EVS30 Symposium
Stuttgart, Germany, October 9 - 11, 2016

Selecting Appropriate Types of Electric Commercial Vehicles for the Sustainable Urban Freight Transport

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Abstract

There are multiple alternatives for urban logistic stakeholders to employ electric commercial vehicles for achieving sustainable urban freight transport. Nevertheless, after reviewing existing work, we observe that few models have estimated the economic, environmental, and social performance of these multiple alternatives. Accordingly, we propose a concept to fill this gap in accordance with multi-criteria decision making. Moreover, we realize this concept by formulating three mathematical expressions on the basis of extending existing models. Our test results show that the proposed concept is feasible to numerically support stakeholders' selection of an appropriate alternative for achieving sustainable urban freight transport.

Keywords: Freight transport, Sustainability, EV (electric vehicle)

1 Introduction

There are multiple options for Electric Commercial Vehicles (ECVs) being employed in Urban Freight Transport (UFT) to achieve sustainability. In accordance with differences among propulsion systems, configurations, and energy sources of electric vehicles [1], the ECVs can be divided into Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs), and Fuel Cell Electric Vehicles (FCEVs). Moreover, in accordance with differences among service customers, purposes of transporting, and features of goods, the UFT can consist of five markets including retail, express/post, Ho(tel)Re(staurant)Ca(tering), construction, as well as waste collection [2][3]. Additionally, a majority of studies have investigated the sustainable transport from economic, environmental, and social dimensions [4][5]. Accordingly, we notice that there are multiple alternatives for urban logistic stakeholders, which intend to consider employing ECVs in their fleet for achieving sustainable UFT.

These alternatives extend the feasibility and diversity of employing ECVs in UFT. For instance, if an express services company intends to partly substitute ECVs for their diesel commercial vehicles, they have four alternatives to do a comparison for their own fleet. The three sustainable dimensions are criteria for supporting the comparison. We regard the four types of ECVs, the five markets of UFT, and the three dimensions of sustainability as a set of vehicle types, a set of markets, and a set of criteria separately. The set of alternatives is derived from the Cartesian product of the set of vehicle types and the set of markets. Therefore, it leads to 20 alternatives in total with respect to the set of criteria.

This paper focuses on comparing the various alternatives to select an appropriate type for each market with respect to sustainable dimensions. We firstly review several existing models and propose three research questions: (1) What have been investigated in these existing models; (2) What are their purposes, advantages, and limitations; (3) How can the urban logistic stakeholders assess and select appropriate types of ECVs in accordance with their own fleet for achieving sustainable UFT. A concept is proposed in this paper to answer the third question with taking into account the advantages and limitations of existing models.

The rest of paper is organized as follows. In section 2, we review the existing models and summarize their purposes, advantages, and limitations. In section 3, we propose our concept including three mathematical expressions according to the findings of reviewing existing models. Section 4 illustrates a case study to test the feasibility of the proposed concept. Finally, conclusion and future work are presented in section 5.

2 Existing Models

A number of studies have investigated the employment of ECVs in UFT by taking into account electric vehicle routing problems, urban consolidation centers, Total Costs of Ownership (TCO), and intermodal transport [6][7][8][9]. However, we observed that employing BEVs in a general urban freight transport system with considering the economic dimension is an alternative studied frequently. It indicates that few urban logistic stakeholders can benefit from these studies and apply them in their own cases. Accordingly, extending the investigation of alternatives has the capability of providing the stakeholders with more options for selecting an appropriate one. Nevertheless, 20 alternatives complicate the selection. Therefore, we review six existing models in this section to get insight into their purposes, advantages, and limitations for supporting us to simplify the selection by proposing a concept. According to the purposes of these models, we divided them into vehicle-oriented models and logistics-oriented models.

2.1 Vehicle-Oriented Models

2.1.1 AFLEET Tool

Alternative Fuel Life-Cycle Environmental and Economic Transportation is abbreviated as AFLEET Tool. It was supported by the Vehicle Technologies Office, U.S. Department of Energy. This tool allows clean cities stakeholders to estimate life-cycle petroleum use, life-cycle greenhouse gas emissions, vehicle operation air pollutant emissions, and costs of ownership for light-duty vehicles and heavy-duty vehicles [10]. They investigated three types of light-duty vehicles and seven types of heavy-duty vehicles with using 16 available fuel types. Users can choose one or more vehicle types and fuel types on the basis of their own cases.

There are several advantages of the AFLEET Tool. First of all, there is a wide range of alternatives, since this tool can estimate and compare multiple vehicle types and fuel types from economic and environmental perspectives. Accordingly, this tool provides more options for users, who are involved in clean cities stakeholders, to select appropriate types in accordance with their own cases. Secondly, this tool takes into account the years of planned ownership to estimate the economic and environmental performance of alternatives. Hence, we consider this tool as a time-dependent tool, which has the capability of presenting the results practically and dynamically. In addition, the AFLEET Tool can calculate life cycle petroleum use, GHGs, and air pollutant emissions. Finally, this tool provides a relatively full database to support users estimating the alternatives, if conditions are such that the users lack corresponding data.

On the other hand, there are two limitations for the urban logistic stakeholders to select appropriate types of ECVs for sustainable UFT by using this tool. Firstly, this tool estimates the petroleum use, GHGs, air pollutant emissions, and costs of ownership exclusive of logistical parameters. Secondly, the social impact as one dimension to assess sustainable UFT is paid no attention. Hence, the conclusion of this tool cannot show the interaction between the calculated results (GHGs, TCO, etc.) and the changes of logistic parameters (transported weight, traveled distance, etc). Moreover, the stakeholders can partly understand the sustainability of their options from the results of this tool without considering the social dimension.

2.1.2 Heavy Truck Benefits Analysis Models

The Heavy Truck Benefits Analysis Models (HTBAMs) are developed by the Energy System Division (ES) at Argonne National Laboratory. It is applied for estimating energy, environmental, and economic benefits by using a market-based approach. The HTBAMs consists of three submodels. The Heavy Truck Energy Balance Dynamic (HTEBdyn) Model calculates the fuel economy of medium-duty (Class 3-6) and heavy-duty (Class 7& 8) vehicles on the basis of vehicles' and engines' characteristics as well as drive cycles [11]. The intended purpose is to estimate the impact of technology improvements and innovations on heavy truck fuel consumption for a variety of duty cycles [12]. Therefore, hybrid electric trucks with integrating regenerative braking systems as one of the technology improvements and innovations are involved in this model. Furthermore, the rest of the models are the TRUCK model and the VISION model. The TRUCK model applies the results of HTEBdyn for estimating the market potential of associated technology changes and calculates the fuel economy of new truck fleets. The VISION model then uses sales projections and historical scrappage rates to project the future stock of heavy vehicle, the fuel economy of the in-use fleet, and total consumption of traditional as well as alternative transportation fuels [13].

There are three advantages to this model. Firstly, the model incorporates driving cycles to calculate the fuel consumption. It implies that the fuel consumption varies with the velocity at each time step so that the accumulated results are closer to real life. Secondly, this model has the capability of predicting future market of heavy trucks to present a long-term view. Additionally, the calculation of total carbon-equivalent emissions covers the emissions from Well to Wheel (WTW).

Nevertheless, several limitations to this model need to be noted. Although the fact that this model took into account the advanced technologies, the alternative fuel types and vehicle types are fewer in number than the AFLEET Tool. In addition, the HTBAMs estimate the change of fuel costs by applying advanced technologies, whereas the total costs for employing these advanced technologies are neglected. Finally, similar to the AFLEET Tool, this model concentrates on estimating the economic and environmental benefits from the automotive point of view without involving the logistical parameters.

2.1.3 ADVISOR

ADVISOR is the abbreviation of Advanced Vehicle Simulator. It is an open source simulation tool, which is written in the MATLAB/Simulink environment and developed by the National Renewable Energy Laboratory. The role of this tool is to provide the vehicle engineering community with an easy-to-use, flexible, yet robust and supported analysis package for advanced vehicle modeling [14]. The fuel economy, the performance, and the emissions of passenger and commercial vehicles with using conventional and alternative fuels can be quantified in this tool. Fuel cells, batteries, and ICE in hybrid configurations are the alternative technologies included in this tool.

The urban logistic stakeholder can benefit from two advantages of this tool. First of all, same as the HTBAMs, this tool calculates the fuel economy in accordance with driving cycles, which constitutes a series of vehicle speeds as a function of time. Moreover, the regenerative braking system is integrated into the calculation. Secondly, ADVISOR contains a wide range of vehicle and fuel types so that a number of stakeholders, such as component suppliers, automobile manufacturers, future governments, and academic researchers, can benefit from the simulation results.

On the other hand, the urban logistic stakeholder cannot directly apply this tool for selecting the appropriate types because of several limitations. Firstly, this tool analyzes the various technologies simply from the environmental point of view. If a stakeholder decides to employ one of the alternative technologies, since it saves more energy and emits less GHGs by simulating in this tool, then this technology is possible inappropriate without calculating its expenditure. Secondly, if the stakeholder is a logistic service company, they need to integrate their logistical parameters into this tool to decide which alternative technologies have the capability of replacing their current commercial vehicles.

2.2 Logistics-Oriented Models

2.2.1 Calculating GHG Emissions for Freight Forwarding and Logistics Services

This is a guidance, which is published by the European Association for Forwarding, Transport, Logistics and Customs Services (CLECAT). The purpose of this guide is to provide a practical tool for logistics service providers that seek to make use of the European standard EN 16258 “Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services”, in order to determine their environmental footprint and seek ways to reduce it [15]. The readers can calculate the energy consumption and GHG emissions in compliance with sample calculations by applying standard values. The energy consumption of the lorries, trains, ships, aircraft as well as buildings, warehouses and handling are involved in this guide.

The contribution of this guide is providing clear methods to calculate the energy consumption and the GHG emissions with taking into consideration of logistical parameters and diverse transport modes. The corresponding equations and WTW standard values are provided in accordance with the EN 16258. The role of these standard values is to transfer different units of energy consumption and GHG emissions into standardized unit megajoule (MJ) and CO_2 equivalent kilogram (kg). Accordingly, this guide supports the freight forwarding and logistics services to analyze their own cases from environmental dimension easily and efficiently.

Nonetheless, there are several limitations for urban logistic stakeholders to follow this guide. In comparison to the former tools, this guide has paid no attention to the time factor, such as driving cycles or planned service years. The total energy consumption and GHG emissions are calculated by actual transport distance, consignment weight, specific energy consumption, and corresponding conversion factors exclusive of the time factor. Furthermore, if conditions are such that the logistics service providers seek a sustainable development in accordance with this guide, the economic and social dimensions are essential to be involved. In addition, the alternative fuels, which has the capability of saving energy and reducing emissions, should be considered for the purpose of the sustainable development.

2.2.2 Straßengüterverkehr Berechnung und Allokation

Straßengüterverkehr Berechnung und Allokation (SBuA) is one module of a tool called CO_2-Methodenbaukasten developed by Institut für Transportlogistik at the Technical University of Dortmund. The objective of this tool is to help small and medium-sized logistic enterprises with balancing their energy consumption, carbon dioxide emissions as well as GHG emissions [16]. This module focuses on the commercial vehicles of using conventional diesel, biodiesel, biodiesel 4%, 5%, 6%, and 7% blend. The energy consumption, CO_2 emissions, and CO_2 equivalent emissions from Tank to Wheel (TTW) and WTW are calculated by inputting the goods types, vehicle types, fuel types, gradient, running road, actual transported weight, and actual traveled distance. The methods of calculation and the standard values are applied in compliance with the guide introduced in the last section.

There are two advantages in this module for supporting our work. First of all, this module involves logistical parameters, such as goods types, transported weight, and traveled distance, to estimate the energy consumption and CO_2 equivalent emissions. Additionally, this module takes into account the calculations of TTW and WTW. It contributes to the logistic enterprises numerically and comprehensively understanding their transport operations from the environmental point of view.

However, several limitations render this module unsatisfied with our research objective. Firstly, this module only examines the environmental parameters. The differences of the expenditure are unclear from the economic point of view. In addition, the social dimension is lacking for selecting appropriate types of ECVs in sustainable UFT. Secondly, the vehicle types and the fuel types are fewer in number than the AFLEET Tool. Finally, this module has paid no attention to the time factor.

2.2.3 EcoTransIT

EcoTransIT World is an abbreviation of Ecological Transport Information Tool – Worldwide. It is free of charge internet application, which shows the environmental impact of freight transport for any route in the world and any transport mode [17]. This application aims to support the forwarding companies, carriers, logistic providers, political decision makers, consumers and non-governmental organizations. The purpose is to assist them calculating the corresponding environmental parameters and comparing them thoroughly from logistic concepts including all transport modes. This application provides two input modes. The standard input mode allows users estimating the energy consumption and GHG emissions quickly and efficiently. The extended input mode provides users some options to adapt their own cases with standardized units, such as changing the goods types, running routes, transport modes, vehicle types, emission standards, load factors, and empty trip factors.

This application transformed the standard EN 16258 into an effective tool. The diverse transport modes and multiple logistical parameters assist the corresponding stakeholders calculating and comparing their own cases. Nevertheless, same as the limitations of the guide in section 2.2.1, this application has paid no attention to the time factor and has only estimated the conventional commercial vehicles from the environmental point of view. Table 1 illustrates a summary of purposes, advantages, and limitations of the existing models.

3 A Concept for Selecting Appropriate Alternatives

On the basis of reviewing the purposes, advantages, and limitations of existing models, we observe that the models, which focus on estimating the economic and environmental performance from the vehicles' point of view, have taken into account the time factor, such as planned services years, drive cycles, and future markets. Moreover, these models involve a wide range of alternatives for users to do the comparison and selection. On the contrary, the models, which concentrate on estimating the environmental performance from the logistical point of view, have taken into consideration of logistical parameters, such as goods types, transported weight, and traveled distance. Nevertheless, there are few alternatives of vehicle and fuel types provided to the users. Furthermore, we notice that none of these models paid attention to the social dimension. Therefore, we conclude that few models can support the estimates of economic, environmental, and social performance of multiple alternatives with considering the time

Table 1: Purposes, advantages, and limitations of existing models

Models	Purposes	Advantages	Limitations
AFLEET	To estimate and compare multiple vehicle types and fuel types from economic and environmental perspectives for clean cities stakeholders	Wide range of alternatives Time-dependent Relatively full database WTW	No logistical parameters No social dimension
HTBAMS	To estimate energy, environmental, and economic benefits for heavy trucks	Drive cycles Future market WTW	Few alternatives No logistical parameters No social dimension
ADVISOR	To provide the vehicle engineering community an analysis package for advanced vehicle modeling	Drive cycles Wide range of alternatives	No logistical parameters No social dimension No economic dimension
CLECAT (guide)	To provide a practical tool for logistics service providers to determine their environmental footprint and seek ways to reduce it	Easy and clear methods Logistical parameters Diverse transport modes WTW	No time factor No economic dimension No social dimension Few alternatives
SBuA	To help small-and medium-sized logistic enterprises balancing their environmental parameters	Logistical parameters WTW	No economic dimension No social dimension Few alternatives No time factor
EcoTransIT	To assist freight transport stakeholders calculating environmental parameters and comparing them from logistic concepts including all transport modes	Logistical parameters Diverse transport modes WTW	No time factor No economic dimension No social dimension No alternative fuel vehicles

factor and logistical parameters. In this section, we propose a concept to fill this gap by extending the existing models with taking into account their advantages and limitations. The goal of this concept is to numerically support the urban logistic stakeholders to select appropriate types for achieving sustainable UFT.

3.1 Framework of the Concept

We define that the four types of ECVs are a set of vehicle types V (Eq.(1)). The five markets of UFT are a set of markets M (Eq.(2)). The set of alternatives A is derived from the Cartesian product of the set of vehicle types and the set of markets (Eq.(3)). The three sustainable dimensions are a set of criteria C (Eq.(4)) for comparing the alternatives.

$$V = \{\text{BEVs, HEVs, PHEVs, FCEVs}\} \tag{1}$$

$$M = \{\text{Retail, Express/Post, HoReCa, Construction, Waste}\} \tag{2}$$

$$A = V \times M = \{(v, m) | v \in V, m \in M\} \tag{3}$$

$$C = \{\text{Economic, Environmental, Social}\} \tag{4}$$

We propose the concept in accordance with the theory of Multi-Criteria Decision Making (MCDM). MCDM is a branch of a general class of operations research models which deal with decision problems under the presence of a number of decision criteria [18]. In this paper, we assume that decision makers are urban logistic stakeholders. The decision problem is which type of ECVs is applicable for decision makers' fleets. The decision criteria are the sustainable dimensions. The decision matrix is illustrated as follows:

Table 2: Decision matrix

Alternatives	Criteria			Results
	C_{eco} (w_1)	C_{env} (w_2)	C_{soc} (w_3)	
A_1	a_{11}	a_{12}	a_{13}	$r(A_1) = \sum_{j=1}^{3} w_j \cdot a_{1j}$
A_2	a_{21}	a_{22}	a_{23}	$r(A_2) = \sum_{j=1}^{3} w_j \cdot a_{2j}$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
A_m	a_{m1}	a_{m2}	a_{m3}	$r(A_m) = \sum_{j=1}^{3} w_j \cdot a_{mj}$

where $A_m \in A$, $m = 20$, $C_{eco} \in C$ is economic criteria , $C_{env} \in C$ is environmental criteria, $C_{soc} \in C$ is social criteria , w_1 is the weight of economic criteria, w_2 is the weight of environmental criteria, w_3 is the weight of social criteria, a_{m1} is the performance of A_m when it is evaluated in terms of decision criterion C_{eco}, a_{m2} is the performance of A_m when it is evaluated in terms of decision criterion C_{env}, a_{m3} is the performance of A_m when it is evaluated in terms of decision criterion C_{soc}, and $r(A_m)$ is the score of A_m. The decision makers determine the ranking of alternatives depending on the scores.

The performance of alternatives with respect to three decision criteria needs to meet the requirements of our proposed concept. It implies that they need to involve the time factor and the logistical parameters. There are several MSDM methods, such as the weighted sum model, the analytic hierarchy process, and the elimination and choice translating reality method. Nevertheless, the numerical measures of these methods for quantifying the performance of alternatives with respect to the criteria cannot involve the time factor and the logistical parameters. Thus, we propose three mathematical expressions to quantify the performance of alternatives by taking into account the time factor and the logistical parameters.

In addition, we process the calculated values of mathematical expressions to determine a ranking of each alternative. Due to the fact that it is difficult to decide the best option directly from the calculated values with respective units, we normalize the calculated values in each column of the matrix to add up to 1. Furthermore, the equations of calculating scores in table 2 is applied in this paper.

The framework of the proposed concept is illustrated in Fig.1. First of all, the decision maker needs to identify the alternatives that they intend to estimate and compare from the set A. According to the identified alternatives, a set of corresponding data can be selected by searching in the database. The database consists of parameters of mathematical expressions and their values are collected by published reports, articles, and databases. If the decision maker has their own data, they can also modify the values or enter new values into the database. Then, the set of data is inputted into the mathematical expressions. In order to confirm the accuracy of the results, we validate the expressions. If the conclusion is not accurate, the procedure will move back to select a new set of data. If the conclusion is accurate, the procedure will move on to calculate the performance of alternatives for each criterion. Filling the calculated results into the decision matrix, the scores of each alternative with respect to three criteria can be calculated. The ranking is derived from the scores. In addition, it is possible to visualize the performance of alternatives to illustrate visible results to help with the decision. In this paper, we concentrate on proposing the concept and the mathematical expressions as well as testing the feasibility of the proposed concept by a case study.

3.2 Mathematical Expressions

The mathematical expressions proposed in this section have following characteristics:

- estimating the economic, environmental, and social parameters
- being adapted to a specific alternative
- time-dependent
- involving automotive and logistical parameters

In addition, we assume that only one commercial vehicle is considered in the calculation of each alternative.

3.2.1 Economic Mathematical Expression

We use the total cost of ownership as the economic parameter to estimate the expenditure of alternatives over the planned service years. The mathematical expression is formulated by referring to the paper

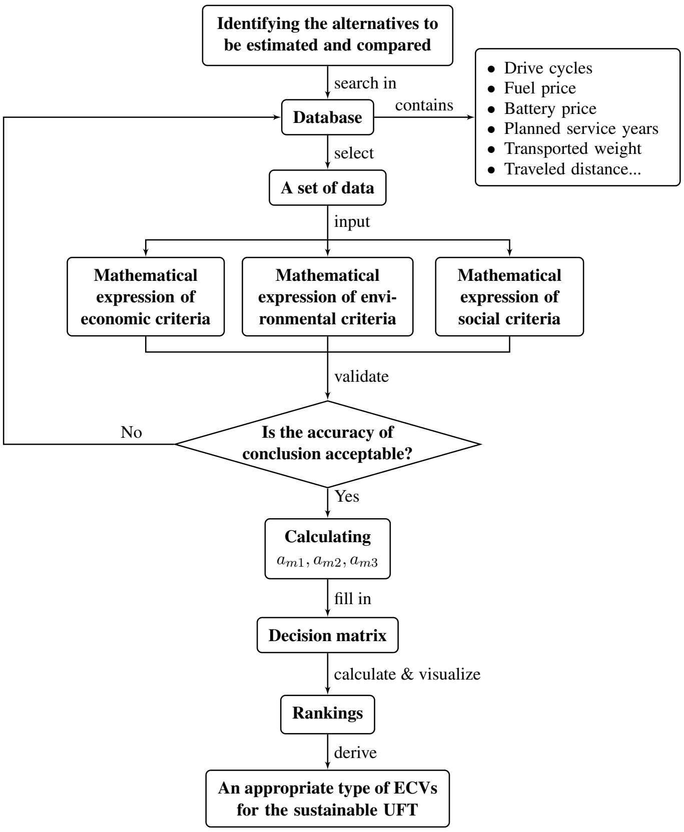

Figure 1: Framework of the proposed concept

[19] and the AFLEET Tool. The TCO in this paper includes the depreciation cost, the subsidies, the battery replacement cost, the fuel cost, as well as the maintenance and repair cost. The insurance cost, as well as the license and registration cost, are not involved, due to the fact that there is no difference between conventional vehicles and electric vehicles in this regard [8]. Moreover, we assume that a new commercial vehicle will be purchased without loans. Thus, the financing cost, which is calculated by vehicle interest payment in the event that there is a loan for purchasing a new vehicle, is excluded from this expression. Additionally, we estimate the present value of TCO. The economic mathematical expression is formulated as follows:

$$\begin{aligned} C_{tot,i,j}(N) = & C_{dep,j}(N) - b \cdot c_S + b \cdot R(N) \cdot c_B \cdot (1 + r_{dis})^{-N} \\ & + \sum_{n=1}^{N} d(n) \cdot (1 + r_{dis})^{-n} \cdot (w(n) \cdot C_{i,j}(n) + C_{M,j}) \end{aligned} \tag{5}$$

where

I = set of markets in UFT, $i \in \{$Retail, Express/Post, HoReCa, Construction, Waste$\}$
J = set of vehicle types, $j \in \{$Diesel, BEVs, HEVs, PHEVs, FCEVs$\}$
n = planned service years, $n \in [1, 2, ..., N]$
$C_{tot,i,j}(N)$ = total cost of vehicle type j operating in market i N years
$C_{dep,j}(N)$ = depreciation cost of vehicle type j in year N
b = whether the commercial vehicle is the BEV or the PHEV (0 or 1)
c_S = subsidies for purchasing a new vehicle
$R(N)$ = whether the battery is replaced in year N (0 or 1)
c_B = battery price
r_{dis} = discount rate
$d(n)$ = annual traveled distance in year n
$w(n)$ = annual transported weight in year n
$C_{i,j}(n)$ = fuel cost of vehicle type j per ton$\cdot$ km in market i in year n

$C_{M,j}$ = maintenance cost of vehicle type j

The depreciation cost is calculated by Eq.(6). It is associated with the purchase price and the resale value of vehicle type j. We assume that the commercial vehicle is purchased before the first planned service year.

$$C_{dep,j}(N) = C_{P,j} \cdot [1 - (1 - r_{dep})^N (1 + r_{dis})^{-N}] \tag{6}$$

where

$C_{P,j}$ = purchase price of vehicle type j
r_{dep} = depreciation rate

Moreover, the fuel cost is the expenditure of using energy for operating the commercial vehicles. In order to integrate the time factor and the logistical parameters into the mathematical expression, we apply a specific fuel price with the unit €/tkm (Eq.(9)). It is the product of the fuel economy per tkm (Eq.(8)) and the fuel price in year n (Eq.(7)). Additionally, the fuel economy can be calculated on the basis of estimating the required energy including aerodynamic drag, rolling resistance, acceleration, and gravitational potential energy by using drive cycles. The drive cycles represent the characteristics of each market in UFT. Furthermore, the fuel economy per tkm can be estimated depending on the payload capacity and the capacity utilization. In conclusion, we propose to use the fuel economy per tkm and the fuel price per tkm to connect the automotive parameters to the logistical parameters with taking into consideration the time factor.

$$c_j(n) = c_j(1) \cdot (1 + r_j)^{n-1} \tag{7}$$

$$P_{T,i,j} = \frac{P_{i,j}}{\overline{W_{p,j}} \cdot \eta_c} \tag{8}$$

$$C_{i,j}(n) = P_{T,i,j} \cdot c_j(n) \tag{9}$$

where

$c_j(n)$ = fuel price of vehicle type j in year n
r_j = fuel price inflation rate of fuel type in vehicle type j
$P_{T,i,j}$ = fuel economy per tkm of vehicle type j for market i
$P_{i,j}$ = fuel economy of vehicle type j for market i
$\overline{W_{p,j}}$ = payload capacity of vehicle type j
η_c = capacity utilization

The subsidy is an economic incentive to purchase electric vehicles from governments. There are commonly two categories. The first category is vehicle-based [20]. It means that the credit amount depends on the all-electric driving range and it is constant for one vehicle. The second category is battery energy based. The credit amount primarily depends on the traction battery capacity ($\geq$ 5 kWh) as well as the source of energy to recharge the battery [21]. Accordingly, BEVs and PHEVs have the capability of obtaining the subsidies.

The battery replacement cost is the expenditure of exchanging the on-board battery. The replacement is associated with the battery life. If conditions are such that the relative battery capacity is less than 80%, the on-board battery should be replaced with a new one. The calendar life, the cycle life, and the mileage life are three ways to describe the battery life [22]. The cycle life refers to the process of discharging and recharging batteries [22]. For instance, a battery with a 3,000 cycle life would last the average driver about 8.2 years (calendar life) if it were fully cycled once each day [22]. The mileage life is described in accordance with the travel distance. For instance, the mileage life of BEVs is about 150,000 miles (241,401 km), whereas the HEVs have the mileage life as high as 250,000 miles (402,336 km) [22]. Due to the fact that the battery system of HEVs cannot be removed, the battery replacement cost is only valid for the BEVs and PHEVs.

The maintenance and repair cost is a constant parameter in the Eq.(5). It represents the expenditure of maintaining and repairing the commercial vehicles per kilometer. Despite the fact that this cost increases with the vehicle age, we assume it to be a constant in this paper.

3.2.2 Environmental Mathematical Expression

We use the total energy consumption and total GHG emissions from well to wheel as the environmental parameters to estimate the alternatives over the planned service years. The total energy consumption is a cumulative environmental parameter. It is the sum of annual energy consumption. At the end of each year, an annual energy consumption is calculated according to the annual transported weight, the annual traveled distance, and the fuel economy per tkm (Eq.(10)). The role of the energy conversion factor from well to wheel is to standardize the unit because of the diverse vehicle types and their energy unit.

$$E_{WTW,i,j}(N) = \sum_{n=1}^{N} w(n) \cdot d(n) \cdot P_{T,i,j} \cdot f_e \tag{10}$$

where

$E_{WTW,i,j}(N)$ = total energy consumption of vehicle type j for market i in N years
f_e = WTW energy conversion factor

Likewise, the total greenhouse gas emissions is a cumulative environmental parameter. Its expression is similar to the expression of total energy consumption. The difference is the conversion factor. This expression applies the factor for converting GHG emissions from well to wheel. The standardized emission unit is the kilogram. The greenhouse gas emissions consist of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) [15][23]. Nevertheless, the CO_2 is often regarded as GHG emissions, since it has the most extensive effects compared to the other two emissions. Thus, this conversion factor applies the concept of CO_2 equivalents to represent the total GHGs including all three emissions.

$$G_{WTW,i,j}(N) = \sum_{n=1}^{N} w(n) \cdot d(n) \cdot P_{T,i,j} \cdot f_g \tag{11}$$

where

$G_{WTW,i,j}(N)$ = total GHG emissions of vehicle type j for market i in N years
f_g = WTW CO_2 equivalents conversion factor

3.2.3 Social Mathematical Expression

A measurable parameter called actual transport capacity is proposed in our paper for the purpose of quantifying the social dimension and estimating alternatives. Equity, human health, education, community, accessibility, and public participation are commonly involved in the social dimension. We select the accessibility as the basic of the measurable parameter. The accessibility refers to people's ability to reach desired goods, services, activities and destinations [5]. In our research, we define the accessibility is goods' ability to reach required services and destinations. The commercial vehicles are the means to accomplish this ability. Nevertheless, the on-board energy capacity and the payload capacity of commercial vehicles are fixed. It not only limits the quantity of transported goods per times per vehicle, but also extends the total traveled distance per day. Accordingly, we propose the actual transport capacity to present the actual ability to deliver goods per times per vehicle by employing different alternatives.

We use the actual transport capacity, which is calculated by on-board energy capacity and the fuel economy per tkm, as the social parameter to estimate alternatives (Eq.(12)). The on-board energy capacity indicates that the amount of energy stored in the vehicles, such as the amount of fuel or the amount of battery capacity. The fuel economy per tkm reveals the actual fuel consuming for transporting a certain weight in a certain travel distance.

$$E_{T,i,j} = \frac{\overline{E}_j}{P_{T,i,j}} \tag{12}$$

where

$E_{T,i,j}$ = actual transport capacity of vehicle type j in market i
$\overline{E}_j$ = on-board energy capacity of vehicle type j

4 Case Study

We collected a set of sample data (Table 3) to test and simulate the feasibility of the proposed concept in MATLAB. The express/post is the selected market in this case study. We applied a drive cycle of express/post market in the simulation [24]. The diesel, the battery electric, and the hybrid electric delivery step van are optional vehicle types. We assume that drivers follow the velocity of driving cycle to drive the commercial vehicles. In addition, batteries are charged once a day in depots. The planned service years are 10 years.

Table 3: Values of parameters [10] [15] [22] [21]

Parameters	Unit	Diesel	BEVs	HEVs
Purchase price	€	61100	141000	98700
Fuel price	€/l or €/kWh	1.13	0.119	1.13
Subsidy	€/kWh	-	392	-
Battery price	€/kWh	-	376	-
Discount rate	%	6	6	6
Depreciation rate	%	15	15	15
Fuel price inflation rate	%	2.6	2.7	2.6
Maintenance cost	€/km	0.3041	0.2103	0.239
Annual traveled distance	km	26554	26554	26554
Annual transported weight	t	471.64	471.64	471.64
Energy conversion factor	MJ/l	42.7	42.7	42.7
GHGs conversion factor	kg/l	3.24	3.24	3.24
On-board energy capacity	l or kWh	113.562	80	113.562
Transported weight per day	kg	1814	1814	1814

Table 4 shows the test results of four alternatives. The first two alternatives are diesel delivery step vans operating in the express/post market. The difference between these two alternatives is the engine efficiency. The first alternative is powered by 46% engine efficiency [12], whereas the engine efficiency of the second alternative is 5% lower than the first one. The rest of test values are constant.

If the decision maker considers the economic dimension as the most important criteria for selecting vehicles ($w_1 = 1, w_2 = w3 = 0$), the diesel delivery step van with 46% engine efficiency (A_1) is the appropriate type since its TCO is the lowest value in four alternatives. If the decision maker considers the environmental dimension as the most important criteria for selecting vehicles ($w_2 = 1, w_1 = w3 = 0$), the battery electric delivery step van (A_3) is the appropriate type since its total energy consumption and total GHG emissions are the lowest value in four alternatives. If the decision maker considers the social dimension as the most important criteria for selecting vehicles ($w_3 = 1, w_1 = w2 = 0$), the hybrid electric delivery step van (A_4) is the appropriate type since its actual transport capacity is the highest value in four alternatives. Therefore, there is no dominant alternative among A_1, A_3, and A_4 since the weight of criteria is uncertain. Moreover, we noticed that the A_2 can be excluded from the optional list, due to the fact that the A_2 has no advantage over the other three alternatives.

Table 4: Test results

Alternatives	Criteria			
	C_{eco} (€)	$C_{env,e}$ (MJ)	$C_{env,g}$ (t)	C_{soc} (tkm)
A_1 (diesel 46% + express/post)	1.7137×10^5	2.6288×10^6	199.4723	888.5225
A_2 (diesel 41% + express/post)	1.7831×10^5	2.9494×10^6	223.7982	791.944
A_3 (BEVs + express/post)	2.0648×10^5	1.2557×10^6	95.2775	131.4085
A_4 (HEVs + express/post)	1.8524×10^5	2.2934×10^6	174.0166	1.0185×10^3

5 Conclusion

By reviewing several existing models, the first contribution of this paper is the identification that few models can estimate the economic, environmental, and social performance of multiple alternatives with considering the time factor and logistical parameters. Accordingly, we propose a concept to fill this gap by extending the existing models with taking into account their advantages and limitations. The goal of this concept is to numerically support the urban logistic stakeholders to select an appropriate type for achieving sustainable UFT. We formulated three mathematical expressions to meet the requirements of the proposed concept. The test results show that the proposed concept is feasible to compare the multiple alternatives by estimating the economic, environmental, and social performance. In addition, it is possible to derive a dominant alternative by determining the weight of criteria.

Future research can concentrate on specifying the mathematical expressions and extending the database for adapting to the various requirements of decision makers. Furthermore, the proposed concept can be connected to the Internet of Things and Industry 4.0 by collecting real-time data of drive cycles. Not only urban logistic stakeholders but also automobile manufacturers can benefit from this connection.

Acknowledgments

The authors would like to acknowledge the support of China Scholarship Council (CSC) and International Graduate School for Dynamics in Logistics (IGS) at the University of Bremen.

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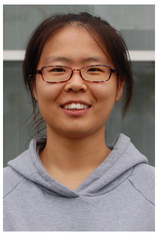

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