loading
- Pavement horizontal loading
- Tyre contact pressure distribution
- Bridge loading

Secondly the dynamical behavior of the vehicle combination ranked by following 16 standards:

- Startability
- Gradeability
- Acceleration capability
- Overtaking provision
- Tracking ability on the straight path
- Ride quality
- Low speed swept path
- Frontal swing

- Tail swing
- Steer tyre friction demand
- Static rollover threshold
- Rearward amplification
- High speed transient offtracking
- Yaw damping coefficient
- Handling quality
- Directional stability under braking

Each standard has 4 levels reflecting the performance. Depending on the performance level the vehicle is allowed to access on dedicated parts of the road network, e.g. Level 1 has general access on any road whereas Level 4 can operate only at remote areas.

In this paper we restrict ourselves only to safety related dynamic standards measures. These will be used to assess the performance of all current Dutch LHV combination together with existing legal European commercial vehicle configurations and potential LHV concepts reflecting on future logistic requirements.

Since the assessment of all performance measures for the various configurations by real experimental testing would be both expensive and time consuming, it has been concluded to carry out the analysis by computer simulations.

The models [7] have been created in multi-body domain using 'TU/e – Commercial Vehicle Library' which allows simulation of various commercial vehicle combinations. The library itself has been developed in a modular way using Matlab Simulink/SimMechanics which makes it transparent and highly generic. The complexity of models is well balanced with calculation time and aims to represent overall dynamical behavior of vehicle combinations with sufficient accuracy. Through the central library one can fast and easily modify particular components so its modification can be (if required) further distributed to the linked models. The scripts attached to the library also enable simulation and easy modification of predefined test scenarios like rollover stability, braking performance or rearward amplification which has been already used in past for internal research [11,12]. For visualization purposes the Virtual Reality Toolbox of Matlab is employed as it enables simple and sufficient graphical animation of simulation results see Figure 4.



Figure 4. Visualization of Multi body model using the Matlab virtual reality toolbox

For the modeling of the tyres, which are crucial in nearly all vehicle dynamics simulations, the TNO/Delft tyre Toolbox has been used. The model employs Pacejka's Magic Formula [6] and offers, if necessary, a number of scaling coefficients being helpful during tuning of the tyre behavior. No active safety systems such as active axle steering, ABS or ESC have been incorporated in the models since we want to judge performance of the combinations as uncontrolled.

To increase the credibility of the library and its sub-models like the tyres, suspension and chassis flexibility, validation measurements have been made. As stated earlier, the testing of all selected combinations would be unrealistic. Hence it has been decided to select two LHV combinations for testing and create their models from the library. Based on extensive qualitative and quantitative models validation will be presumed that the rest of LHV models,

being assembled from identical sub-models of TU/e – Commercial vehicle Library, will perform with sufficient accuracy.

For the validation testing following two LHV combinations have been chosen:

- D-combination, composed from the rigid truck with 20 feet (6.1m) container, A-type double-axle dolly and 45 feet (13.7m) container semitrailer
- B-combination (commonly known as B-double) composed from the tractor, B-dolly carriage unit and double deck semitrailer

Figure 5 shows a photo of both combinations.





a) Figure 5. Tested LHV vehicle a) D-combination b) B-combination

Both selected configurations have been loaded by two different loading patterns to simulate normal and dangerous load distribution which could eventually lead to unstable behavior. The main goal of 'unsuitable loading' was to increase the yaw inertia of towed vehicles by positioning of the load far from the center of gravity. Both loading patterns however respected maximal axle loading as prescribed by 96/53 EC regulation.

The test instrumentation involves more than one hundred measurement channels, including accelerations, both translational and rotational velocities, positions, articulation angles and selected signals from the CAN-bus. Around forty signals were used for model validation, the remaining signals will be used for later stages of the project. The test plan has been set up to primarily cover the test routines prescribed by PBS [5] like lane change, low speed cornering but also specially dedicated tests to validate suspension model like passing over a predefined vertical obstacle. During the validation the models have been provided by steering angle of towing vehicle, its wheel velocities and the road profile. Subsequently model outputs have been compared with particular measured signals to prove a similar behavior.



For illustration, some of the validation results for the D-combination are presented for sine wave steer input at constant velocity 70 km/h (Figure 6 shows simulation inputs).

In Figure 7, six representative signals (three signals for truck, one for dolly and two for semitrailer) are selected to give comparison between the model behavior and experimental results.



**Figure 7. Validation results** 

One can see a very good match for the lateral acceleration, as well as for yaw rate and roll angle of all vehicles. It provides confidence in the simulation model's lateral behavior, being important for a number of performance measures. Furthermore quantitative differences and delay in axle chassis distance measurement can be observed, linked with vehicle roll. The cause is most likely the simplified model of axle, allowing only a translational and rotational degree of freedom in the center of axle with respect to chassis, as well as employment of linear spring and damper models. As the primary purpose of the models is to simulate the vehicle behavior with reasonable accuracy we consider their performance as sufficient and we will employ them for evaluation of various performance measures.

#### 3. PBS Analysis

To judge the performance of all vehicle combinations mentioned before, we will apply the Australian performance based approach. The assessment procedure contains sixteen safety related standards however only fourteen will be used because the remaining two ('Ride quality' and 'Handling quality') are not yet robustly incorporated in [5]. The tests can be further divided into four sections:

- Longitudinal performance at low speed
  - Longitudinal performance at high speed •
- Lateral performance low speed
  - Lateral performance high speed

All results listed in Tables 1-4 are based on simulations of multi-body models which directly reproduce the original test routines described in [5]. Green color of the column designates conventional European combinations, blue column are current Dutch LHV combinations and red column are potential configurations reflecting future logistical needs.

Longitudinal Performance Low speed												
		L1	L2	L3	LZV_A	LZV_B	LZV_C	LZV_D	LZV_E	LZV_H	LZV_I	
Startability		Level 1	Level 1	Level 1	Level 2	Level 2	Level 1					
slope	[%]	19	21	24	14	13	18	19	19	16	18	
Gradeability												
A -mantain motion		Level 1	Level 1	Level 1	Level 3	Level 3	Level 2	Level 1	Level 1	Level 2	Level 2	
slope	[%]	20	23	24	14	14	18	20	20	16	18	
B- mantain speed		Level 1										
velocity [km/h]		87,62	87,67	87,62	87,48	87,49	87,45	87,45	87,49	87,54	87,45	
Acceleration Capability		Level 1										
time to travel 100m	sec	12,4	11,66	11,82	14,34	14,42	13,97	13,85	13,81	13,54	14,01	

Table -1. Longitudinal performance at low speed

In Table-1 the longitudinal performances at low speed are listed. Note that only combinations C and I had towing vehicles with two driven axles, all other combinations had only one driven axle. All vehicles meet the criteria for achieving Level 1 for Gradeability-B and Acceleration capability. Contrary to it, Gradeability - A and Startability was difficult to pass for LHV combinations which are towed by the tractor. In this case the vertical force on the rear axles of the towed vehicle was not sufficient, due to the load distribution and the height of center of gravity, to ensure sufficient traction force to move the vehicle. The longitudinal peak friction of the tyre road contact has been decreased compared to original test description ( $\mu$ =0.6) to simulate wet/snowy pavement as can occur at European roads.

Longitudinal Performance High speed												
		L1	L2	L3	LZV_A	LZV_B	LZV_C	LZV_D	LZV_E	LZV_H	LZV_I	
Tracking Ability on straight path		Level 1										
Swept path	[m]	2.61	2.66	2.61	2.65	2.64	2.7	2.7	2.72	2.67	2.73	
Braking		Level 1										
Longitudinal acceleration	[g]	0.4877	0.466	0.4798	0.4798	0.4876	0.4562	0.4748	0.4839	0.4781	0.479	
Overtaking Provision		Level 1	Level 1	Level 1	Level 2	Level 1	Level 2					
Vehicle lenght	[m]	18.42	18.45	16.16	24.98	24.95	22.6	24.95	24.92	18.7	27.5	

Table -2. Longitudinal performance at high speed

Tracking ability on the straight path, which assesses the width of the envelope of vehicle when travelling over the banked road, as well as braking (Table-2) does not revealed any problems as all vehicle combinations operate stable and in Level 1. The main issue remained overtaking provision which is directly related to the total vehicle length. All LHV's ended up in Level 2 which is due to the length exceeding twenty meters. In general this performance measure is set up correctly also for European scale, because LHV's should not get access to city areas and rural roads with one lane, as overtaking of normal commercial vehicles (L1-L3) is already rather difficult at these roads.

Lateral Performance Low Speed											
		L1	L2	L3	LZV_A	LZV_B	LZV_C	LZV_D	LZV_E	LZV_H	LZV_I
Low speed swept path		Level 1									
Swept path	[m]	5,01	4,3	5,05	6,07	7,26	5,05	5,98	5,05	5,82	6,45
Frontal Swing (Prime mover)		Level 1	Fail								
Distance	[m]	0,48	0,65	0,55	0,61	0,59	0,65	0,68	0,65	0,55	0,76
Tail Swing		Level 1	Level 4	Fail							
Distance	[m]	0,16	0,18	0,03	0,15	0,07	0,11	0,14	0,11	0,38	0,82
Steer - Tyre Friction Demand		Level 1									
Friction	[%]	25	33	41	35	38	47,5	41,9	41	28,5	46

Table -3a. Lateral performance at low speed

Next the lateral performance during low speed is listed in Table-3 a)b). All vehicles could pass this part of assessment on Level 1 except combination I, which fails in tail and frontal swing. This is caused by large distance between the axles and the rearmost point of the trailer and due to fact that none of the axles is being steered. Both frontal and tail swing can obviously be improved by active steering.

More attention should be paid to the performance measure at low speed swept path. According to the simulation, all assessed combinations perform in Level 1 which can be very misleading with respect the different operational condition between Australia and Europe. For assessing the performance test routine prescribes ninety degree curve with radius of 12.5m for outer wheel of the towing vehicle. This maneuver can be sufficient if the performance of the vehicle combination at road crossing is intended to assess. In Europe however it is very common to use roundabouts which can possibly result in turns of higher than ninety degrees. For such a type of maneuver Australian test procedure is insufficient. The different behavior is illustrated on the figure 8, where LHV combination A negotiates the ninety degree curve as well as 360 degree circular path with same curvature radius. One can see that the swept path width, being the difference of distance between inner most track and outer most track, gradually increases with degree of the curvature until saturates to steady state.



Figure 8. Low speed cornering of LHV- A

For benchmarking we simulated a 360 degree circular path for all combinations and compared it with the original ninety degree turn from PBS, the results are listed in Table 3b.

Benchmarking Low Speed Swept Path												
		L1	L2	L3	LZV_A	LZV_B	LZV_C	LZV_D	LZV_E	LZV_H	LZV_I	
90 degree turn R 12.5m												
Swept path	[m]	5,01	4,3	5,05	6,07	7,26	5,05	5,98	5,05	5,82	6,45	
Circular path R 12.5												
Swept path	[m]	6,72	4,985	5,226	10,87	х	6,244	8,803	6,305	9,231	8,623	
Percentual differ	ence [%]	34.13	15.93	3.48	79.07	x	23.64	47.21	24.85	58.61	33.69	

### Table -3b. Low speed swept path 90

It can be observed that substantial differences in the results exist. The magnitude of the difference is related to a number of parameters like vehicle length, number of axles, number of articulations and distance between them. As can be concluded from Table- 3b exceeding of certain limit for these parameters could eventually make it impossible to negotiate prescribed maneuver such as in case of B-combination.

The last part of assessment is the lateral performance at high speed see Table -4. The Australian approach in this part prioritizes the safety. Hence only one performance level exists for yaw damping, rearward amplification and rollover threshold which needs to be satisfied to pass the assessment. It basically means that all vehicles (no matter on length or weight) should be equally stable at high speed.

Lateral Performance High Speed											
		L1	L2	L3	LZV_A	LZV_B	LZV_C	LZV_D	LZV_E	LZV_H	LZV_I
Static Rollover Treshold		Level 1	Level 1	Level 1	Fail	Level 1					
Lateral Acceleration	[g]	0,359	0,404	0,371	0,335	0,352	0,356	0,394	0,39	0,382	0,362
Rearward Amplification		Level 1	Level 1	Level 1	Fail	Level 1	Fail	Level 1	Fail	Level 1	Level 1
Unitless	[-]	1,36	2,106	1,72	2,47	1,63	2,54	2,08	3,76	1,34	1,37
High Speed Transient Offt	racking	Level 1									
Distance	[m]	0,1	0,23	0,15	0,45	0,2	0,29	0,15	0,62	0,1	0,4
Yaw Damping Coefficient		Level 1	Fail	Level 1	Level 1						
Unitless	[-]	0,48	0,33	0,275	0,304	0,633	0,267	0,596	0,02	0,505	0,3

Table -4. Lateral Performance High Speed

The simulations have shown that three of the currently operating LHV combinations perform outside the limits of Australian PBS scheme. The rearward amplification (RA) is problematic for combinations A, C, and E. It is caused by low static rollover threshold which is used to evaluate RA performance limit. In addition combination E has also problems with yaw damping coefficient caused by low number of axles per vehicle and relatively small distance between articulation joint and axles.

On the other hand combination B and D passed the assessment and show even better performance than current European legal combinations L2 and L3 for which they can be considered as more stable.

# 4. Conclusions

From analysis we conducted several conclusions can draw.

- All conventional combinations L1-L3 have passed the assessment on Level 1. The best performing appeared to be L1 (tractor semitrailer) which is also the mostly used commercial vehicle combination on the European roads.
- The best performing vehicle from the LHV group was LHV-D which ended up with Level 2 classification, followed by LHV-B which satisfies also all test routines with Level 3 classification.
- To meet the strict Australian limits the other combinations have either problem with low speed maneuverability, such as LHV-I, or high speed lateral stability like LHV-A, C and E, which seems to be also the worst performing combination of all. The poor performance of these combinations originates at their composition, which is realized through the modules which are normally used for combinations (L1-L3). Although these modules are highly modular every towed vehicle should be adequately modified for usage in LHV combination. A simple example can be to increase the number of axles at drawbar trailers which decreases rearward amplification [9]. The fact that three of the combinations did not meet the Australian criteria, does not necessarily mean that those vehicles are dangerous on the road since in reality sufficient high speed stability is ensured through active safety systems (ESP, RSC,...) but the performance without them should considered as well. Another approach to improve the performance of the vehicles is active axle steering [10] which can remarkably enhance both low speed maneuverability as well as high speed stability, however its application due to additional weigh and relatively high purchase cost is not always welcome by the fleet owners.
- Performance based standards give more freedom for the modularity of the transport than a prescriptive approach however it cannot be directly taken from Australia without competent modifications. The crucial point is to adopt low speed maneuverability test routines as well as their performance limits which should be set more tightly to stimulate LHV's using steering systems. It can be nicely illustrated on potential combinations I and H which are very attractive for future logistic needs but have completely non-satisfactory maneuverability. Furthermore all test procedures should count on different environmental operational conditions in Europe such as snow or ice and should be adopted accordingly.
- Besides the infrastructure measures also environmental and sustainable performance measures should be incorporated; these could involve measures like aerodynamic drag resistance, CO<sub>2</sub> emission/ton/km...etc. The environmental measures do not have to be necessarily linked with permitting the vehicle to operate on particular road, but should ensure that fleet owners operating within certain performance Level will benefit from it through possible advantages such as reduced taxes or other advantages.
- The categorization of four performance levels can be reduced to three corresponding to; Level 1 general access including city areas, Level 2 public roads and highways, Level 3 highways plus especially dedicated roads leading to distribution centers.
- All vehicles operating within PBS scheme should be compulsory equipped with active safety systems (ABS, ESP and RSC) and drivers must be specially trained.
- The policy which enables cross border operation of LHV's within European Union needs to be ratified.

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