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A CONCEPTUAL FRAMEWORK FOR SUSTAINABLE FREIGHT LAND TRANSPORT SIMULATION – PART 1

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Abstract
Freight transport is a fundamental activity for the economic growth of a country or region, and the transport sector is one of the main contributors to gross domestic product (GDP) measurements. The total tons to be transported per year and transport types must be taken into account by state organisations for infrastructure planning, routes, prices and taxes. Governments make investment decisions according to the size of the freight mobilised per year. Transportation companies should contemplate external and internal variables, for example, fuel prices, distances, environmental impact, among others. Sustainability has become a determining factor in transport companies' decision making. This paper presents a novel study about the factors that affect freight land transport from the sustainability perspective. Then it proposes a conceptual framework to act as a roadmad to build a simulation model of freight land transport by defining the key parameters in economic, social and environmental terms.
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Key Words: Freight Land Transport, Sustainability, Circular Economy, System Dynamics

1. INTRODUCTION

Road transport is one of the most representative ways to move heavy freight and, thus, road conditions are critical for an efficient transport system. This implies investing in road maintenance and repair, which is why the authorities in charge of setting load limits face several fundamental decisions. For example, allowing the flow of overloaded vehicles to reduce transit times and transport costs and, therefore, increase the service demand. For example, allowing economies of scale or formulating stricter load limit policies that help to maintain good road conditions would reduce repair costs and the risk of accidents. These decisions have an impact on indicators of CO_2 emissions and other particulate pollutants as the vehicle traffic on roads produces the largest amounts of CO_2 and metal particulate emissions.

This article aims to identify different policies to make heavy freight transport more sustainable in terms of economic, environmental and social issues. To this end, a conceptual framework is proposed to be the basis of system dynamics [1-3] simulation model that integrates several influencing factors and quantifies the system's efficiency in terms of economic indicators to help both decision makers and transport operators to regulate load limits. Litman and Burwell [4] present a detailed definition of sustainable transport that consists in three fundamental concepts: (i) sustainable transport enables the safe and constant supply of individual and societal needs by ensuring human and ecosystem health to guarantee the stability of future generations; (ii) sustainable transport must be value for money, i.e. efficient and affordable operation, which requires offering a variety of transport modes to choose alternatives; (iii) emission control and global waste management are central sustainable transport objectives. To achieve sustainable transport, Zhou [5] presents a number of strategies, such as: controlling CO_2 emissions and implementing reduction alternatives, promoting road safety, traffic management, marketing and telematics as tools to improve public transport. Apart from improving the competitiveness of road transport alternatives like trains, transporters' performance and transport operators' services should increase. All this is achieved by increasing the decision-making capacity of the government offices in charge of transport management to improve the operations of the responsible ministries.

One of the main factors that affects the sustainability of the freight transport system is road conditions. If they are poor, they have impacts, like shorter vehicle service lives, increased fuel consumption, more CO_2 emissions, higher risks of accidents, among others. Ghisolfi et al. [6] propose a system dynamics model to evaluate the relation between excess weight in the transport of ornamental stones on roads, operational transport and costs associated with traffic accidents and pavement maintenance. Here, the main contribution of the work is to present a conceptual framework of the land freight transport system and freight regulation policies to achieve sustainability.

The rest of the article is structured as follows. Section 2 presents the literature review. Section 3 proposes a conceptual framework about integrating sustainability into the land freight transport system. Finally, Section 4 presents the conclusions and the identified future research lines.

2. LITERATURE REVIEW

The transport system sustainability research trend has grown. System dynamics has become an important tool in decision making [7], and is especially useful for evaluating different transport regulatory policy scenarios [8, 9], e.g., freight volume regulation, fuel taxes, traffic and others. In addition, other tools like statistics or linear programming are presented to evaluate the relations between sustainability and transport. For freight transport, Piattelli et al. [10] propose a system dynamics model to assess the effects of different sustainability policies on the growth of multimodal freight transport in Germany and to measure the impact of policies, such as carbon taxation, infrastructure investments and operational cost coverage.

In order to understand external transport effects on the environment, spatial organisation, public health, safety, security and congestion, it is necessary to formulate strategies to improve these aspects, but they must not stop productive activity. Based on the assumption that the transport system must meet sustainability criteria, Himanen et al. [11] developed a thematic network (STELLA 1) that aims to identify an R&D-oriented sustainable transport policy agenda. They propose that sustainable transport policy should address the internalisation of externalities in pricing, infrastructure and system dynamics. Safety, security and public health must also be taken into account and integrated into transport planning and operation. Schade and Schade [12] developed a system dynamics model for the economic evaluation of sustainable transport policies called ESCOT, which aims to describe the path towards a sustainable transport system in Germany and to evaluate its economic impacts. Jeon and Amekudzi [13] examine different initiatives on sustainable transport in North America, Europe and Oceania to obtain a definition of sustainability and its measurement.

Given the need to consider the transport problem as a whole rather than its separate components, Ülengin et al. [14] propose a theoretical framework for formulating transport system policies by considering social, environmental and energy impacts. Hang and Li [15] developed a methodological framework to evaluate the effect of truck weight regulation on transport system efficiency in China. They propose a system dynamics model that consists in five interrelated subsystems: freight demand forecasting, transportation cost, truck usage, fleet evolution, pavement condition. The study of the effect of freight regulation policies on transport costs has also been addressed by [16], who propose a two-level modelling approach using linear programming. The model represents the interaction between road transporters' loading practices and responsible authorities' planning decisions about road maintenance and load control to strike a balanced system in the long run, while fulfilling social responsibilities. Liu and Mu [17] developed a model to evaluate the impact of applying different transport weight regulations on sustainability in the land freight transport system. Liu et al. [18] developed a system dynamics model to assess the effects of overweight on sustainability and to propose road transport system improvements in which vehicles comply with legal weight limits. They compare the effects of possible solutions to the real situation with overloaded trucks and identify the applicable modal shift and policies to increase sustainability by reducing total costs. Dong et al. [19] investigate the benefits of underground transport for sustainable urban development by simulating and evaluating different scenarios using the Vensim software®.

Concerns about resource depletion and ecological and social damage caused by economic practices have led to promote and implement of transition processes toward green economy, which was defined by the United Nations Environmentally Programme (UNEP) in 2009 as an economy that provides long-term improvement of well-being and reduces inequality, while enabling future generations to avoid significant environmental risks and impoverishment.

Reverse logistics and circular economy have been driven by the objective to slow down the depletion of natural resources. Collection, recycling and remanufacturing of end-of-life products are activities that allow companies to work towards sustainable development and, at the same time, to promote the use of sustainable transport by, for example, implementing electric vehicles for last-mile logistics. Alamerew and Brissaud [20] developed a simulation model of the dynamics of cost, revenue, strategic and regulatory decisions. They applied the model to electric vehicle batteries. Wanke et al. [21] developed a statistical analysis of the sustainability efficiency of the transport system in China by investigating the relation between CO_2 emission levels and the respective freight and passenger volumes for each transport mode.

Ultimately, environmental sustainability is affected by overloaded truck traffic, and even if a percentage of vehicle overloading is allowed to improve economic sustainability, it is not an environmentally and socially sustainable practice. Overloading considerably deteriorates the paved road network, and leads to longer transit times, more CO_2 emissions, higher risks of accidents, among others. Some of the reviewed studies evaluate only the economic aspect, while others integrate social aspects like road use or road safety, and others propose environmental approaches like the impact of alternative vehicle use or replacement by rail transport. The main novelty of this proposal is to integrate the three dimensions of sustainability in land freight modes of operation to find the best options for more sustainable transport performance. Thus new insights into sustainable land freight transport aspects are provided through a conceptual framework.

3. CONCEPTUAL FRAMEWORK

The main objective of the conceptual framework is to present a holistic view of the land freight transport system from a sustainable perspective. To this end, the relations among key sustainable system components (economical, social, environmental) are identified and described. On the economic side, the efficiency of processes and the contribution to a region's internal economy or GDP, among other economic indicators, are evaluated. On the social side, the service level, investments in infrastructure and safety are taken into account. For the environmental aspect, the impact of land freight transport use on emissions of polluting gases, particulate matter and noise is evaluated, as are the effects of overweight vehicles on the state of pavements, pavement maintenance, fuel consumption, fleet use, among others. This conceptual framework is divided into three main levels or dynamic modules, which are interlinked by information flow which, in turn are divided according to their components. The economic module deals with everything related to transport system efficiency and productivity; i.e. operational costs, fixed costs, supply, demand, among others. The social module evaluates social costs, including risk of accidents, employment generation and public investment. Finally, the environmental module deals with the factor of pollutant and greenhouse gas emissions, particulate matter waste, load regulation and pavement use. To understand the interactions among the modules, it is necessary to understand the key sustainable transport criteria and to devise evaluation policies that compare different scenarios and determine which is the most sustainable. Fig. 1 presents the conceptual framework by integrating the three sustainability areas into the freight transport system. The economic components are depicted in blue, the social components in orange, the environmental components in green, the total cumulative cost in pink, and the components representing the interconnections are not colour-filled.

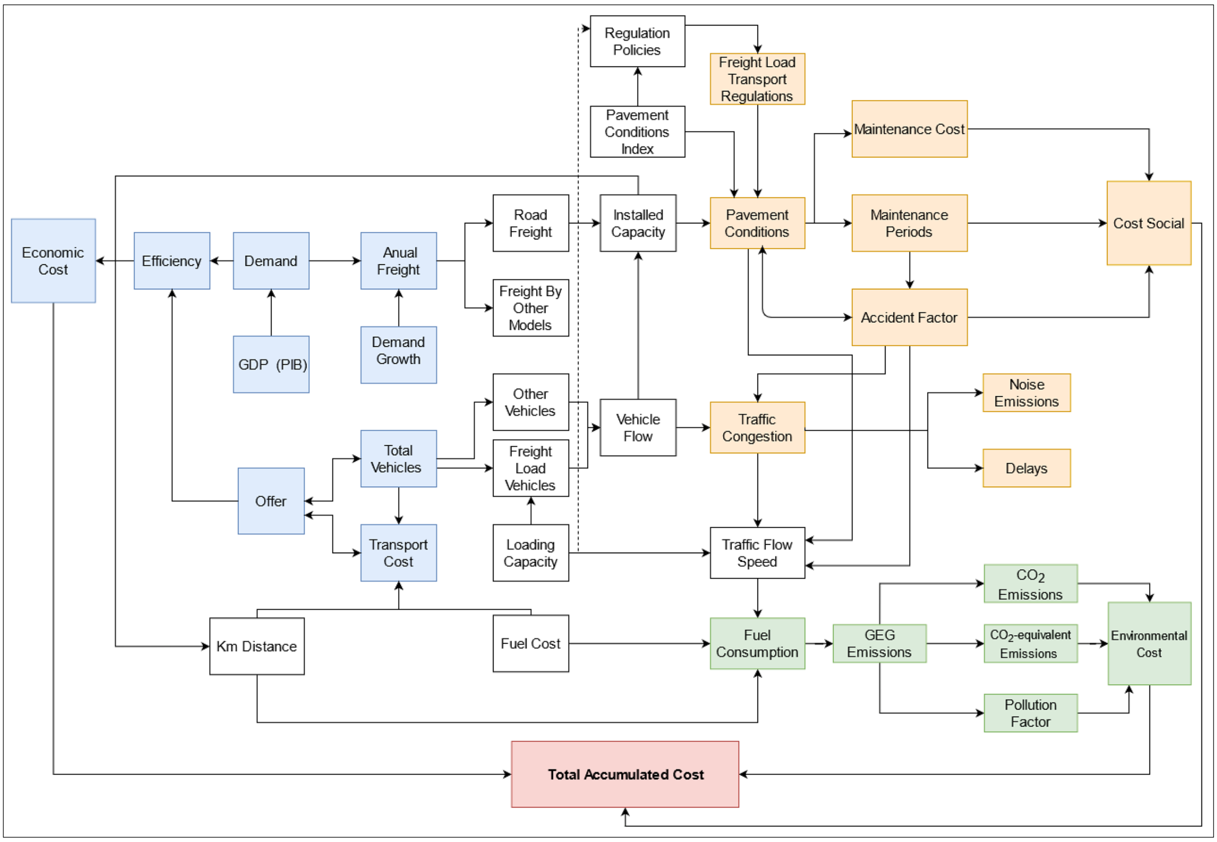

Figure 1: Conceptual framework.

The causal diagram (Fig. 2) represents the structure of the proposed model, which consists in seven modules, five of which were adapted from [6], while modules 6 and 7 were originally proposed according to the above-developed conceptual proposal: Module 1: Load volume generation; Module 2: Flow velocity; Module 3: Load ratio for the route; Module 4: Pavement condition and maintenance; Module 5: Social cost; Module 6: Environmental cost; Module 7: Policy evaluation. Based on the nomenclature proposed in Table I, the equivalent traffic volume is defined.

Table I: Nomenclature.

Mathematical representation		**Formula/Comments**	**Units**
Variable	**Description**		
α	Linear regression coefficients	0.15	Dmnl
α'	Linear regression coefficients	Typified cases	Dmnl
β	Linear regression coefficients		Dmnl
β'	Linear regression coefficients	Typified cases	Dmnl
$\% A_{CM}$	Percentage of accidents without casualties		Dmnl
$\% A_{CV}$	Percentage of accidents with casualties		Dmnl
$\% A_{SV}$	Percentage of accidents without casualties		Dmnl
A_A	Accidents per year	$A_A = P_{Ac} \cdot D$	Accidents/Year
A_{CM}	Number of accidents with fatalities	$A_{CM} = A_A \cdot \% A_{CM}$	Accidents/Year

Mathematical representation		Formula/Comments	Units
Variable	**Description**		
A_{CV}	Number of accidents with casualties	$A_{CV} = A_A \cdot \% A_{CV}$	Accidents/Year
A_{SV}	Number of accidents without casualties	$A_{SV} = A_A \cdot \% A_{SV}$	Accidents/Year
C	Route capacity		PCE/Hour
C_{Ac}	Cost of road accidents	$C_{Ac} = TCC \cdot [(A_{CV} \cdot C_{CV}) + (A_{SV} \cdot C_{SV}) + (A_{CM} \cdot C_{CM})]$	$/Year
C_{CV}	Cost of accidents with casualties		$/Accidents
Cg1	Generalised cost of route 1		$/Ton
Cgn	Generalised cost of route *n*		$/Ton
C_{MC}	Corrective maintenance cost	$C_{MC} = (C_{MCK} \cdot D) \cdot TCC$	$/Year
Cc_M	Cost of accidents with fatalities		$/Accidents
C_{MCK}	Corrective maintenance cost per km		$/(km·Year)
C_{MP}	Cost of pavement maintenance	$C_{MP} = (V_{PA} \cdot V_{Sc}) \cdot [(C_{MR} \cdot OM) + (C_{MC} \cdot OM)]$	$/Year
C_{MR}	Restorative maintenance cost	$C_{MR} = (C_{MRK} \cdot D) \cdot TCC$	$/Year
C_{MRK}	Restorative maintenance cost per km		$/(km·Year)
CMul	Cost of overcharge fines		$/Ton
Cop_D	Operational cost per distance, depending on the value of the pavement condition index (*PCI*)		$/km
CPea	Toll costs		$/Veh
C_S	Social cost		$
C_{SV}	Non-casualty accident costs		$/Accidents
D	Distance in km		km
d	Fuel density		kg/L
ESAL design	Equivalent number of axles to be driven on the route per year		Times/Year
E_{VL}	Equivalent vehicles for light-duty vehicles (PCE)	Zero is considered to be	Dmnl
E_{VP}	Equivalent vehicles for heavy duty vehicles (PCE)		Dmnl
FC	Climate factor		Dmnl
F_C*(type i)*	Load factor of vehicle type *i*		Times/Axis
FC_{Ac}	Accident correction factor		Dmnl
Fe(type i)	Axle factor of vehicle type *i*		Axles/Veh
F_Eqx_F	Fleet equivalency factor		Times/Veh
F_{GA}	Adjustment factor		Veh/PCE
FHP	Peak hour factor		Dmnl
F_R	Frictional force		Nw
η	Engine efficiency		Dmnl
i	Vehicle type index	*B, LT, ST, MT*	Dmnl
i'	Index cost rate		Dmnl
L_{HV}	Calorific value of fuel		(NW·km)/kg
mf_F	Annual fleet fuel consumption	$m_{fF} = m_{fVT} \cdot V_{TT}$	kg/Year
mf_V	Fuel consumption per vehicle		kg/hour
n	Number of routes available		Dmnl
N	Normal force		Nw
n'	Number of vehicles in each category		Dmnl
OM	Maintenance operation		Dmnl
P_{AC}	Road accident forecast per km	$P_{Ac} = V_{Sc} \cdot D \cdot 10^{-6} \cdot e^{-0{,}312} \cdot FC_{Ac}$	Accidents/year
PCI	Pavement condition index	$PCI = PCI_0 \cdot e^{-\alpha Y^{\beta}}$	Points
PCI_0	Initial *PCI* value 20	100	Points
P_L	Percentage of light vehicles	0	Dmnl
P_m	Engine power	$P_m = F_m \cdot V$	(NW·km)/hour
P_{VP}	Percentage of heavy vehicles		Dmnl
q	Angle of elevation, depending on the slope of the route		Dmnl
TCC	Cost growth rate		Dmnl
TCM	Average daily traffic growth rate per year		Dmnl
T_{FL}	Free flow time (time with free speed)		Time/veh
V	Vehicle speed		km/hour
V_{PA}	Number of heavy goods vehicles per year		Veh/year
V_{SC}	Number of overloaded vehicles		Veh/year
W	Freight weight	Weight load · gravity	Nw
Wx	x component of weight	*W* (sin *q*)	Nw
Wy	Weight component	*W* (cos *q*)	
Y	Pavement service life		Dmnl
μ_k	Coefficient of friction depending on the material		Dmnl

$$V_{TE} = \frac{V_{TT}}{FHP \cdot F_{GA} \cdot F_{VP}} \tag{1}$$

The peak hour factor, *FHP*, and the grade adjustment factor, F_{GA}, are parameters for each route under study, which depend on the slope and the type of route (flat, undulating or mixed).

These values are known thanks to the measurement work done by the agencies in charge. The heavy vehicle factor, F_{VP}, is given by Eq. (2).

$$F_{VP} = \frac{1}{1 + P_{VP}(E_{VP} - 1) + P_L(E_{VL} - 1)} \tag{2}$$

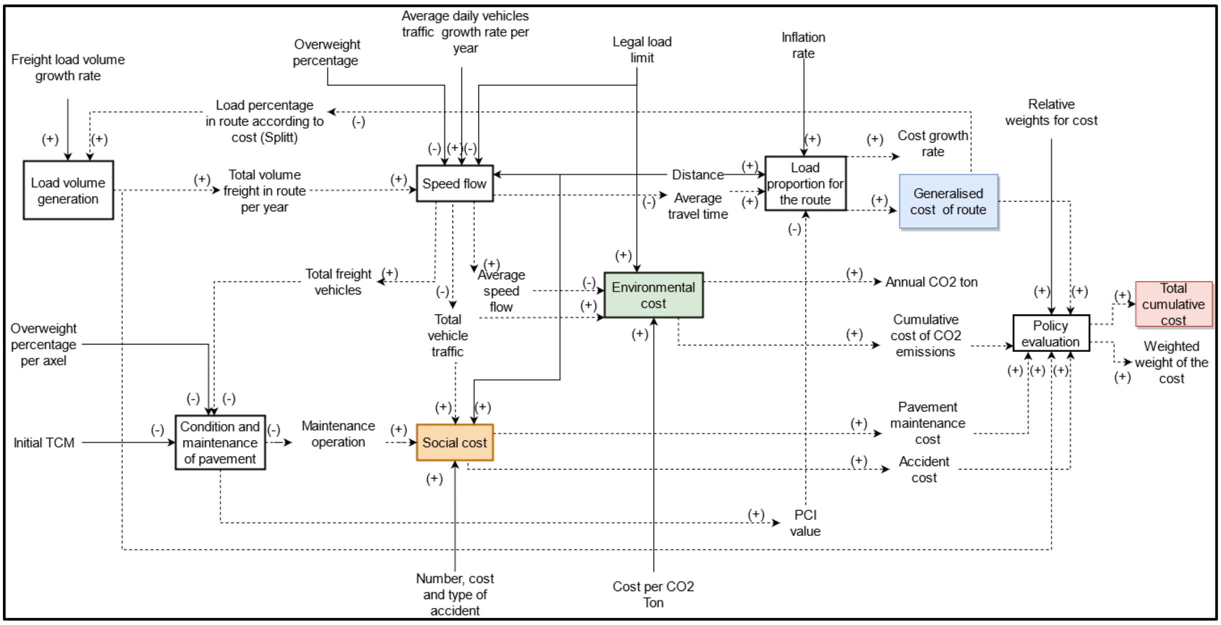

Figure 2: Causal diagram.

In the event of a flow velocity modulus, it is assumed that P_L equals zero. *FVP* is used to find the equivalent vehicles according to the route's initial capacity and its traffic volume. The equivalent traffic volume to route capacity ratio is used to find the average travel time in Eq. (3), and is a function known as BPR (Bureau of Public Roads) according to [6].

$$T_{MV} = T_{FL} \cdot (1 + \alpha \cdot (V_{TE}/C)^{\beta}) \tag{3}$$

The percentage of in-route load is calculated with Eq. (4) based on the work by [6].

$$P_{CR} = \frac{e^{-Cg1}}{\sum_1^n e^{-Cgn}} \tag{4}$$

The total generalised cost is given by Eq. (5).

$$C_{gT} = \left(C_{opD} \cdot D\right) + (C_{opT} \cdot T_{MV}) + CMul + CPea \tag{5}$$

In order to calculate the equivalent single axle load, *ESAL design*, which corresponds to the multiplication of the fleet equivalence factor by the regional climate factor and by the total traffic volume on the route, it is necessary to: define the vehicle type to be converted into equivalent axles; calculate the load of each vehicle by adding the overweight per axle and the tolerance margin; the load factor of each vehicle according to vehicle type; the axle equivalence factor, which corresponds to the sum of the load factors per vehicle type, multiplied by the axle factor of each vehicle type; calculate the fleet equivalence factor, which corresponds to the sum of the axle equivalence factors. For this purpose, it is necessary to know the permissible axle load per axle group, the overweight tolerance, the axle load factors per vehicle type and the climate factor. Table II presents the values for axle load and load factor per vehicle type. Table III provides the climatic factor according to precipitation.

Table II: Axle load and load factor per vehicle type (source: the authors based on [6], [22] and [23]).

Type of vehicle	**Axes**	**Permissible load per axle group** (tonnes)	**Total Load** (+Tolerance 10 %)	**Axle weight** (tonnes)	**Load factor**
Single tyres	1	6	6.6	6.6	(P/7.77) 4.32
Double tyres	1	10	11	11	(P/8.17) 4.32
Double tandem	2	17	18.7	9.35	(P/15.08) 4.14
Triple tandem	2	25.5	28.05	9.35	(P/22.95) 4.22

Table III: Climatic factor (source: the authors based on [24]).

Climatic factor (according to annual precipitation in mm)		
Climate	**Value**	**Range of variation**
Tropical	0.02	0.005 a 0.03
Cold	0.06	0.025 a 0.1

The calculation of the equivalence factor per axle is given by:

$$F_{Eqxe\ (type\ i)} = F_{e\ (type\ i)} \cdot TCM \cdot \sum_{n'} F_{C(type\ i)n'} \tag{6}$$

where i can take the value of *B* (bus), *LT* (light vehicle), *ST* (semitrailer) and *MT* (multitrailer) and n' is the number of vehicles in each vehicle type. Eq. (7) below provides an example of applying Eq. (6) to a specific vehicle type, in this case a bus or type *B*.

$$F_{Eqxe\ (type\ B)} = F_{e\ (type\ B)} \cdot TCM \sum F_{C\ (type\ B)single} + F_{C\ (type\ B)double} \tag{7}$$

The calculation of the fleet equivalence factor is given by:

$$F_{EqxF} = \sum_{i} F_{Eqxe\ (type\ i)} \tag{8}$$

The *ESAL design* is calculated as follows:

$$ESAL\ design = F_{EqxF} \cdot FC \cdot V_{TT} \tag{9}$$

In order to calculate the pavement condition index (*PCI*), the values of coefficients α' and β' can be based on [25]. The pavement condition deterioration calculation is given by:

$$PCI = PCI_0 \cdot e^{-\alpha Y^{\beta}} \tag{10}$$

The calculation of the service life of the pavement is given by:

$$Y = \frac{ESAL\ design}{Current\ ESAL\ design} \tag{11}$$

Eq. (11) provides the route's equivalent axle capacity to the equivalent axle capacity ratio required for the current heavy traffic volume. The *ESAL design* by capacity is calculated by the same procedure as for the *Current ESAL design*, with the difference lying in the fleet factor being calculated by assuming that the overweight percentage per axle of each vehicle equals zero. The calculated maximum capacity value equals 400 and comes from the average traffic volume when there is no overload (14.4 vehicles), divided by the capacity reduction adjustment factor and the degree of capacity adjustment. Pavement condition and, therefore, the *PCI*, is related to factors like roughness, and the international roughness index (*IRI*) is a measure that allows pavement condition to be classified. Roads can be classified according to road type, pavement condition (using the *IRI*) and land type. Table IV presents a road classification, as well as the relation between the *PCI* value and the *IRI*, which allows the pavement condition to be rated and the need for a maintenance operation to be applied.

Table IV: Classification of routes (source: the authors based on [6]).

Criterion	**Ranking**
Road types	Several lanes
	Wide track
	Two-lane federal highway
	Two-lane state highway
	Unpaved highway
IRI (International Roughness Index) pavement types	Good
	Regular
	Mediocre
	Poor
Land types	Flat
	Slightly undulating
	Undulating
	Very undulating
	Mountainous

According to [25], corrective maintenance is recommended when the *IRI* reaches a value between 3.5 and 4.6 points. If the *IRI* value is higher than 4.6 points, restorative maintenance should be performed. Table V shows the effect of each maintenance type on the *PCI* value.

Table V: Relation between *IRI* and *PCI* (source: Ghisolfi et al [6]).

Pavement condition	**Roughness**	**Condition**	**Intervention**	**Effect of maintenance**
	IRI (m/km)	***PCI*** (points)	**Maintenance**	***PCI*** (points)
Very good	1 to 1.9	100	no	no
Good	1.9 to 2.7	80	no	no
Regular	2.7 to 3.5	60	no	no
Mediocre	3.5 to 4.6	40	Corrective	80
Very bad	>4.6	20	Restorative	100

Eqs. (12) and (13) explain the cost calculation for each maintenance type and Eq. (14) explains the pavement maintenance cost calculation. At the end of the module, the level variable that accumulates the annual pavement maintenance costs is obtained. Next, Eqs. (15) to (20) are presented.

Calculating the restorative maintenance cost:

$$C_{MR} = (C_{MRK} \cdot D) \cdot TCC \tag{12}$$

Corrective maintenance costing:

$$C_{MC} = (C_{MCK} \cdot D) \cdot TCC \tag{13}$$

Calculating the pavement maintenance cost:

$$C_{MP} = (V_{PA} \cdot V_{Sc}) \cdot [(C_{MR} \cdot OM) + (C_{MC} \cdot OM)] \tag{14}$$

Calculating the accident forecast on the road:

$$P_{Ac} = V_{Sc} \cdot D \cdot 10^{-6} \cdot e^{-0{,}312} \cdot FC_{Ac} \tag{15}$$

Calculating the number of accidents on the road per year:

$$A_A = P_{Ac} \cdot D \tag{16}$$

Calculating the number of CV-type accidents:

$$A_{CV} = A_A \cdot \%\, A_{CV} \tag{17}$$

Calculating the number of SV-type accidents:

$$A_{SV} = A_A \cdot \% \, A_{SV} \tag{18}$$

Calculating the number of CM-type accidents:

$$A_{CM} = A_A \cdot \% \, A_{CM} \tag{19}$$

Calculating the cost of road accidents.

$$C_{Ac} = TCC \cdot [(A_{CV} \cdot C_{CV}) + (A_{SV} \cdot C_{SV}) + (A_{CM} \cdot C_{CM})] \tag{20}$$

Based on Newton's laws and the force diagram, the following Eqs. (21), (22), (23) and (24) were derived.

Calculating engine force using the summation of forces on the X-axis:

$$F_m = F_R + W(sin\ q) \tag{21}$$

As velocity is constant, acceleration is assumed to be zero. Weight W equals the transported load multiplied by the gravity value.

Y-axis force summation:

$$N = W(cos\ q) \tag{22}$$

Calculating frictional force:

$$F_R = N \cdot \mu_k \tag{23}$$

The engine force to move the load, Eq. (24), is obtained by replacing Eqs. (22) and (23) in Eq. (21):

$$F_m = W[(sin\ q) + \mu_k(cos\ q)] \tag{24}$$

Fig. 3 shows the force diagram for the load transport of a heavy vehicle on a road with a given slope. Eqs. (25), (26) and (27) are defined from the engine laws for power and power use. With this, fuel consumption is obtained, as shown in Eq. (28).

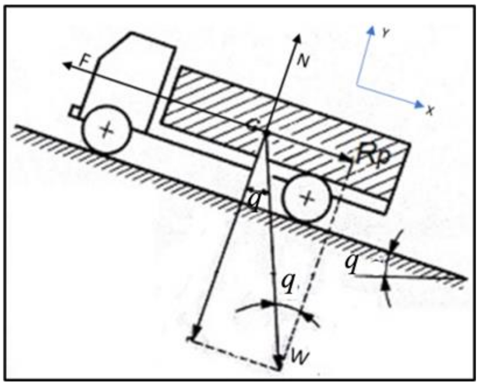

Figure 3: Kinematic representation of load transport, summation of forces.

Calculating engine power:

$$P_m = F_m \cdot V \tag{25}$$

Power use can be expressed in two ways as shown in Eq. (26) and (27).

$$P_C = \frac{P_m}{\eta} \tag{26}$$

$$P_C = m_f \cdot L_{HV} \tag{27}$$

Fuel consumption according to vehicle speed and load:

$$m_f = \frac{W[(\sin q) + \mu_k(\cos q)] \cdot V}{L_{HV} \cdot \eta} \tag{28}$$

Eqs. (29) to (35) represent the information flows and calculations of the first part of the model.

Consumption per vehicle according to the average journey time:

$$m_{fVT} = m_{fv} \cdot T_{MV} \tag{29}$$

Annual fleet fuel consumption:

$$m_{fF} = m_{fVT} \cdot V_{TT} \tag{30}$$

Consumption per vehicle according to travelled distance:

$$m_{fVD} = m_{fVT} \cdot D \tag{31}$$

Annual fleet fuel consumption according to total travelled distance:

$$m_{fFD} = m_{fVD} \cdot D_T \tag{32}$$

$$D_T = D \cdot V_{TT} \tag{33}$$

Litres of fuel consumed per vehicle in litres per km (L/km):

$$Lm_f = m_{fVD} \cdot d \tag{34}$$

Annual consumed litres of fleet fuel:

$$LTm_f = Lm_f \cdot D_T \tag{35}$$

7. CONCLUSIONS

This article presents a conceptual framework that involves the three sustainability factors to allow a holistic and systemic view of land freight transport. The conceptual proposal identifies that overweight in freight transport has negative social and environmental effects, but positive economic effects for transport companies.

Public organisations like regulatory bodies are considered to be in charge of proposing preventive and corrective actions for overweight freight transport. However, these actions should be subject to evaluations for all the routes that they are proposed to be implemented into. Thus the managerial implications of a simulation model aim to support organisation in making this type of decision by knowing the starting parameters, the load limit and the respective tolerance. In addition, the application of fines and tolls on roads can be defined. It is also noteworthy that the model can be used to determine a CO_2 emission cost according to route utilisation, overload and the fuel price, which makes the environmental cost a relevant decisional aspect. Therefore, the proposed theoretical framework is a useful tool for decision making and scenario analyses for both public organisations and private companies.

A forthcoming work is oriented to: (i) assess the effects of regulatory land freight transport policies on sustainability by experimentally implement the proposed conceptual framework through a system dynamics simulation model; (ii) determine the best scenario for sustainability in terms of vehicle load limit policies by transport companies and regulatory legal entities; and (iii) analyse the effect of overloading on road pavement conditions and their environmental, social and economic impacts.

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