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Integrated emission and fuel consumption calculation model for green supply chain management

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Abstract

In today's highly competitive environment, green supply chain management issues are gaining interest from both academia and industry. The aim of this study is, constructing a fuel consumption and CO_2 emission calculation model considering vehicle technical specifications, vehicle load and transportation distance in green supply chain environment. A graphical user interface is established for the model. The proposed model is evaluated with various examples for different types of vehicles. The presented model offers an effective tool for operational decisions of transportation systems by calculating CO_2 emission and fuel consumption.

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Keywords: Supply chain management, green logistics, CO_2 emissions, fuel consumption;

1. Introduction

Supply chain management concept has become one of the most important managerial trends in business environment. One of the main reasons contributing to this importance is the large share of logistics costs in the finished product costs. Green supply chain management can be defined as integrating environmental issues into supply-chain management, including the processes from product design to end-of-life management of the product after its useful life.

The importance of environmental issues is continuously translated into regulations, which potentially has a tangible impact on supply chain management. As a consequence, there has been an increasing amount of research on the intersection between logistics and environmental factors (Jabali et al. 2012).

Green logistics is concerned with producing and distributing products in a sustainable way, taking into account of environmental and social factors. Thus the objectives are not only concerned with the economic impact of logistics policies on the enterprises carrying them out, but also wider effects on daily life, such as the effects of pollution on the environment. In high competitive environment, industrial organizations have to investigate logistics strategies and adopt green supply chain applications to consider accurate use of natural resources as a social responsibility.

Government regulations and customer demands are making environmental responsibility an increasingly important factor in overall supply chain operations. Among these operations transportation has the most hazardous effects on the environment, such as CO_2 emissions, energy consumption, noise and toxic effects on the ecosystem.

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The aim of this study is, constructing a fuel consumption and CO_2 emission calculation model considering vehicle technical specifications, vehicle load and transportation distance in green supply chain environment. A graphical user interface (GUI) is established for the model. In the GUI, the user can change the parameters of the model according to the technical specifications of the vehicle. The proposed model is evaluated with various examples for different types of vehicles.

2. Literature review

Wu and Liu (2012) proposed a predictive system for fuel consumption using a radial basis function neural network. Apaydın and Gönüllü (2008) used fixed values for calculating CO_2 emission and fuel consumption. Kuo (2010) calculated fuel consumption and CO_2 emission with respect to vehicle load and vehicle speed. Jabali et al. (2012) modeled fuel consumption and CO_2 emission as a function of speed. Bektaş and Laporte (2011) calculated fuel consumption based on average speed and vehicle load. Suzuki (2011) considered vehicle load, average speed based on the road gradient and average amount of fuel consumed per hour while a vehicle is waiting at customer sites to calculate the fuel consumption. Ubeda (2011) considered vehicle load for calculating fuel consumption. Xiao et al. (2012) formulated a linear function dependent on vehicle load for fuel consumption. Huang et al. (2012) modeled linear regression for fuel consumption as a function of vehicle load and distance and then multiplied fuel consumption value with a constant emission rate to obtain CO_2 emission value. Demir et al. (2011, 2012) and Liu and Helfand (2009) used mathematical equation to calculate fuel consumption.

3. Fuel consumption and CO_2 emission calculation

According to our knowledge, the previous studies ignored the acceleration rate and/or did not directly consider the vehicle load while calculating the fuel consumption. To get more realistic results in this study, the fuel consumption is calculated considering the vehicle technical specifications, vehicle load and the route distance. We dwelt on the needed energy to move vehicle with constant speed or acceleration in real time. This energy is basically equal to total resistance forces (F_T). The F_T includes rolling resistance (F_{Ro}), aerodynamic resistance (F_{Ae}), grade resistance (F_G) and acceleration resistance (F_{Acc}).

F_{Ro} is the result of deformation work on tires and roadway, is given by equation 1:

$$F_{Ro} = fG = fmg \tag{1}$$

Where f is the coefficient of rolling resistance, m is the vehicle weight and g is the gravitational constant (Braess and Sheiffert, 2005). Aerodynamic resistance F_{Ae} can be calculated from the following equation 2:

$$F_{Ae} = c_d A\rho \frac{v^2}{2} \tag{2}$$

Where c_d is the aerodynamic coefficient, A is the frontal surface area, ρ is the air density and v is the speed. F_{Acc} can be calculated from the following equation 3:

$$F_{Acc} = \lambda ma \tag{3}$$

Where λ is the transmission variable and a is the acceleration rate. F_G is calculated as in equation 4:

$$F_G = mgSin\alpha \tag{4}$$

Where α is the coefficient related to gradient of the road. In this study the grade resistance is assumed to be constant and the total force F_T at the wheels for a given acceleration and grade is as in equation 5:

$$F_T = F_{Ro} + F_{Ae} + F_{Acc} \tag{5}$$

Assume that, P_T is the total power at the wheels and calculated as in equation 6:

$$P_T = F_T v \tag{6}$$

To convert the total force to the fuel consumption, consumption value b, which can be obtained from vehicle technical specifications, multiplicities with the total power (P_T) and the fuel consumption is obtained by equation 7:

$$consumption = bP_T \tag{7}$$

Furthermore, fuel consumption amount can be converted to CO_2 emission by equation 8:

$$emission = c_e \times consumption \tag{8}$$

Where c_e is the vehicle carbon emission constant and this value can be obtained from vehicle technical specifications.

To calculate the total fuel consumption and CO_2 emission of a vehicle in a specified distance, formulations defined above are developed as a function of time. By using these functions, a fuel consumption and CO_2 calculation algorithm is proposed to compute the total fuel consumption and CO_2 emission of the vehicle for a definite route. To simplify the use of algorithm, GUI is established. In the GUI, the user can change the parameters of the algorithm according to the technical specifications of the vehicle. The GUI calculates the total fuel consumption and CO_2 emission amount based on the vehicle weight, vehicle technical data and route distance. The user can display the time versus cumulative fuel consumption and time versus cumulative CO_2 emission graphics via GUI.

4. Computational results and discussion

To demonstrate the applicability of the fuel consumption and CO_2 calculation algorithm an example with a specific vehicle data is performed. The results of the example and the time versus cumulative fuel consumption graphics GUI views are presented.

The time versus cumulative CO_2 emission graphics GUI views are presented in Figure 2. The vehicle technical data, presented, are pertaining to small pick-ups. It can be seen from the results in Figure 1 and 2 that the calculated fuel consumption for 1 km is 0.2576 kg and total CO_2 emission is 0.7916 kg.

To evaluate the performance of the algorithm computational experiments are performed for different type of vehicles. The results of computational experiments is presented in Table 1.

Table 1. Computational experiments

		1 km		10 km		50 km		100 km	
Vehicle Type	Vehicle Load (kg)	Fuel Consumption (kg)	CO_2 Emission (kg)	Fuel Consumption (kg)	CO_2 Emission (kg)	Fuel Consumption (kg)	CO_2 Emission (kg)	Fuel Consumption (kg)	CO_2 Emission (kg)
Car	1300	0.2576	0.7916	0.7194	2.2104	2.7718	8.5161	5.3373	16.3983
Pickup	1090	0.2467	0.7578	0.8897	2.7333	3.7472	11.5131	7.3193	22.4878
Van	3500	0.5076	1.5604	1.6822	5.1685	6.9016	21.2046	13.4259	41.2498
Truck	4250	0.5902	1.8134	1.9333	5.9400	7.9028	24.2805	15.3646	47.2062
Bus	5900	2.1737	7.1379	5.1328	168548	18.3291	60.1878	34.8059	114.2900

It can be concluded from the results that the fuel consumption and CO_2 emission amount has direct correlation with vehicle type and travelled distance.

Obtained results showed that the proposed algorithm can be applied to any kind of vehicle type. In the algorithm the fuel consumption is calculated considering the vehicle technical specifications, vehicle load (kg) and the route distance differently from previous studies.

Among supply chain operations transportation has the most hazardous effects on the environment, such as CO_2 emissions, energy consumption, noise and toxic effects on the ecosystem.

The model presented in this paper offers an effective tool for operational decisions of transportation systems by calculating CO_2 emission and fuel consumption.

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