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EXHAUST EMISSION ESTIMATION IN FREIGHT TRANSPORT SYSTEMS

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Abstract

Modelling of transport systems is a complex issue requiring taking into account many factors that allow for the mapping of the real system and thus allowing decision support. In the era of increasingly higher requirements for services, transport also faces the challenges of sustainable development. Therefore, it is necessary to conduct research both in the sphere of technical and organizational solutions aimed at limiting pollutant emissions. Mapping in the model the negative impact of transport on the environment allows for planning the implementation of the transport service taking into account the pro-ecological criterion. This is particularly important in urban areas where traffic and especially heavy goods vehicles are particularly onerous for inhabitants and require limiting transport work in the city area and the use of environmentally friendly rolling stock. The aim of the article is to present the considerations regarding the modelling of transport systems including pollutant emissions. The article introduces the problem of cargo distribution and a review of the models of estimation of pollution emission in the micro and macro scale was carried out. Next, a mathematical model was proposed which is a variant of the Vehicle Routing Problem of the so-called Green VRP. In the distribution model was used COPERT methodology for estimation of harmful substance emission. In article examples of calculations carried out on the example of the city of Warsaw for the organization of cargo distribution due to the CO emission criterion was presented. The article ended with a short synthesis of the work carried out.

Keywords: *transport, freight transport, modelling, emission estimation, COPERT, Green VRP*

1. Introduction

Modern transport management is important in the field of cargo distribution and should be to combine and manage a single, controllable whole logistics activity of all business entities operating in the serviced area. At the same time, this management should be carried out in a manner that ensures the desired level of service quality while minimizing total costs, including the costs of environmental pollution. Undoubtedly, logistics services depending on the area of operation are characterized by various problems. In this context, the most complex issue is the service of urban agglomerations, due to:

- high population density, i.e. a wide spectrum of consumers,
- a high density of buildings,
- overloading the road network and the poor condition of city roads,
- spatial discrepancies between the place of residence and employment,
- restrictions in the development of transport infrastructure and high prices for underground construction solutions,
- environmental protection (emission of pollutants and noise).

Jacyna and Merkisz [9] indicated the functioning of the distribution system is connected with its negative impact on the environment. It is mainly manifested by the emission of exhaust gases into the atmosphere and excessive noise. This has particular consequences in urban areas due to the high traffic volume and the negative impact on the health of inhabitants (Krzyżanowski, Kuna-Dibbert and Schneider [16]). Issues related to the impact of transport emissions on the environment are taken, among others, in the works: Dablanc [4], Figliozzi [8], Jacyna et al. [10], Lewczuk et al. [17].

Due to a number of test results stating that the emission of harmful substances, noise emission, vibrations and congestions have a negative impact on public health it is necessary to take measures to improve the quality of air in cities, reducing vehicle traffic and thus emission of harmful substances emitted by means of transport. However, this involves the need to develop methods for assessing applied solutions, and thus requires models that allow estimating the impact of transport on the environment.

This article presents the problems of cargo distribution planning. Selected models for estimation of pollutant emissions from means of transport were characterized, as well as an optimization problem based on the VRP problem with the implemented COPERT model. Based on the results obtained as part of experimental work the main conclusions were presented.

2. Cargo distribution planning

Cargo distribution planning requires the use of appropriate methods and tools to support the decision-making process. Among these methods, the main role is taken by mathematical modelling, which allows for the mapping of the problem and the boundary conditions and assumptions underlying it.

Distribution of loads is a characteristic problem that fits with the vehicle routing problems (VRP). It includes planning transport routes and scheduling orders. The VRP issue is a development of the Traveling Salesman problem (TSP). In TSP, one vehicle visits all points in a given area exactly once, minimizing, for example, the length of the route, its duration, or cost. Many variations have emerged since the introduction of the VRP problem, but also the methods of solving it. Individual problems differ in assumptions and considered constraints and criteria functions. General formulation of VRP issues presented by Toth, Vigo [24] defined as CVRP, takes into account the limitation on the vehicle's capacity. The formulation of this problem is as follows.

Data:

- $G = (W, L)$ – the structure of the transport network as a directed graph,

- $W=\{0,1,...,n\}$ – a set of vertices of the graph, with each vertex $j \in W\setminus\{0\}$ has a client's interpretation with a defined demand $d_j > 0$, vertex $j=0$ is the object sending the load, e.g. a warehouse,
- $L=\{(i,j):\, i,j\in W,\ i\neq j\}$ – a set of graph arcs, each arc being described with the cost of a transition c_{ij},
- subset S, where $S\subseteq W\setminus\{0\}$, the sum of the demand $d(S)=\sum_{j\in S} d_j$,
- a set of identical vehicles K with the same capacity C, which is connected with the minimum number of vehicles needed to carry out the task $K_{\min}=\left\lceil \frac{d(W\setminus\{0\})}{C}\right\rceil$, and the minimum number of vehicles $\gamma(S)=\left\lceil \frac{d(S)}{C}\right\rceil$ to serve clients in a subset S.

Decsion variables $X=\left[x_{ij}:\ \ x_{ij}\in\{0,1\}\right];\ \ x_{ij}=\begin{cases}1 & \text{while } (i,j)\in L \text{ is in the route,}\\ 0 & \text{otherwise,}\end{cases}$ which should be designated in such a way that the **criterion function** with interpretation of the cost of transport implementation assumes **minimum** values:

$$F(X)=\sum_{i\in W}\sum_{j\in W} c_{ij}x_{ij} \quad\longrightarrow \min \tag{1}$$

and meet constraints:

$$\sum_{i\in W} x_{ij}=1, \qquad \forall j\in W\setminus\{0\}, \tag{2}$$

$$\sum_{j\in W} x_{ij}=1, \qquad \forall i\in W\setminus\{0\}, \tag{3}$$

$$\sum_{i\in W} x_{i0}=K, \tag{4}$$

$$\sum_{j\in W} x_{0j}=K, \tag{5}$$

$$\sum_{i\notin S}\sum_{j\in S} x_{ij}\geq \gamma(S), \qquad \forall S\subseteq W\setminus\{0\},\ S\neq\phi, \tag{6}$$

$$d_j\leq \mathrm{C}, \quad \forall j\in W\setminus\{0\}, \tag{7}$$

where (2.2 and 2.3) means that each vertex has exactly one predecessor and accordingly one successor, (2.4 and 2.5) says that exactly the same goes from node 0 (e.g. warehouse) and the same amount is returned, (2.6) means that the S subset of clients to visit is visited by the number of vehicles not less than the minimum number of vehicles needed to service, (2.7) determines that the demand of a single customer cannot be greater than the vehicle's capacity.

The minimum number of vehicles $K_{\min}$ and the number of vehicles K needed for customer service is related to the assumption about the use of vehicle capacity. Determining the value K is connected to the solution of the problem BPP (bin packing problem), which, like VRP, is an NP-difficult issue [2]. The inclusion of this problem allowed for the determination of value $\gamma(S)$, and thus assuming that the payload of the vehicle does not have to be fully utilized. Description of the problem and its application can be found for example in Cornuejols, Harche [3].

There are many modifications of VRP but particularly important, which corresponds to the content of this article is GVRP (Green VRP). A relatively new group in the VRP family, which assumption is to include ecological criteria in the planning of deliveries. There is a large variety of models for estimating pollutant emissions (e.g. COPERT or CMEM) taking into account fuel consumption or harmful emissions depending on various vehicle parameters and routes. There is also a large diversity in VRP assumptions, from CVRP (taking into account capacity) by VRPTW (problem with time windows), SVRP (stochastic VRP) or MOVRP (multicriteria). The inclusion of many criteria is of particular importance when looking for a compromise between the vehicles used and the costs incurred. One-criterion problems are often based on the minimization of fuel consumption and the same cost associated with it. It may also be considered to use electric vehicles with the planning of battery charging operations [6].

The considerations related to Green VRP, taking into account the multi-objective function of the goal, are presented, for example, in Molina et al [19], they formulated criterion functions include the cost of the task (minimizing), CO2 emissions (minimizing), emissions of NOx (minimizing). However, as other assumptions was taken:

- the transport fleet is heterogeneous with different payload, type and type of fuel,
- the number of vehicles is unlimited,
- vehicles start routes and end at the same point,
- time windows of customers are taken into account,
- customer demand must be met,
- customer demand cannot exceed the vehicle's capacity,
- each customer is visited only once,
- each route has a time limit due to the permissible working time of the driver of a given type of vehicle.

3. Estimation of harmful substances emission

In most cases, the emission of pollutants is connected with the emission of harmful substances. It should be noted, that the term pollution could also be understood as noise, light or other substances such as, for example, the remains of the tires or linings of brake pads. For various pollutants, models for estimating a given phenomenon are developed, but this applies mainly to emissions of harmful substances and noise [12, 14]. This article focuses on the emission of harmful substances.

The development of a model for emission estimation requires testing of real transport means and measurement of selected harmful substances emissions in various conditions. The most accurate models are those that were based on vehicle emissions tests during real road operation conditions. Most models are developed, based on laboratory tests, which may differ significantly from true emission values. Detailed models allow for accurate estimation of emissions from a single vehicle and require very accurate data on its travel (driving time phases, speed values, accelerations, ambient temperature, engine, etc.), not to mention the exact parameters of the vehicle. However, such models are very difficult to use on a large scale; therefore, there are some simplifications that allow estimating emissions, for example for a whole group of vehicles and many trips, while averaging certain driving parameters. The degree of simplification may vary depending on the accuracy of what is desired and the nature of the research being carried out. Three types of models emerge from the above [6]. Microscale model (very high accuracy per unit of time, requires many input data), a model on a macro scale (accuracy to a group of vehicles or a given region over a longer period). The third type of models is the so-called Indicator based on the simplest data (e.g. dmc and type of fuel) and distance travelled.

Based on the review work [6], the main representatives from each type of pollutant emission assessment model can be specified. It should be emphasized that only those selected from these models are so advanced that they allow estimation of emissions of various harmful substances.

Some of them are limited to estimating fuel consumption and related CO2 emissions.

Microscale models allow for accurate estimation of fuel consumption and/or emission of pollutants, but require many detailed data regarding working conditions and variables regarding the course of the journey. However, they allow you to provide consumption and emissions at a selected time. Micromodels include, for example, CMEM, VT-CPFM or PERE.

CMEM [23] is a model developed for delivery vehicles and small trucks under normal working conditions. It was developed to estimate fuel consumption and a wide range of harmful compounds including (CO, HC, NOx), taking into account the cold start for various vehicles and technologies. The model allows to predicting second-by-second tailpipe (and engine-out) emissions and fuel consumption.

VT-CPFM [22], basically, these are two models for estimating fuel consumption. However, it also allows the estimation of CO2 emissions (which in fact results directly from fuel consumption). The first model does not require any engine operating parameters, and the fuel consumption is estimated on the basis of acceleration and speed. In turn, the second more detailed model requires additional data (e.g. rotational speeds for gear changes). The first model may apply to models of traffic flow distribution and estimation of fuel consumption, but it does not take into account e.g. the aspects of gear changes and the impact on fuel consumption as opposed to the 2nd model.

PERE [20], a micro model developed as a support for the MOVES model (macro scale model). This model is treated as a supplement to the shortcomings of the MOVES model, but also it extends its capabilities with additional fuels. The use of this model allows modelling fuel consumption from conventional vehicles, but also hybrids and with fuel cells.

The second group of models are macroscopic models. They allow the estimation of fuel consumption or pollutant emissions for the entire modelled object, e.g. Intersections, distribution system, mass transport system in the city, etc. It is possible to conduct research on a larger scale and observe the impact of the transport system, but at the expense of accuracy (relative to reality, as well as microscopic models). Among the main models of this type, for example, COPERT, HBEFA, MOVES or EMITRANSYS can be mentioned.

COPERT [21] is software for estimating emissions, but also the methodology of its estimation, developed under the supervision of the EEA (European Environment Agency). This is the 5th version of the model (COPERT v5), which currently allows estimating emissions and fuel consumption for various types of drives (including hybrid vehicles or energy consumption for electric vehicles) on three levels of detail. General estimation is based on the distance and structure of vehicles to hot/cold emission and traffic conditions.

HBEFA [15] it is a set of emission indicators for car transport in Europe. The latest version 3.3 of 2017 takes into account a number of parameters, including traffic situations and hot / cold emission, for the majority of available vehicles. In addition, these indicators allow estimating fuel consumption.

MOVES [7] was developed on the basis of the MOBILE model by EPA (Environment Protection Agency). This model is used to estimate pollutant emissions and is functionally similar to the COPERT model. It allows you to evaluate the total emissions of road transport including wide range of user-defined conditions.

EMITRANSYS [11, 1] model was developed by the Faculty of Transport of Warsaw University of Technology and Faculty of Machines and Transportation of Poznan University of Technology. It is a methodology of shaping the transport system based on the study of the difference between emission specified for vehicles in laboratory conditions for the needs of certification and measurements in real conditions. On this basis, the authors determined the coefficient for each of harmful compound is defined as follows:

$$k_s = \frac{E_{rz,s}}{E_{N,s}} \tag{8}$$

where:
s – harmful compound, for which emission factor was specified,
$E_{rz,s}$ – pollution emissions obtained in real conditions [g/km] for s-th compound,
$E_{N,s}$ – pollution emissions according to exhaust emissions standards [g/km].

This factor allows the determination of appropriate emission factors for LGV vehicles, the emission of which is evident in grams per kilometre [g / km] and HGV for which emission standards are defined in grams per kilowatt-hour [g / (kWh)]. However, it takes different values for different conditions [11].

In addition, the above-mentioned models there are also a number of other solutions that can be used on a larger or smaller scale. These are also typically indicative solutions such as those found in DEFRA for calculating GHG emission [5]. It should be emphasized that studies on the impact of transport on the environment do not only concern the value of pollutant emissions or fuel consumption. Intensive work on modelling dispersion of pollutants is also carried out [13, 18], or noise emission to the environment [12, 14].

4. Mathematical model of the distribution system including pollutant emissions

For the purpose of the conducted research, a mathematical model of the VRP problem with the pollutant emission criterion was developed. The model is a single-criterion; however, for the purpose of the calculation example an additional assessment indicator (not being a criterion function) is presented about the interpretation of the time of distribution. The purpose of developing the model was to adopt data to a certain extent analogous to the classical problem and expanded by assumptions regarding the emission of pollutants. This model is called GVRP. The following input data has been assumed (the model elements are shown schematically in Fig. 1):

– $G=(W,L)$ – the structure of the transport network as a directed graph,
– $W=\{0,1,...,n\}$ a set of vertices of the graph, with each vertex $j\in W\setminus\{0\}$ has a client's interpretation with a defined demand $p_j>0$, vertex $j=0$ is the object sending the load,
– r – route number (run) and belongs to the set R routes run, and the size of this set is less than or equal to the number of customers and greater than or equal to the integer value of the demand divided by the highest load capacity of the vehicle: $|W|-1\geq|R|\geq\left\lceil\frac{\sum_{j\in W}p_j}{\max_{s\in S}\{q(s)\}}\right\rceil$,
– s – vehicle number belonging to the vehicle set S, each vehicle is characterized by a capacity q(s) and category sc_kat(s),
– $L=\{(i,j): i,j\in W,\ i\neq j\}$ – a set of graph arcs, each arc being described as a transition time depending on the type of vehicle $t_{ij}(s)$, and length l_{ij},
– $H(r)=\{j:\ j\in W, r\in R\}$ – a set of vertices visited during r-th run.

Decision variables are as follows:

– $X=\left[x_{ij}(r):\quad x_{ij}(r)\in\{0,1\}\right]$, where: $x_{ij}(r)=\begin{cases}1 & \text{if } (i,j)\in L \text{ is in } r\text{-th route},\\ 0 & \text{otherwise},\end{cases}$
– $Z=\left[z(r,s):\quad z(r,s)\in\{0,1\}\right]$, where: $z(r,s)=\begin{cases}1 & \text{if } s-th \text{ vehicle support } r-\text{th route},\\ 0 & \text{otherwise}.\end{cases}$

Based on the above assumptions and documentation of the COPERT V model and vehicle emission factors (EMEP/EEA air pollutant emission inventory guidebook – 2014 [21]), it is possible to formulate the criterion function with the interpretation of the CO emission amount, expressed in grams (g):

$$– \quad F(X,Z)=\sum_{r\in R}\sum_{s\in S}\left[z(r,s)\left[\begin{array}{l} Ef(eq(sc\_kat(s))\cdot \sum_{i\in H(r)}\sum_{j\in H(r)} l_{ij}x_{ij}(r) \\ \cdot\left(1+\lambda(r)\cdot(e^{cold}/e^{hot}(sc\_kat(s))-1)\right)\end{array}\right]\right]. \quad (9)$$

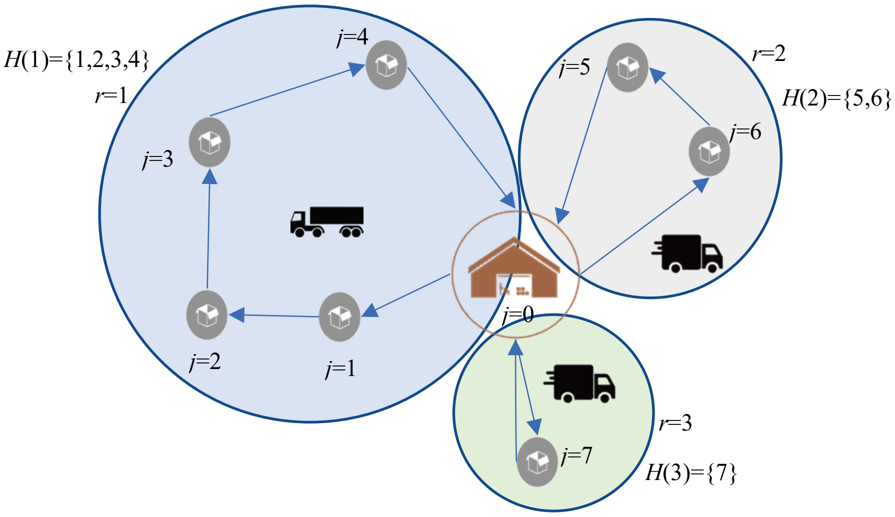

Fig. 1. Scheme of distribution system example based on developed model

The determination of the CO emission value in accordance with the above function requires the determination of additional assumptions. The function of the criterion includes cold/hot start emission for which they are used:

– $\lambda(r)$ – share length of the route travelled with an unheated engine,

– $e^{cold}/e^{hot}(sc\_kat(s))$ – emission correction indicator,

– $Ef(eq(sc\_kat(s))$ – unit emission indicator (g/km),

the above elements are determined depending on the specific problem; exemplary assumptions to them are presented in the calculation example in the next point.

The constrains for the task were taken from the classic VRP problems, namely, the reduction of the vehicle's load capacity on the route, visiting each customer only once, the same number of vehicles leaving and returns to the warehouse (j = 0). The most important mathematical records are presented in the data characteristics and in the discussion of the classical CVRP problem in point 3.

5. Estimation of pollutant emissions in planning cargo deliveries – Warsaw Case Study

Distribution systems can function in different areas in terms of population density, building density, infrastructure status, etc. However, cities are sensitive in terms of the negative impact of transport. Freight transport is necessary for the functioning of cities, but it is necessary to plan it so that it reduces void runs, minimize transport work carried out in the city, and thus limit its impact on the environment [25].

One of the examples of cities where there is a significant problem with environmental pollution is Warsaw. Transport alongside production activities and energy is one of the main activities causing an increase in the concentration of harmful substances in the atmosphere. For traffic forecasts for 2020, (daily pipeline distribution is shown in Fig. 2) daily emissions are presented in Tab. 1 for the main types of substances [14].

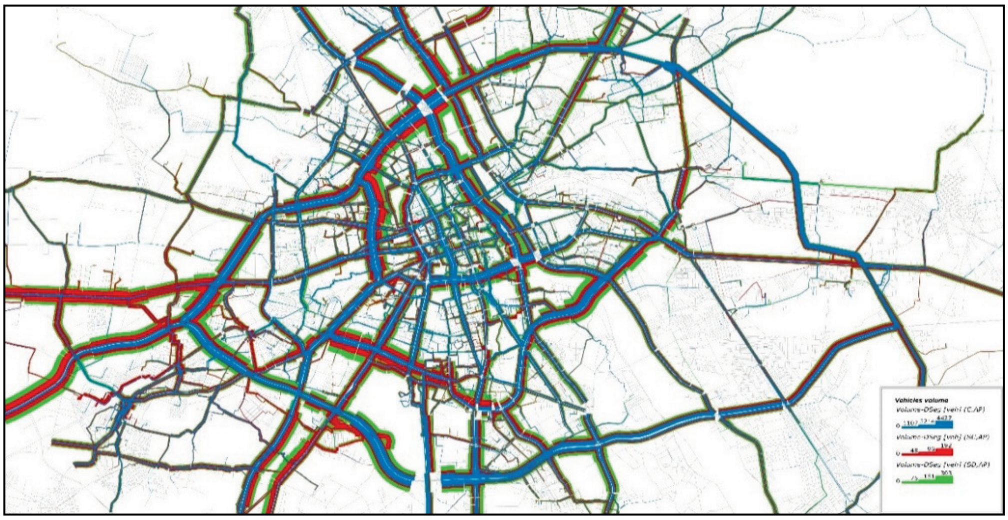

Fig. 2. Traffic distribution in Warsaw for 2020 [14]

Tab. 1. Pollutants emission from private and freight transport in Warsaw 2020 [14]

Harmful compound	Cars	LGV	HGV
CO_2 [g]	285 394 853	21 181 387	52 305 337
CO [g]	404 999	15 724	85 782
HC [g]	28 769	2 679	3 922
NO_x [g]	439 007	67 698	136 668
PM [g]	5753.075	2699.509	1504.012

It should be noted that in the case of the examined CO emission, the transport of loads constitutes 25% of emissions of this substance; therefore, it was accepted as a criterion. For the purposes of the research, it was assumed that selected LGV (Tab. 2) and lorry trucks as well as truck vehicle combinations with semi-trailer might be used to implement the delivery plan – HGV (Tab. 3). The vehicles were parameterized in accordance with the formulas for estimating pollutant emissions resulting from the COPERT V model.

Tab. 2. Parameters of petrol and diesel LGV (light good vehicle) – GVM ≤ 3.5t [21]

sc_kat	Fuel type	EURO	a	b	c	d	e	eq
1	PB	1	0.0037	-0.5215	19.127	x	1	1
2		2				x	0.61	1
3		3				x	0.52	1
4		4				x	0.28	1
5		5	0.343	-0.013	-0.007	3.098	x	2
6		6	0.341	-0.013	-0.007	3.229	x	2
7	ON	1	22.3E-05	-0.026	1.076	x	1	1
8		2				x	1	1
9		3				x	0.82	1
10		4				x	0.65	1
11		5	x	x	x	0.001	x	3
12		6	x	x	x	0.001	x	3

Determination of carbon monoxide during realization of distribution plan requires designation of the value of individual routes. For the purpose of determining the function of the criterion, the following criteria were adopted:

- the unit emission formulas will be written as $Ef(\mathrm{eq}(sc\_kat(s))$, it was assumed that the indicators: $\mathrm{a}(sc\_kat(s)), b(sc\_kat(s)), c(sc\_kat(s)), d(sc\_kat(s)), e(sc\_kat(s))$, will be saved as *a, b, c, d, e*; while $eq(sc\_kat(s))$ as *eq,* therefore, the unit formulas are written as follows:

$$Ef(\text{eq}(sc\_kat(s))=\begin{cases} e\cdot(a\cdot V(r)^2+b\cdot V(r)+c) & \text{for eq=1,}\\ \dfrac{a+c\cdot V(r)+d/V(r)}{1+b\cdot V(r)} & \text{for eq=2,}\\ d & \text{for eq=3,}\\ a\cdot V(r)^3+b\cdot V(r)^2+c\cdot V(r)+d & \text{for eq=4,}\\ a-\left(b\cdot\exp\left(-1\cdot c\cdot V(r)^d\right)\right) & \text{for eq=5,}\\ a\cdot b^{V(r)}\cdot V(r)^c & \text{for eq=6,}\\ a+\left(b\cdot\left[1+\exp\left(-1\cdot c+d\cdot\ln\left(V(r)\right)+e\cdot V(r)\right)\right]^{-1}\right) & \text{for eq=7,}\\ \exp\left(a+\dfrac{b}{V(r)}+c\cdot\ln\left(V(r)\right)\right) & \text{for eq=8,}\\ \left(c\cdot V(r)^2+b\cdot V(r)+a\right)^{-1} & \text{for eq=9,}\\ a\cdot V(r)^b+c\cdot V(r)^d & \text{for eq=10,}\end{cases} \tag{10}$$

– the emission correction factor for selected vehicles is recorded as:

$$e^{cold}/e^{hot}(sc\_kat(s))=\begin{cases}3.84 & \text{for } sc\_kat(s)=1,\ldots,6\\ 1.66 & \text{for others,}\end{cases} \tag{11}$$

– velocity V in the formula will be the average speed on the route r and will be saved as $V(r)$, and will be determined in accordance with the following relationship:

$$V(r)=\frac{\sum_{i\in H(r)}\sum_{j\in H(r)} l_{ij}x_{ij}(r)}{\sum_{i\in H(r)}\sum_{j\in H(r)}\sum_{s\in S} t_{ij}(s)x_{ij}(r)z(r,s)};i\neq j. \tag{12}$$

The basic element in the COPERT model is the unit emission indicator. Depending on the traffic conditions, type of road (city, town, motorway), type of vehicle, fuel and emission standards, as well as medium speed, it adopts different values. The same applies to the correction factor needed to determine the cold start emission. The following assumptions were made to determine the delivery plan based on the emission criterion:

- heavy-duty trucks are equipped with SCR (selective catalytic reduction) or EGR (exhaust gas recirculation) technology,
- the inclination of the road and the degree of loading of the vehicle are omitted,
- all roads are treated as urban roads,
- the average ambient temperature is 8ºC (average annual temperature for the capital city of Warsaw),
- average vehicle speed when driving with a cold engine is 20 km / h,
- the range of medium speed is $V=\langle 12;86\rangle$ km/h,
- λ is estimated depending on the route length and is equal to $\lambda(r)=\dfrac{2}{\sum_{i\in H(r)}\sum_{j\in H(r)}\sum_{s\in S} t_{ij}(s)x_{ij}(r)z(r,s)}$ with the assumption that the minimum length of the route is 2 km, and for shorter routes $\lambda(r)=1$,
- the harmful substance considered is carbon monoxide (CO).
- in the example at the outskirts of the city, there are 2x consolidation centres in the city (Warsaw, Poland), recipients from various industries and with different demand was identified (48x recipient).

Tab. 3. Parameters of diesel HGV (heavy good vehicle) – GVM >3.5t [21]

sc_kat	GVM (type)	EURO	a	b	c	d	e	eq
13	3.5t<DMC<=7.5t	1	-3.2229E-06	0.000754846	-0.057332668	1.864212091	x	4
14		2	0.415569825	-1.109782536	0.034756735	1.224233318	x	5
15		3	-4.70954E-06	0.000934279	-0.063635271	1.917815907	x	4
16		4	7.799532114	1.011553127	-0.996594827	x	x	6
17		5 (SCR)	0.036	5.098	2.217	1.510	-0.028	7
18		5 (EGR)	1.096	1.003	13.881	-1.235	x	5
19		6	0.107	-2.324	-0.735	x	x	8
20	7.5t<DMC<=12t	1	0.510361321	20.02690214	-0.108837737	0.803861619	0.019505416	7
21		2	0.161775233	0.042897061	-0.000312496	x	x	9
22		3	-8.64359E-06	0.001743745	-0.118838123	3.41011888	x	4
23		4	13.84669059	1.009575429	-1.007710437	x	x	6
24		5 (SCR)	0.327	8.932	2.088	1.546	-0.020	7
25		5 (EGR)	2.169	2.025	10.521	-1.239	x	5
26		6	0.638	-2.059	-0.758	x	x	8
27	12t<DMC<=14t	1	24.30114449	1.007371776	-0.93858862	x	x	6
28		2	0.108522354	0.04088738	-0.000306807	x	x	9
29		3	0.696787542	15.86469919	-0.588038613	0.258817855	0.06252776	7
30		4	23.38774691	-1.225412866	0.287240765	-0.010107065	x	10
31		5 (SCR)	0.713	13.097	1.258	1.241	0.021	7
32		5 (EGR)	2.732	2.546	11.310	-1.363		5
33		6	0.072	67494.110	-11.661	0.057	0.077	7
34	34t<DMC<40t	1	63.71634652	1.010513679	-1.064381556	x	x	6
35		2	36.86695921	1.012203646	-1.010599039	x	x	6
36		3	1.237192485	36.11660837	-0.177807094	0.564975448	0.04448809	7
37		4	50.53877997	-1.392528428	2.183829884	-0.323243627	x	10
38		5 (SCR)	0.933	39.458	0.418	1.172	0.005	7
39		5 (EGR)	6.352	6.146	5.045	-1.115	x	5
40		6	0.425	0.161	-0.001	x	x	9

The calculations were based on the genetic algorithm implemented in the author application. It was necessary to plan the deliveries, the order of the recipients visited and the size of delivery, as well as selects the vehicle type bearing in mind the limitations related to, among other things, the capacity of the vehicle.

The exemplary calculation to verify the model and its suitability. Thanks to it, it is possible to determine the directions of further work on the model and expand it with additional assumptions. Sample results for the developed model and input data set are presented in Tab. 4, for three variants. The first variant was implemented only with vehicles up to 3.5 t DMC, while the second variant only with larger vehicles. The third variant was mixed due to vehicles.

Tab. 4. Results for calculation of optimization task in Warsaw Case Study

Variant	Total distance [km]	CO emission [g]	Time of service [h]	Number of runs	Average number of customer serviced at each run
LGV	598.05	416.3	1.34	10	4.8
HGV	328.25	328.83	2.73	4	12
Mixed	320.7	279.44	2.2	6	8

The table also presents the variant assessment indicator due to the time of its implementation, which was not an optimization criterion, but is also important from the customers' point of view. It was determined based on the model and time of travel. It is, of course, possible to introduce a cost as well as other criteria for the implementation of transport, but this would require a more accurate calibration of the model.

5. Conclusions

The considerations presented in the article relate to the issue of estimation of pollutant emissions and consideration of its impact in the planning of cargo transport. The very problem of supply planning is a very complex issue from the model itself to the criteria and methods of solving it. Taking into account the emission of pollutants and selection of appropriate model to the purpose of the research additionally complicates the problem.

The work presents a mathematical model developed on a single criterion, it can be noticed that proper development of the model allows for planning deliveries and selection of means of transport for their implementation in a way allowing reducing CO emissions to the atmosphere. Of course, the larger set of permissible solutions (greater variety of vehicles), makes a better possibility to properly compose a vehicle fleet. Further works will present an extended model with additional criteria, which will allow for taking into account other decision-making aspects. As the experiments show on the model, the function criterion is correlated with the distance travelled, it is necessary to take into account additional criteria.

The problem of modelling green transport systems is very important, especially in the context of transporting cargo and choosing means of transport. In the coming years, the current trend will be increasingly stronger in terms of reducing emissions in urban areas and introducing zero-emission zones. For the above reason, this research will be continued.

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