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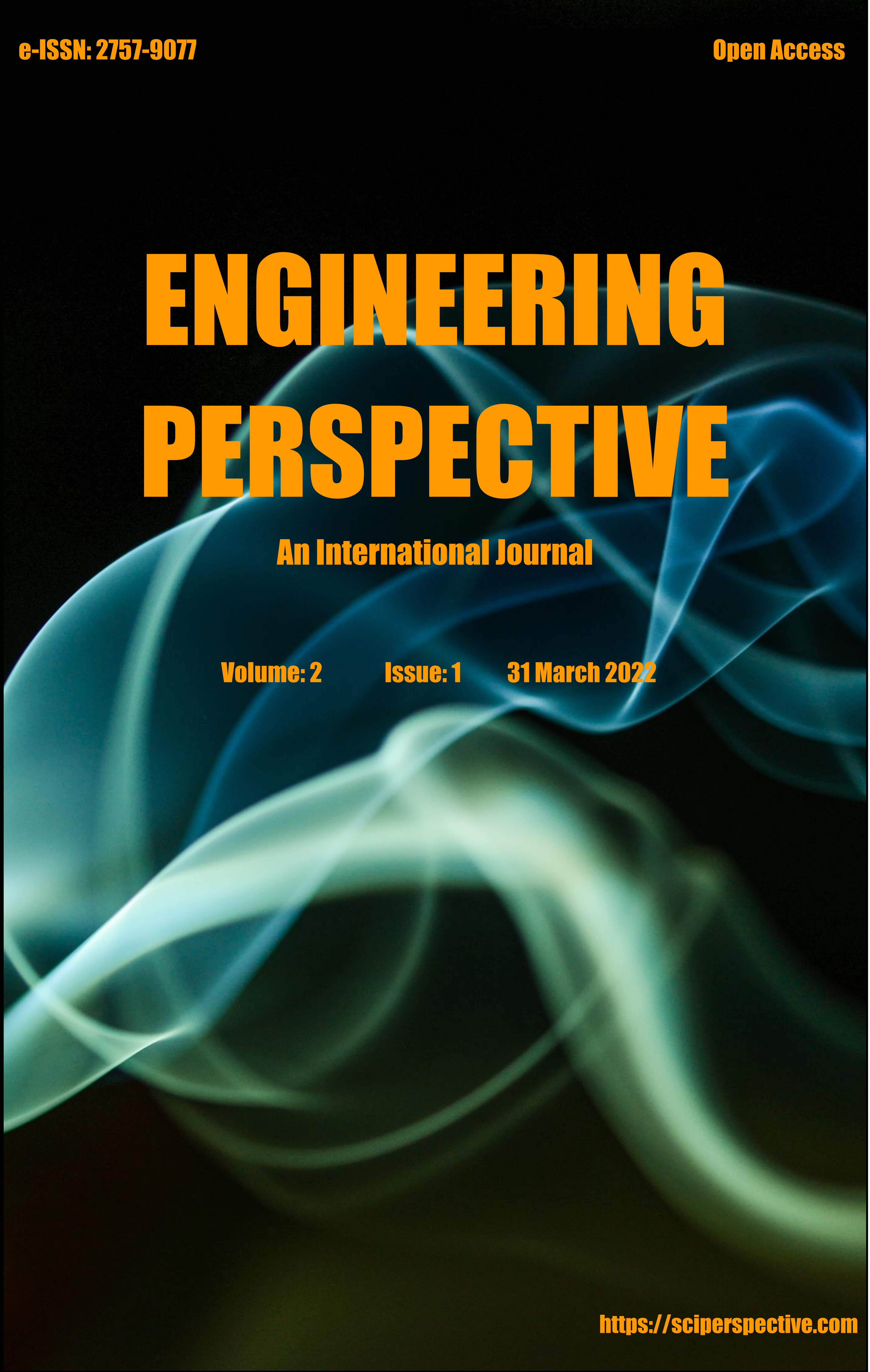

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Fatigue and Dynamic Behavior of Prestressed Concrete Sleepers

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ABSTRACT

In ballasted railway tracks, one of the important components that supports the rails and distributes wheel/rail loading onto the ballast supporting formation is a railway sleeper. In this paper, the dynamic and fatigue response of prestressed concrete sleepers used along the Ethiopian National Railway lines (Chinese Type II sleeper) is presented. For simulation, a finite element modelling package, ANSYS was employed. Concrete was modelled using a three-dimensional solid element (SOLID 65) and the behavior of prestressing wires was simulated using truss elements (LINK 180). Validation of simulation results was done using existing experimental data of Rikard's model. To obtain resonance conditions; the harmonic response of the sleeper for the excitation in the range of 0-2000Hz and variation of stress and displacement amplitudes with respect to frequency were studied. It's observed that the most resonant frequency corresponds to the third bending mode shape. From fatigue life assessment in this study, it is observed that the sleeper fails before attaining its design life of 40 years (11,300,400 cycles). This is due to the development of cracks which are likely to limit the sleeper's ability to hold the geometry of the line. As a result, the sleeper cannot attain the main technical standards of speed of 120 km/h and axle load of 25 tons. The minimum life of the sleeper is equivalent to about 31.8% of its design life. Moreover, it was observed that at a speed of 80km/h and an axle load of 25 tons, the life of the sleeper was found to be 85%. Thus, to attain the design life of the sleeper, during operational phase, it is recommended to limit the speed of the train to 80km/h.

Keywords: ballasted track, fatigue, frequency response, prestressed concrete sleeper, speed.

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1. Introduction

The railway sleeper is a vital railway component that lies between the rail and the ballast whose functions include; uniform transfer and distribution of loads from the rail foot to ballast bed, provision of an anchorage for the fastening system, and the restraining of lateral, longitudinal, and vertical movement of the rails [1], [2]. In addition, sleepers provide a cant to the rails to help develop proper rail-wheel contact by matching the inclination of the conical wheel shape [2]. The sleepers can be manufactured using timber, concrete, steel, or other engineering materials and concrete is commonly used around the world [3]. Prestressed concrete sleepers (PCSs) are the most commonly used type of sleepers. They play an essential role in track performance, behaviour and safety [4]. Besides, the large weight, PCSs provide stability for heavy haul and are more sustainable than timber counterparts [5].

Throughout their life cycles, sleepers experience static, dynamic and often impact loading conditions whose levels depend on the type and speed of the train, the track geometry, the wheel-rail interactions associated with abnormalities in either the wheel or the rail and the ballast reaction on the sleepers [6]. Usually, a few hundred-wheel axles act sequentially on each sleeper during the passage of a single train producing two dynamic effects; the resonance phenomenon caused by the build-up of the response induced by a wheel impact on the sleeper; and creep or fatigue caused by the repetitively acting loads [7]. Fatigue failure can therefore be defined as the failure that occurs below the stress limit of a material when it has been exposed to repeated loadings [8]. Fatigue failure involves progressive process of micro-crack initiation and propagation that leads to macro-cracks that grow to the point at which failure occurs [9]. Fatigue damage of prestressed concrete sleepers is mainly due to the accumulation of defects caused by the repeated load from trains [10]. Fatigue failure in prestressed concrete members can occur due to failure of concrete from flexural compression, diagonal tension or shear, failure of strands or failure of bond [11].

In this paper, the dynamic and fatigue behaviour of sleepers is investigated. Besides, the minimum lifetime of the sleeper and optimal speed of the train is estimated.

2. Model Validation

A simple static sleeper model with fixed support condition was modelled, analysed and compared with Rikard model [12].

The model was created using the design modeller of ANSYS workbench. The concrete was modelled using a three-dimensional solid element, SOLID65, which has the material model to predict the failure of brittle materials. To simulate the behaviour of prestressing wires, truss elements, LINK180, were used to withstand the initial strain attributed to prestressing forces, by assuming a perfect bond between these elements and concrete. Pre-tensioning was modelled using an initial strain of 5mm/m in the tendons corresponding to the prestressing forces at final stage (sustained prestressing force after all losses). At the validation step, a sleeper was subjected to the same hydraulic jack loading as the Rikard model [12]. The load applied to the rail seat area varied from 0 to 237.5 kN.

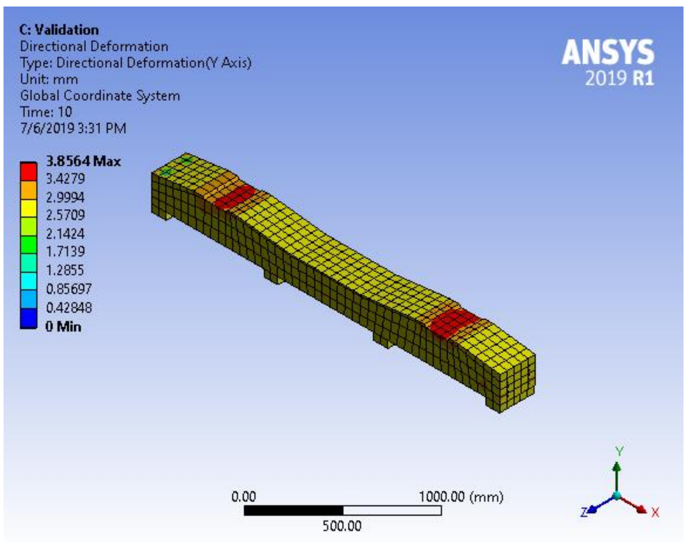

Figure 1. Deformation at 237.5 kN load

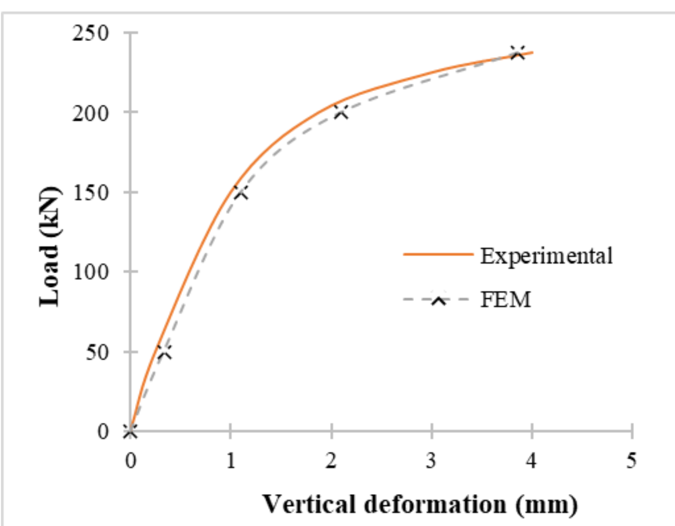

Figure 2. Force - Deformation graph

The resulting force-deformation diagram matches very well to the Rikard model [12] which proves that the quality of the FE results is good and thus, further modelling and analysis using FEM follows in the next sections of the paper.

3. Numerical model

The sleeper used for modelling is the Chinese type II sleeper which is currently in use on the Ethiopian National lines. The detailed drawing and dimensions are shown in Figure 3;

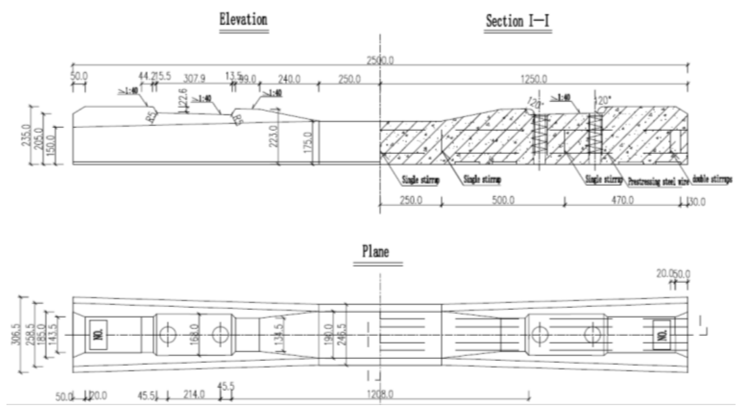

Figure 3. Type II sleeper drawing

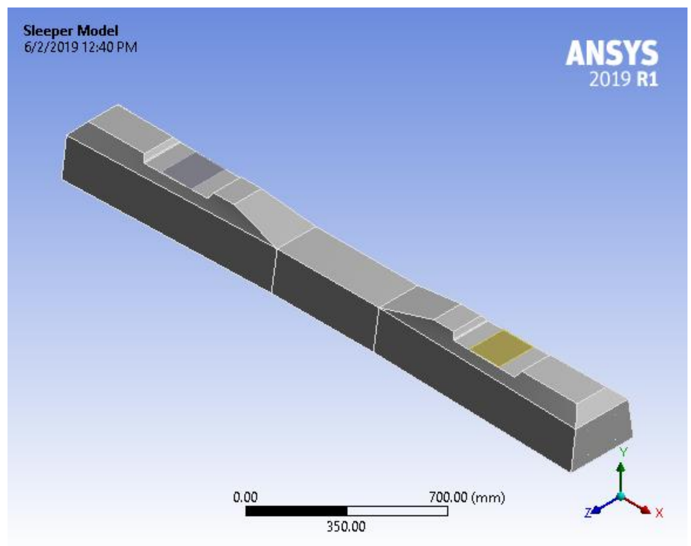

Figure 4. Sleeper geometry in ANSYS

3.1 Material property of the sleeper

For concrete grade C60 and prestressing steel, the material properties are listed in Table 1 and Table 2 respectively;

Table 1. Material property of concrete [13], [14], [12]

Density ρ_s (kg/m^3)	2400
Young's modulus, E_c (MPa)	37720
Poisson's ration, v_c	0.2
Compressive strength, σ_{cc} (MPa)	60
Tensile strength, σ_{ct} (MPa)	2.85
Fracture energy, GF (N/m)	154

Table 2. Material property of prestressing steel [13], [14], [12]

Density, ρ_s (g/cm^3)	7.8
Young's modulus, E_c (GPa)	200
Poisson's ratio, v_c	0.3
Characteristic strength for prestressed steel wire, f_{ptk} (MPa)	1750
Diameter, θ (mm)	5

3.2 Dynamic modelling of the sleeper

Since railway track is always subjected to a variety of time-dependent loads, understanding the dynamic track behaviour is essential in order to evaluate the structural safety and service life of the railway track components [15]. Sleepers are subjected to extremely high forces and strains under dynamic loading and also play an essential role in the dynamic response of global railway track, vibration damping and energy dissipating into the ballast [16]. It is known that sleeper damage can in some cases arise from the sleeper's resonant behaviour, such damage being cracking of sleepers in the vicinity of the fastening, with this damage mostly occurring at resonant frequencies of the sleepers [15].

The sleeper is modelled as a solid element as in the previous static model. But most importantly, the sleeper model is supported by a viscously damped, massless elastic foundation with certain stiffness that simulates the underlying ballast supports which allows the sleeper to move up and down.

4. Results and discussions

4.1 Natural frequency extraction

To examine the vibration characteristics of concrete sleepers, modal analysis is used. In this model, 20 mode shapes are extracted, some of which are shown in Figure 6. To obtain resonance conditions; harmonic response of the sleeper for the excitation in the range of 0-2000Hz and variation of stress and displacement amplitudes with respect to frequency were studied.

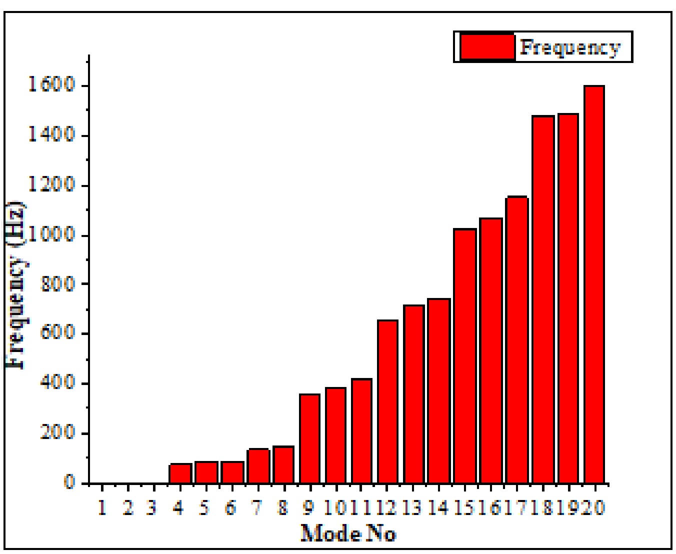

Figure 5. Mode No vs Frequency

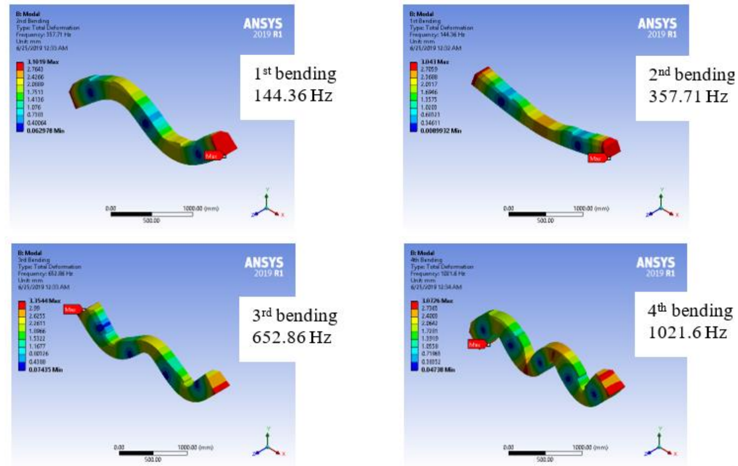

Figure 6. Mode shapes No 8, 9, 12 and 15 corresponding to 1st, 2nd, 3rd and 4th bending respectively.

Table 3. Frequencies and mode types

Frequency (Hz)	Type of mode
144.36	1st Bending
357.71	2nd bending
652.86	3rd Bending
1021.6	4th Bending

4.2 Vertical displacement and stress

The numerical results of dynamic structural response are considered as vertical displacement at rail seat and the stresses in the sleeper as shown in Figure 7 and Figure 8 respectively.

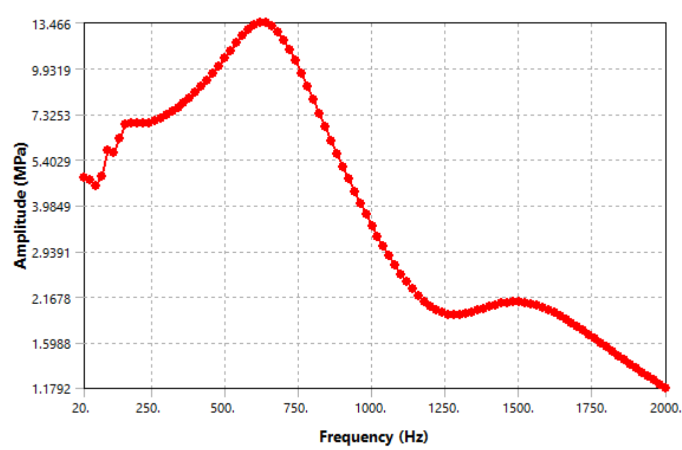

Figure 7. Stress amplitude at rail-seat

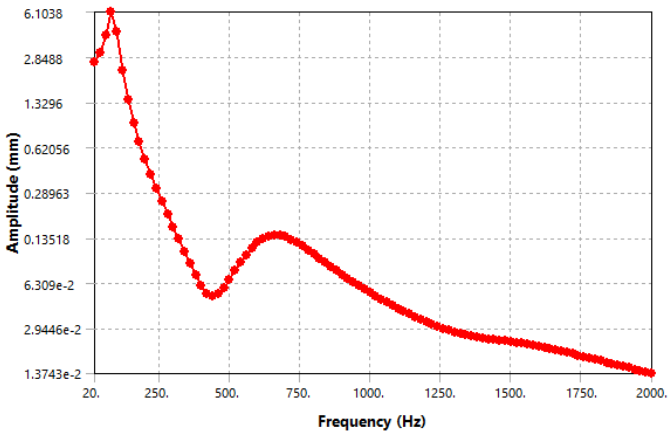

Figure 8. Vertical displacement at rail-seat

Knothe and Grassie [17] propose a frequency range of 0-1500Hz for damage to track components, such as the sleepers. Since the resonant behaviour up to 2kHz is discussed for the sleeper, the work is accordingly relevant to the entire frequency range in which the dynamic behaviour of the sleepers is of any significance to loading on the sleepers themselves or indeed to loads on the track more generally.

4.3. Static Analysis

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time.

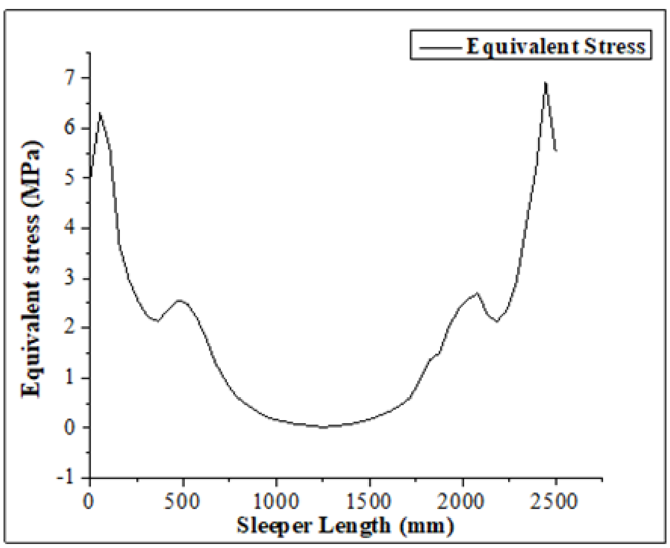

Figure 9. Variation of Equivalent stress along the sleeper

4.4 Fatigue Analysis (cyclic loading)

The mechanical properties of the material will change under repeated cyclic loading, such as permanently increasing strain on the member, causing the stiffness to decrease. Cyclic loading may also cause a concentration of stress at the pre-stressed wires' surface, which can lead to sudden fracture [18], [19].

In terms of the deformations, the FE model captured the general trend of increasing deformations with the number of cycles. The FE results show almost similar deformation between 10^3 and 10^6 cycles, and a large increase in deformations after 10^6 cycles until when the sleeper fails due to fatigue at 3.6 x 10^6 cycles. Most cracks are found under the rail seat areas where the loads are applied and at the bottom edges of the sleeper. The location of cracks and crushes correspond with the location of failure of the sleeper.

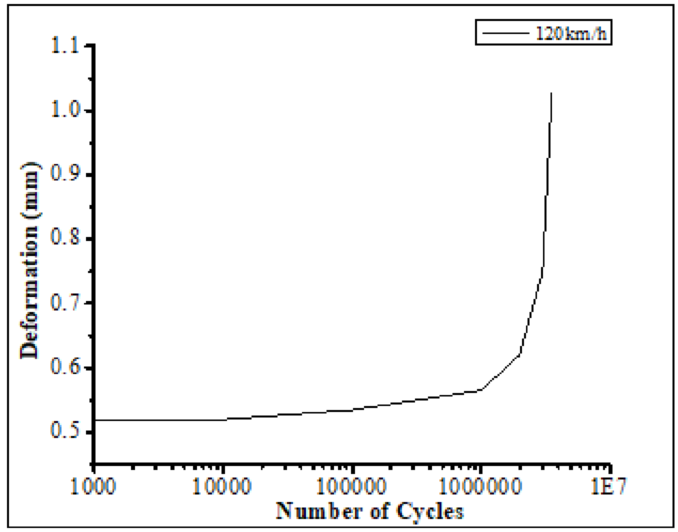

Figure 10. Deformation at rail-seat

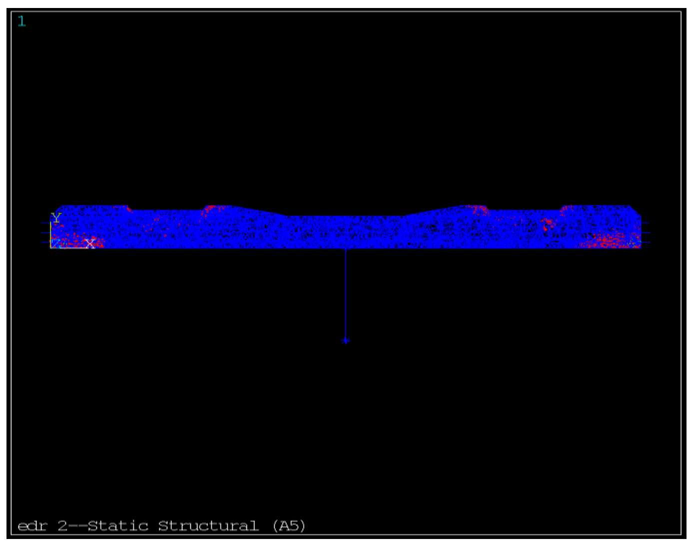

Figure 11. Crack pattern along the sleeper

To determine the ability to hold the geometry of a railway line, most railway organizations use a criterion to judge whether the sleeper is valid or not. Therefore, any cracking that leads to a sleeper's inability to keep the geometry of a railway line has to be considered as failing this criterion.

Table 4. Summary of FE results.

Analysis type	Results	Value
Static analysis	Vertical deflection (mm)	0.039
	Maximum equivalent stress (MPa)	7.3686
Fatigue results (cyclic loading)	Life	3,590,822
	Damage	3.147
	Safety Factor	0.972

The stresses induced in the sleeper are far below the allowable stress levels that the sleeper should be subjected to. However, due to the impact of repeated loadings, the sleeper as it is cannot attain the main technical standards of speed and axle load set by The Ethiopian Railways Corporations. The target speed used for analysis is 120km/h and 25tons for the axle load with an approximation of $1.13x10^7$ load cycles on each rail seat of the sleeper. To achieve the required loading cycles, a reduction in target speed and axle load or both is necessary to reduce the stresses induced in the sleeper and consequently increase the life span of the sleeper.

Table 5. Variation of fatigue life with speed.

Speed (km/h)	Stresses (MPa)	Fatigue Life (cycles)	Fraction of total life	Damage	Safety Factor
120	7.3686	3,590,822	31.8%	3.147	0.971
100	7.3105	5,294,990	46.9%	2.134	0.985
80	7.2236	9,694,696	85.8%	1.166	0.997

At a speed of 120km/h and an axle load of 25tons, the sleeper life is 31.8% of the total design life of the sleeper. A reduction of the speed to 100km/h increases the life of the sleeper to 46.9% of the total design life while a speed of 80km/h would increase the lifespan of the sleeper to 85.8% of the total design life.

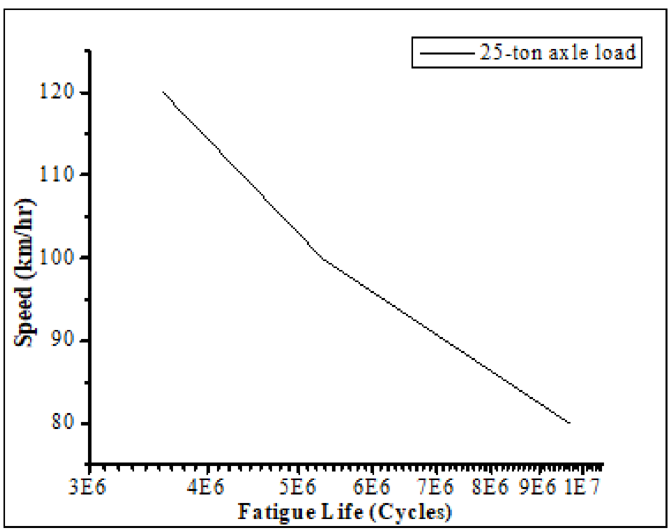

Figure 12. Variation of fatigue life with Speed

Figure 12 shows a clear relationship between speed and fatigue life. The fatigue life of the sleeper reduces as the line speed increases. An increase in line speed increases the rail seat load on the sleeper thus inducing more stresses into the sleeper which in turn reduces the life of the sleeper. The optimum speed to achieve above 80% of the life of the sleeper should be 80km/h with an axle load of 25-tons.

5. Conclusions

In this paper, the dynamic and fatigue response of the Chinese type II sleepers is assessed. Dynamic analysis of the sleeper obtained natural frequencies and mode shapes. It's observed that the most resonant frequency corresponds to the third bending mode shape. For the constant amplitude load considered in this simplistic model, the sleeper fails after 3,590,822 load cycles. Moreover, it is observed that at a speed of 80km/h and an axle load of 25 tons, the life of the sleeper was found to be 85%. Thus, to attain the design life of the sleeper, during the operational phase, it is recommended to limit the speed of the train to 80km/h.

It can be seen from the study that the Chinese type II sleeper is not adequate in fatigue. The sleeper develops cracks which are likely to limit the sleeper's ability to hold the geometry of the line and therefore failing in that criterion. Future studies on fatigue life optimisation of the Chinese type II sleeper are recommended to be carried out to increase the life of the sleeper to be able to serve its intended design life.

Since literature data on fatigue of concrete is scattered, it's also recommended for the sleeper to be tested in the laboratory for fatigue to validate the numerical results obtained in ANSYS.

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Tarekegn, Abrham Gebre: Supervision, article editing and revision.

Wantono Francis: Conceptualization, writing original draft, article editing and writing final paper.

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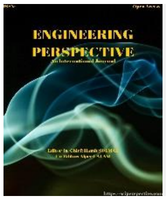

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VECTO Review: Reducing CO2 emissions from heavy duty vehicles

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ABSTRACT

Increasing fuel efficiency and reducing CO2 emissions in road transport is the main agenda of the heavy-duty automotive industry, which is the locomotive of road freight transport in Europe. Fuel efficiency is one of the most important competitive factors affecting the sales figures of heavy-duty vehicles such as trucks and trailers. A regulatory requirement has arisen for standardized measurement and validation of fuel efficiency and CO2 emission rates of heavy-duty vehicles and vehicle combinations of many types, shapes, and sizes. In 2018, a standardized computer simulation (VECTO) was published by the European Union that provides the calculation of CO2 emission values and fuel efficiency of heavy-duty vehicles. VECTO provides market customers with the opportunity to compare heavy-duty vehicle offers and select the most efficient vehicle combination according to their operational needs. In this article, studies containing information about VECTO in the literature were compiled and the potential of VECTO in reducing greenhouse gas emissions was examined.

Keywords: Fuel consumption, Greenhouse gases, Trailer, Truck, VECTO

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1. Introduction

The EU has started to reshape all its policies on the axis of climate change to achieve the rising targets of combating climate change with the European Green Deal. In order to reduce climate, energy, land use, transport, and taxation policies, a draft law package named "Fit for 55" has been published, which includes a series of legal regulations; on the other hand, announced the draft carbon regulation at the border, which envisages the implementation of a system parallel to the ETS in imports. Within the scope of the package, many measures such as increasing the use of renewable energy, more energy efficiency, lower-emission transportation modes, and the infrastructure and fuels that will support them, setting a zero-emission target for new motor vehicles to be put on the market by 2035, aligning taxation policies with the Euro-pean Green Deal targets, etc. commission recommendations are included.

With the legislation published by the authority on the efficiency and greenhouse gas emissions of heavy-duty vehicles in Europe, it can be understood that responsibilities for increasing efficiency are at the door for HDV manufacturers. To achieve a reduction of greenhouse gas emissions of 15% by 2025 and 30% by 2030, manufacturers have a lot of responsibilities. Manufacturers need to work on more technology to increase efficiency. Furthermore, by the end of 2022, the European Commission must assess additional aspects that were left out in the first phase of the standards but that can increase the effectiveness of the CO2 regulation [19]. Some of those aspects; are incentive mechanisms for electric trucks, new CO2 targets for 2035 and 2040, and the inclusion of trailers in regulation. In this context, it is of great importance for manufacturers to know VECTO, analyze it correctly, and correctly identify the points that need to be focused on for efficiency.

Heavy commercial vehicles cannot be compared with light vehicles in terms of standardizing their carbon emissions. Because heavy commercial vehicles come in many shapes, sizes and weights, there are thousands of different types on the market. Also, unlike light-duty vehicles, HDVs are sold with many possible combinations of engines, transmissions, and body styles. To type-approve all the possible combinations would be expensive and impractical, so engine dynamometer testing has historically been the preferred method for criteria pollutant emissions type-approval tests of heavy-duty engines [16]. VECTO takes the results from the testing, or measurement, of key relevant components of the HDV as inputs, and calculates the fuel efficiency and CO2 emissions of their use together (i.e.

for the whole vehicle) driven over vehicle-class specific mission profiles [17]. Vehicle Original Equipment Manufacturers (OEM) have to use VECTO to determine the fuel consumption and CO2 emissions of the vehicles undergoing the certification process and subsequently report officially the CO2 emissions values [18]. The potential benefits of VECTO compared to the traditional physical testing approach are discussed later in the article.

2. VECTO Review

2.1. The effect of HDVs on greenhouse gas emissions: Market overview

Despite their relatively small numbers, on-road commercial vehicles are responsible for a disproportionately large percentage of transport sector fuel consumption and GHG emissions due to their heavier weight and the greater number of miles traveled [1]. Road transport accounts for the vast majority – around 70% – of all transport emissions [2]. Curbing the CO2 emissions of the HDVs globally is of key importance for increasing the sustainability of the transport sector [3]. Fig. 1. shows the share of HDVs in greenhouse gas emissions originating in the EU.

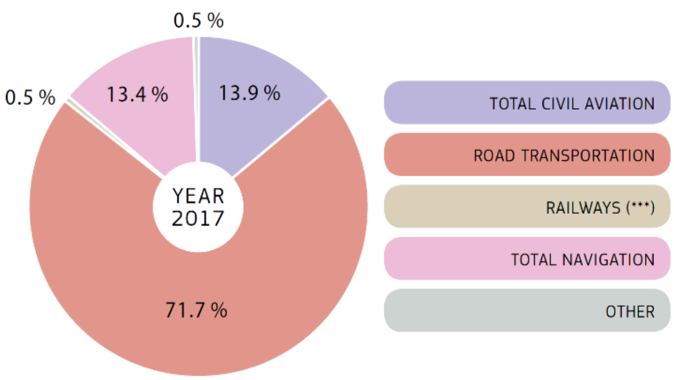


Figure 1. GHG Emissions from EU Transport [4].

On February 19, 2019, representatives of the European Commission, the European Parliament, and the European Council agreed on a compromise for setting carbon dioxide (CO2) emission standards for new heavy-duty vehicles (HDVs) for the first time in the European Union (EU). The targets will reduce the average CO2 emissions from the highest emitting HDV segments by 15% in 2025 and by 30% in 2030, both relative to a baseline determined from 2019 and 2020 data. [5].

2.2. What is VECTO?

The Vehicle Energy Consumption Calculator Tool (VECTO) is software made available to the public by the European Commission for calculating the fuel consumption and greenhouse gas emission, thus efficiency, of a complete vehicle. VECTO was included in the vehicle type approval regulation in May 2017 as an official software documenting the greenhouse gas emissions and fuel consumption values of heavy-duty vehicles in Europe. VECTO software has some modules. These are the Air Drag tool and Engine tool which are required for the calculation and certification of various efficiency measures. For a given driving cycle and payload, VECTO uses the results of component testing and vehicle characteristics to simulate the fuel consumption and CO2 emissions of a given vehicle [6]. For the following components, relevant input data for VECTO must be delivered from standardized test procedures: Vehicle mass, tires, engine, transmission, and aerodynamic drag [2]. VECTO calculates according to the transport operation of the heavy-duty vehicle. For example, since the conditions will be different in regional transportation and long-distance transportation, these are defined in the system as a variable.

VECTO simulates CO2 emissions and fuel consumption based on vehicle longitudinal dynamics using a driver model for simulation of target speed cycles. Engine speed is determined based on a gearshift model, the gear ratios, and the wheel diameter. Fuel consumption and CO2 emissions are then interpolated from an engine fuel/CO2 map [7]. Fig. 2. shows the scheme of the general VECTO model.

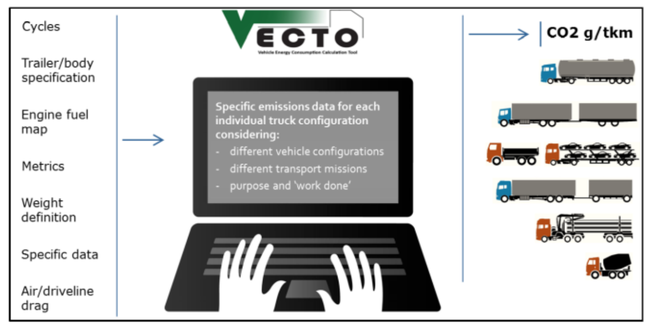


Figure 2. Scheme of the VECTO model [8].

VECTO has the potential to positively affect technical developments on productivity and the economic dynamics of countries. Unlike engine dynamometer tests, simulation can capture the influence of individual components upon whole-vehicle efficiency, and unlike whole-vehicle dynamometer testing, simulation makes it possible to test a high number of vehicle types and subtypes with small marginal costs [16]. Thanks to VECTO, the greenhouse gas emission values of heavy-duty vehicles of many shapes, sizes, and weights are easily measured with the help of theoretical calculations proven by physical tests. By obtaining the data calculated by VECTO from the manufacturers, the market customers learn the fuel consumption of the vehicle they will buy from a reliable standard source.

3. How to reduce GHG emissions from HGVs

Allowed vehicle length and weight, trailer design, driving dynamics, transport operation, and infrastructure are the main parameters in reducing C02 emissions. The main sources of efficiency improvement in vehicles are improvements made in the engine, tires, and aerodynamics. Driving support systems, in addition to the main resources, help vehicle users to use the vehicle more efficiently, helping to increase efficiency. Trucks have the potential to achieve two-thirds of the total improvement in CO2 emissions. Improving the aerodynamics of vehicle trains (truck-trailer combination etc.) can contribute to reducing CO2 emissions. Efficiency can be greatly increased by using many techniques together. Every little improvement in productivity is like a piece of the puzzle.

3.1. Operations & driver training

Driver training is very important. Because driving dynamics affect the fuel consumption of vehicles. It is possible to reduce CO2 emissions by optimizing vehicle speed, focusing on efficiency in driving techniques, route planning, and efficient loading-unloading operations in accordance with the conditions of the region where the transportation will be made. For this purpose, it is aimed to improve the driving behavior of drivers through GPS-based, automatic gear shifting strategies and 'eco-driving' modes in new generation trucks.

3.2. Maximum weights and dimensions

Efficiency in transportation can be increased by increasing the maximum allowable mass and dimensions. Variable vehicle combinations are the best example of this. The European Modular System (EMS) is a method that allows combinations of vehicles to be longer and heavier in certain transport zones. EMS increases efficiency and reduces environmental damage. National authorities approve a vehicle combination that is longer and heavier than a standard vehicle combination that is 16 meters long and weighs 40 tons. Thus, EMS makes it possible to transport more cargo at once. The use of this concept in Europe, where road transport is intense, means a great contribution to increasing efficiency. Another feature of EMS is that it brings more flexible solutions. If road conditions allow, long vehicle combinations or shorter vehicle combinations can be used flexibly according to the requirements of the operations. Thanks to the trailers and semi-trailers that can be connected one after another by mechanical connection, it is very easy to implement, and countries can adapt to their local conditions. Fig. 3. shows the possible combinations of EMS.

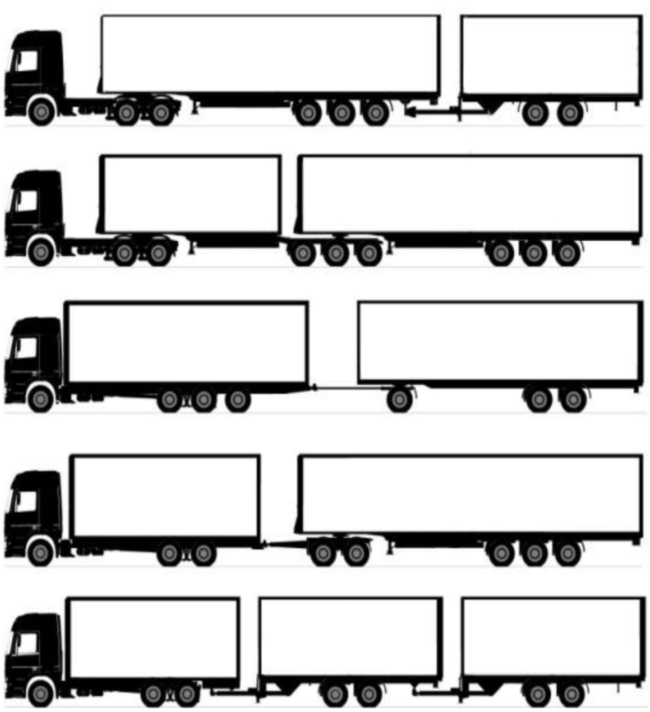
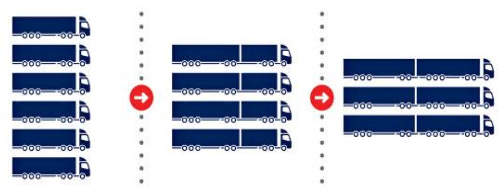


Figure 3. Possible combinations of EMS [9].

The European Modular System (EMS) allows more loads to be transported at once by combining trailers and semi-trailers. CO2 emissions can be significantly reduced in transportation with high-capacity vehicles. Long vehicle trains offer the same carrying capacity with fewer vehicles. Thus, lower carbon emissions and fuel consumption are achieved.

As an example, the load carried by a standard 16.5-meter tractor-semi-trailer combination can be transported at one time by one 25-meter truck-trailer-trailer combination. Infra-structure studies must be ready for long vehicle combinations to be used efficiently within Europe. Depending on the route conditions, long train vehicles may be preferred, but since long vehicle combinations can cause problems on the roads in transit circulation between countries, they are applied in countries where road conditions allow.

After Finland and Sweden joined the European Union in the 1980s, the EMS approach began to be developed. The event that triggered this approach was the inclusion of Scandinavian countries such as Finland and Sweden. Both countries have long allowed combinations of long and heavy vehicles on highways. After joining the Union, restricting the mass and dimensions according to the current legislation of the EU would limit the competitiveness of both countries. For this reason, the EU reached a consensus and decided on a standard concept. EMS is defined in article 4(b) of the 96/53 EC directive. Thus, every member state in the EU is free to use any of the standardized concepts. This has also contributed to the creation of a competitive environment in increasing productivity. Thus, the share of this technique in reducing greenhouse gas emissions is understood. According to ACEA, the fuel savings that can be achieved by increasing the load carried at once and the decrease in greenhouse gas emissions are given in Fig. 4. Of course, for this concept to be seen more on the roads, the road infrastructure must be suitable.



Vehicles (and drivers)	6	4	3
Vehicle length	16.5 m	25.25 m	32 m
Load per vehicle	100 m³	150 m³	200 m³
Fuel consumption	3.5 ml/m³km	3 ml/m³km	2.5 ml/m³km
CO2 emissions	100%	85% = -15%	73% = -27%
Road use	499 m	368 m	296 m

Figure 4. Efficiency increases with modular system use [7].

3.3. Highway infrastructure

Road infrastructure is one of the main factors in greenhouse gas emissions. Efforts to increase the availability and capacity of road infrastructure will directly play a role in reducing greenhouse gas emissions. Contribution to emissions targets can be achieved by constructing and maintaining roads with low rolling resistance.

Another infrastructure issue is the improvement of traffic flow. The use of intelligent and connected transportation networks using intelligent transportation systems (ITS) is important. The vision for ITS is one of "intelligent mobility towards fully informed people, zero accidents, zero delays, with reduced impact on the environment, where services are affordable and seamless, with privacy respected and security provided" [10]. By allowing the transportation operations to be carried out with long vehicle combinations, the road structure indirectly increases efficiency.

3.4. Energy Recovery from HGVs

There are many factors that increase the fuel consumption of trucks and create inefficiency. These factors combine to create a huge inefficiency. The strong dependence of the loss mechanism on the duty cycle, payload, and vehicle type results in wide-ranging estimates for the respective typical losses [11]. Table 1. shows an overview of the loss areas targeted by the technologies for providing efficiency. There are currently several new technologies being implemented into VECTO, which are not yet applicable to new vehicles being registered now [12].

By using existing energy recovery methods, fuel consumption and thus CO_2 emissions of vehicles and vehicle combinations used in road freight transportation can be greatly reduced. Energy recovery has been the subject of research and innovation in patents since the 1970s. In recent years, manufacturers have realized that energy recovery systems offer cost-effective alternatives to increase efficiency and that the potential benefits of these systems are open to development. ERS is used by many vehicle manufacturers today. In an automotive industry that is clearly focused on efficiency gains, the increase in new vehicles using ERS highlights the energy use benefits of these techniques.

Table. 1. List of technologies by category [13].

Engine	Aerodynamics	Tires	Axles and transmission
Turbochargers Intake/exhaust Waste heat recovery Internal friction reduction Engine efficiency Engine downspeeding Lubricant Engine Control Unit (ECU) optimization Cooling fan Alternator Water pumps Oil pumps	External grilles Active flow systems Mirror replacement Tractor cabin and trailer fairings Boat tails Vortex generators Adjustable fifth wheel Vehicle redesign	Wide base single tires Low rolling resistance tires Tire pressure monitor systems Automatic tire inflation systems	Automated Manual Transmission (AMT) Continuously Variable Transmission (CVT) Dual Clutch Transmission (DCT) Additional gear ratios Axle efficiency Lubricants
Hybrids	**Mass**	**Idling**	**Components and auxiliaries**
Hydraulic hybrids Full/mild electric hybrids Flywheel	Mass reduction	Stop-start systems Auxiliary power units Neutral idle	Electric hydraulic power steering LED lighting Air compressor A/C efficiency and refrigerant Reflective paint and glazing Predictive cruise control Advanced Driver Assistance Systems

Internal combustion engines convert very little of the energy they take from the fuel into work. Much of this useful energy is lost through inefficiencies. In terms of trailers, which are non-motorized vehicles; increasing the total efficiency, especially in heavy tonnage trailers, is of great importance in terms of reducing carbon emissions. With the energy recovery systems and aerodynamic modifications to be installed on the trailer, it is aimed that the motor vehicle pulling the trailer will consume less energy, thus reducing the carbon emissions and increasing the total efficiency.

In the AEROFLEX AB project carried out by companies such as TIRSAN, Van ECK, Scania, 4-5% thanks to double-deck loading platforms, 4-6% using the loading area more effectively, 5-12% due to the integration of more flexible, advanced powertrains, aerodynamic improvements applied to the complete vehicle. Thanks to the project, 5-10% energy savings were aimed at, and it was revealed that up to a 30% efficiency increase could be achieved at the end of the project. Thus, it has been proven that VECTO is not just a theoretical approach.

3.5. Platooning

Platooning is when two or more electronically communicating vehicles travel in close succession in a convoy on the highway. The other trucks in the convoy follow the lead truck in front. Drivers can leave the conveying and act independently if desired. Tests are ongoing to commission this technique in Europe. Conveying reduces fuel consumption and CO_2 emissions. Considering the close movement of the trucks in a row, the air friction per vehicle is reduced, providing a great advantage in terms of aerodynamics. We can liken this technique to birds flying in groups. According to the study by Ertico, the conveying technique provides up to 16% improvement in CO_2 emissions in vehicles following the leader. A photograph of the tests carried out by Scania CV AB is given in Fig 5.

Figure 5. HDV platoon traveling of Scania CV AB [14].

This technique also increases security. The vehicles in the conveying brake automatically; when the leading truck brakes, the following trucks automatically react 5 times faster than a human can react and brake automatically. It allows drivers to carry out their daily routines such as daily administrative work or searches.
It is necessary to introduce legal regulations and standards to further improve the conveying technique. In addition, conveying incentive taxation contributes positively to the increase in the number of vehicles using the technique. The most important factor in putting this technique into use is the regulation of the highway infrastructure. In this direction, serious infrastructure investments of countries are required. Physical tests will more clearly demonstrate the usefulness of the technique. Standard conditions are important: For example, how many vehicles should be in the conveying to maintain efficiency? The answers to such questions can be given because of research and tests. The recent emergence of several platooning-related projects indicates that platooning is becoming increasingly important [14].

4. Comparison of EU-US GHG Emissions

Theoretical and artificial frameworks put into effect by the legislation may not coincide with real-life CO_2 emission values. This is the difficulty of regulatory approaches introduced by legislation.

CO_2 emissions from trucks and trailers cannot be addressed in a single regulatory policy, as trucks and trailers come in thousands of different shapes and sizes. Considering the multi-stage production process of trucks and trailers, which manufacturer should be responsible for the compliance of a completed truck or trailer with the legislation becomes a separate issue. In the current approach, 35 different legal regulations have been made by considering only the most important truck classes, as the uniform legislation will not apply to all truck classes. VECTO addresses these complex and inefficient regulatory processes.

With the relevant legislation, it is obligatory to declare the CO_2 values for every truck produced in the EU. In the future, this legislation will also be inclusive of trailers. In the USA, the calculation of CO_2 data is non-specific due to the small variety of engines used and the limited number of input parameters. While in the USA all manufacturers use a generic engine type, in Europe the input data must be inclusive of the actual performance of each manufacturer's unique engine type. When analyzed based on weight carried at one time, in the current legal framework, the standard vehicle combination used in the EU emits 16% less CO_2 compared to the vehicle combination used in the USA. When analyzed based on the volume transported at one time, the standard vehicle combination used in the USA is compared to the standard vehicle used in the EU. Compared to the combination, it performs better in terms of CO_2 emissions. As seen in Fig. 6. US standard vehicle combination can legally carry 21% more volume.

Volume Comparison		
Interior length	13.62m	16.00m
Interior width	2.47m	2.50m
Interior height	2.75m	2.80m
Interior volume	92.5m^3	112.0m^3

Figure 6. EU-USA transportable volume comparison [15].

These results point to an important issue regarding the efficiency of road transport in Europe: the need to update existing mass and dimensions legislation. Currently, the efficiency of heavy-duty vehicles is limited by the legal requirements on maximum weight, size, and speed imposed by regulations. Modifications to these legal boundary conditions have become essential to increase efficiency. A potential increase in fuel efficiency of 14% can be expected if long combinations commonly used in the USA are allowed to circulate freely within Europe. Of course, to make this legal regulation, as mentioned at the beginning of the article, the road infrastructure must be suitable for long vehicle combinations.

5. Conclusion

Fuel costs account for 30% of operating costs in the transport sector. The fuel factor is of great importance in increasing the competitiveness of transport service providers. That's why Fuel efficiency and CO_2 emissions targets are market-oriented. According to ACEA's data, the total operating costs of the tractor-semi-trailer combination with a total combined weight of 40 tons are given below in Fig. 7.

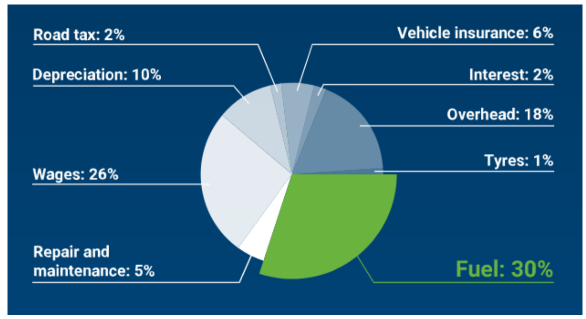


Figure 7. Total operating costs of a 40-tonne tractor-semitrailer combination [15].

Based on the standard, reliable and transparent software, all customers can see the fuel consumption values of the vehicles they will purchase, which will contribute to the selection of the most efficient vehicle and therefore to the reduction of greenhouse gas emissions. This will also increase the competitive environment for efficiency in the market. Both the competitiveness of the market will increase and the damage to nature will be minimized. With the VECTO legislation, a carbon emission reduction target of 15% until 2025 has been set. This target for 2030 is 30%. If vehicle manufacturers cannot achieve the carbon emission values determined in the target-ed years, they will have to pay a fine for each vehicle. VECTO provides customers with real and reliable information about the fuel efficiency of their heavy-duty vehicles and vehicle combinations by calculating the amount of CO_2 emitted per ton, the amount of fuel consumed, with inputs such as the volume and weight of the cargo. This simulation tool will enable customers to choose the most economical vehicle specification. Various configurations such as engine-transmission combination, aerodynamic characteristics, and tire characteristics are considered in the calculation.

The European Commission is actively developing the VECTO simulation in close cooperation with the industry. In 2018, configurations for the certification of vehicles were introduced. CO_2 declaration for trucks (classes 4, 5, 9, and 10) has started to be issued. An 18-month transition period has been defined for producers from the date of entry into force of the legal regulation.

As a result, heavy-duty vehicle manufacturers are encouraged to innovate to produce the most efficient vehicles for the market. The advantage of using a simulation, as opposed to a test-based approach, is that each unique tool can be evaluated easily and efficiently. Simulation is not just a theoretical computational tool; in the database of the VECTO simulation, there are many data entries obtained by physical tests. The input data integrated into the simulation includes very precise calculations. Thus, VECTO ensures that the most cost-effective tools can be quickly selected by end-users.

Abbreviations

VECTO: Vehicle Energy consumption Calculation Tool

GHG: Greenhouse Gases

HDV: Heavy-duty Vehicles

GVW: Gross Vehicle Weight

ERS: Energy Recovery System

EMS: European Modular System

ITS: Intelligent Transportation Systems

ACEA: European Automobile Manufacturers Association

Conflict of Interest Statement

The author declares that there is no conflict of interest in the study.

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