Air Pollution Optimal Traffic Control in Integrated Street Canyons

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Abstract

This paper presents a system analysis integrated approach to pro-ecological urban traffic management and control problems. In this context optimal (in the sense of air pollution) traffic road control problems in street canyons are formulated and solved. A general traffic control idea for street canyons is proposed with emphasis on the development of advanced hydrodynamic control models of street canyon including: multi-lane, 1-D bidirectional model of movement of several types of vehicles, of several emission types, and of emitted pollutants. The optimal in the sense of total travel time, pollutant emission and concentration pro-ecological control problems for an isolated street canyon and three integrated substitute street canyons representative of the inner city are formulated and illustrated by 12 numerical examples.

Keywords: traffic road control, integrated approach, air pollutant modelling, street canyons, hydrodynamic model

Introduction

The upward trend of road transport social costs due to air and noise pollution motivates the search for a more efficient use of existing transportation facilities and services. In the most developed countries these costs are approximately estimated to a few percent of GDP and show an increasing non-linear tendency. The forecast of the road traffic increase in Europe (between 80 and 150% by the year 2025 [11]) pose difficult challenges to keep transport related social costs within sensible bounds (e.g. expressed by "sustainable mobility" paradigm [9]). The highly distributed scientific research is concentrated mainly on the identification and evaluation (by simulation, empirical and analytical models) of different aspects of transportation-environment interactions for DSS in tactical/strategical transportation planning or short/medium term prediction purposes. As a result, network evaluation and management tools which are based on socio-economic measures and impacts analysis of transport measures in terms of pollutant and energy consumption [11] are proposed. Research projects of a technological nature are concerned with proposals of technological innovations (e.g. alternative fuels, efficient silent engines, catalytic converters). Presently several general-purpose predictive dispersion models are available (e.g. EPA models HIWAY-2 [25] and CALINE-4 [10], JEA (1982) and TOKYO (1983) models [28], TRRL PREDCO model [16]). However, only a few models may be indirectly applicable to traffic control purposes (e.g. EMAM type model used in SATURN program [22, 23], empirical models APRAC [17], GZE and PWILG [27], OMG volume-source model [18]).

The weak points of the existing approaches are connected with:

- Oversimplified representation of the main determinants of pollutant concentration in streets vicinity, e.g. traffic road processes which create the emission source and physical processes which proceed in the street canyons. A common assumption of a straight line emission source with constant rate of emission over the length of road (HI-

WAY, CALINE) or user defined road segments (PRED-CO) is an example. In EMAM models, vehicle operating mode representation seems to be oversimplified, especially in cases when the "fluid" vehicle homogeneous queueing model is used for representation of vehicle queue mode (SATURN). The most widely used gaussian pollutant dispersion models have limited range of applicability due to their simplifying assumptions.

- Low quality of model input parameter estimates, e.g. meteorological parameters.

- Poor real-time measurement data and data-based experimental knowledge about temporal and spatial pollutant concentration distributions in various types of street canyons.

Hardware advances (new generations of intelligent video-camera traffic detectors, progress in communication tools and computational performance of modern microcomputers) have provided the basis for a new range of important improvements in pro-ecological planning, management and real-time adaptive control [3, 4, 8]. The benefits from these options are functionally conditioned by their appropriate integration with the technological functions of modern IVHS systems i.e. Advanced Traffic Management (ATMS), Traveller Information (ATIS), Vehicle Control (AVCS) systems. The TEDMAN (Traffic Environmental Design and MANagement) methodology is probably the first such proposal [4]. The transportation related real-time information infrastructure creates a new fundamental component of these advanced systems and has been used for providing:

- information service and decision support for people before their trip (e.g. for best trip selection).

- information service and control assistance (e.g. transit users trip co-ordination, routing drivers around accidents or congestion) for travellers during their trips

- enhancement of the drivers control of the vehicle for increase of travel safety and efficiency (e.g., on-board computers, collision-warning and avoidance systems).

The successful practical implementation of the above tasks calls for a new efficient network analysis and control tools (e.g. real-time dynamic algorithms for O-D estimation, traffic assignment, network operation optimisation with AI tools for congestion prediction, accidents detection and logical aggregation of distributed network data). The data and knowledge bases supplied with traffic detectors data create a data-rich real-time environment not only for real-time control algorithms but also for development of sophisticated traffic and air pollution models [7].

In this paper a pro-ecological integrated traffic control idea is proposed and an appropriate advanced control model for street canyons is developed. In the next section the general control idea is presented. The last two sections are devoted to the mathematical control model of street canyons and 12 numerical results.

General Traffic Control Idea for Street Canyons

The integrated pro-ecological traffic planning and management methodology is summarized in Fig. 1. The main points of this methodology are as follows [1, 4]:

- The integrated multilayer pro-ecological traffic planning and management methodology follows in the natural way from an advanced hierarchical integrated individual traffic, and public transport systems [2, 3, 5, 8].

- In general, it is based on recent developments in TRAFFITRONICS [4] (TRAFFIC, elecTRONics, Informatics, Communications, Computers) technologies and progress in wide-area intelligent network analysis, management and real-time control tools. The operational information for these tools has to be ensured by integrated high quality real-time data and knowledge bases updated and completed by: traffic data from video-detectors [3, 5], AID, ATIS and AVL/GPS systems [4]; meteorological data; pollutant emission and concentration data (e.g. lidar measurements); whereas the operational efficiency is guaranteed by well equipped data estimation methods, multicriteria intelligent planning, management and control actions [2, 3] supported by automatic decisions assistance tools (e.g. humans operators DSS supplemented by GIS-visualisation, AI-interpretation and ATIS real time knowledge presentation).

In particular, the planning process must be integrated with:

- real-time operation of the transportation system (i.e. must include a rich family of traffic, emissions, concentrations and other EIA analysis models that reflect continuous real-time feedback in system operation, available information about management actions for continuous system analysis, and forecasting).

- powerful intelligent analysis support equipped with models and a knowledge base which organise and use rich bodies of data [13], and tools capable of dealing with and efficiently searching through a practical continuum of potential alternatives (instead of a few) to match options against policies and objectives.

- advanced multilevel (national: local, regional, state and international) intelligent co-ordination support of a variety of planning process participants (professionals, decision makers, stakeholders, citizens and interest groups) which improves the efficiency and quality of the deliberation and consensus seeking of national and international group processes [19].

The management and control processes must be integrated with:

- data-rich real-time environment and advanced knowledge, methods and tool bases

- computer-based decision support systems equipped with high proportions of automated monitoring, surveillance and intelligent management functions to realize beneficial pro-ecological (i.e. reducing adverse environmental impacts) actions with a short reaction time to on-line detected traffic and environmental situations,

- library of intelligent multicriteria control [2, 3] and management methods [11] which make it possible to perform integrated (traffic control, route guidance, public transport control, parking control, traffic priorities, restraints and incentives for use different modes of transport) wide-area tasks. The potential pro-ecological contribution of these integrated tasks (strategies) may be predicted in
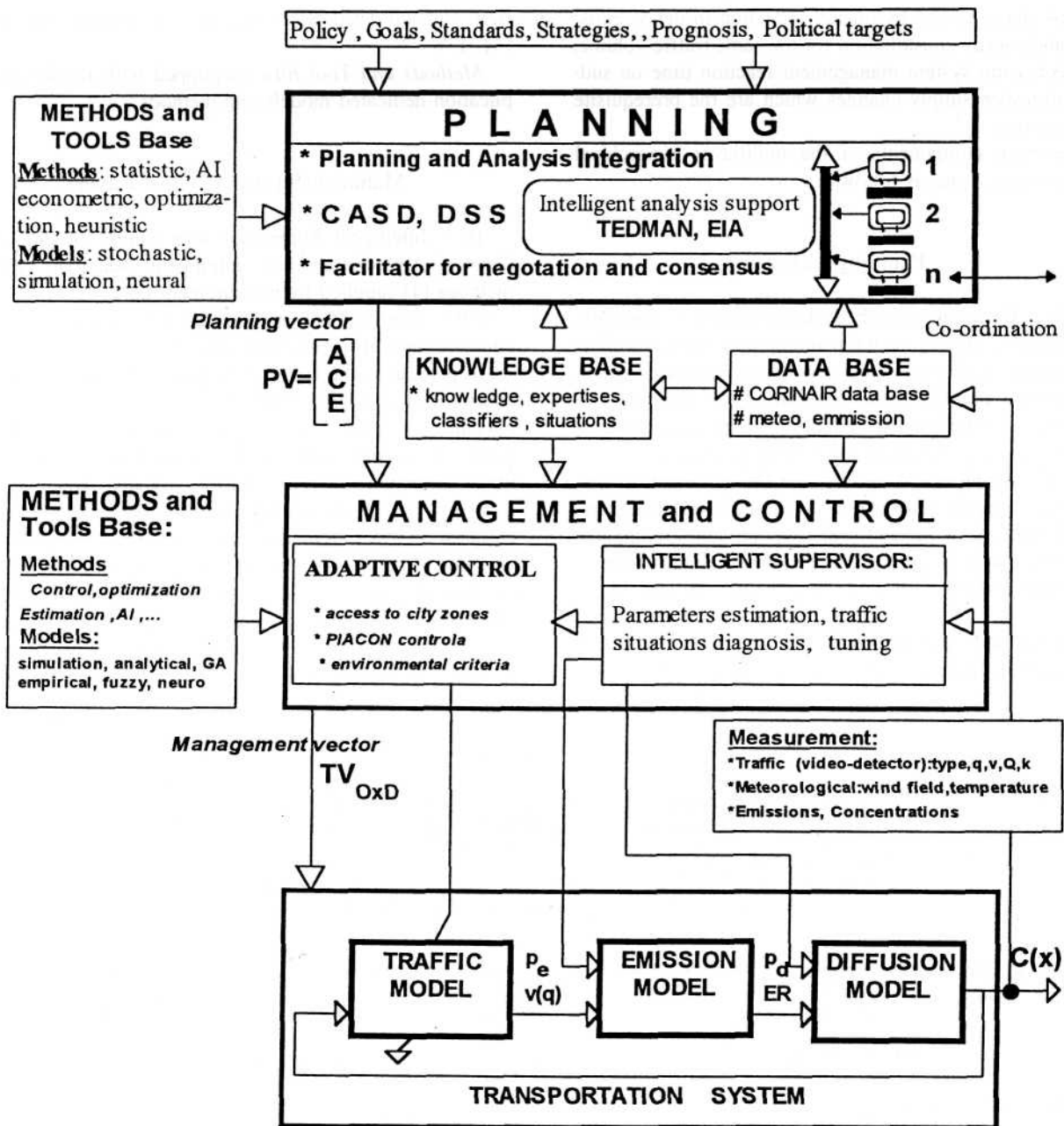
Legend:

PV - planning vector (A - actions; C - criteria; E - environment descriptors)

TV - management vector (trips' vector O x D; standards of air quality)

q - traffic flows vector ; v(q) - average speeds on the network links.

P_e, P_d - emissions and diffusion parameters in the models

ER - traffic flows emision rate in the network

C(x) - pollutant concentration in the x- point in the network

Fig. 1. Integrated Pro-ecological Traffic Planning and Management Metodology

terms of both demand and supply side effects. Demand reduction in the time-space context due to reducing wasted trip time, emissions and energy, travellers more rational choices of trip determinants (mode, route, departure time etc.) on the basis of available up-to-date information about travel alternatives, incidents, navigation, road use pricing. Significant improvements on the supply side due to more efficient use of the existing infrastructure capacity (reduction of traffic disturbances, accidents, improving the operation of signals), providing system-level optimum traffic

patterns characterized by overall reduction in delay, emissions and energy consumption for the same traffic volume, and decreasing system management reaction time on sudden/unforeseen supply changes which are the prerequisite of congestion.

The main components of the multilayer hierarchical system in Fig. 1 are as follows:

Planning Layer

DSS - Decision Support Systems applied to complex, multiobjective environmental planning processes as well as for complex deliberative and negotiating processes which are common practice in transportation planning [9, 11]. The environmental context includes the national/international co-ordinating and integrating group processes.

CASD - Computer Aided System Design which is usually a basic operation unit in the planning layer. The common availability of PC and high level structural computer languages stimulate the fast development of new interactive CASD tools (e.g. TEDMAN computer package [5, 6, 8]).

DECISION-MAKING BASE:
Data and Knowledge Bases which are generated, verified and up-dated automatically by modern AI tools [11, 13].

Methods and Tool Bases equipped with family of application dedicated models and methods.

Management and Control Layer

IS - Intelligent Supervisor with family of emission, diagnosis, prediction and intelligent adaptive control methods [4] supplied by measurement unit.

CP - Control Plant represented by cascade of traffic, emission and diffusion submodels [1, 6].

In particular, the street canyon pro-ecological adaptive control idea is summarized in Fig. 2. The control structure contains two levels. At the bottom direct control level the traffic in the street canyon is controlled by real-time optimal selection of the traffic signals green splits $g_i \, e \, [g_{min}, g_{max}]$ and cycle times $C \, e \, [C_{min}, C_{max}]$ on the entrance and exit signalized junctions. The availability of video-detectors makes it possible to use direct environmental measures in single and multicriteria control problems [8]. Entrance control is a general gating type of control which, by selection of entrance traffic signal parameters, controls the number of vehicles entering the street canyon.
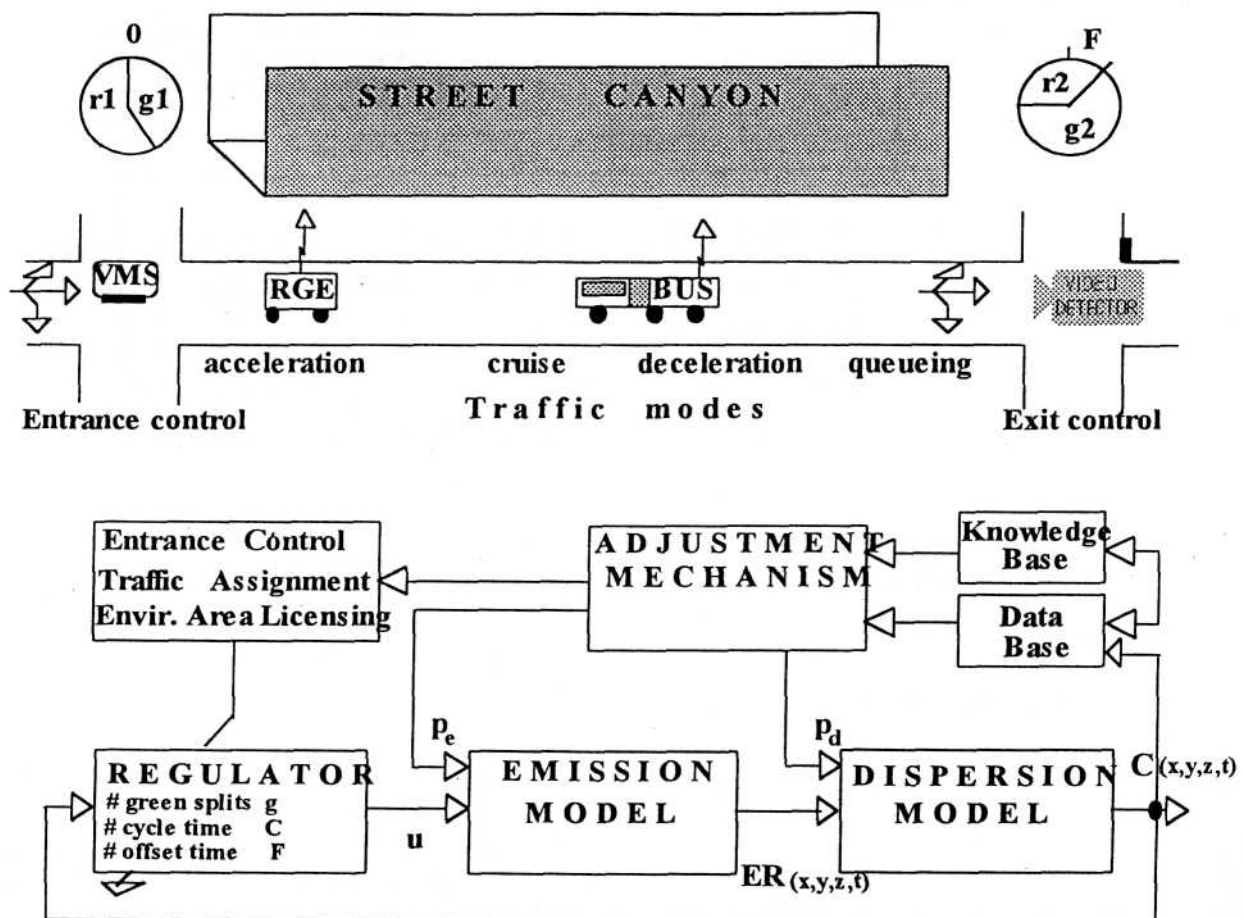

Fig. 2. Illustration of the pro-ecological control idea for the street canyon.

Similarly, exit controls determine the number of vehicles leaving the street canyon. Additionally, the entrance and exit junctions are co-ordinated by appropriate selection of the green signals starts offset time F e [0, C]. Cycle time optimization in signal co-ordination was presented in [7]. At the upper supervision level the adjustment mechanism supplies the emission and dispersion models with real-time estimated parameters p_e / p_d and activates (if necessary) two area-wide pollution sensitive pro-ecological control strategies: the traffic gating strategy which is a dynamic traffic re-routing strategy assigning the traffic to diversion routes (optimal in the sense of travel and environmental standards) in order to unload the route with estimated and/or predicted environmental alert conditions, and the environmental area licensing strategy which after identification of the "clean" status of each vehicle restricts the number of non-clean vehicles entering the street canyon. The implementation of these strategies calls for on-line solution of the traffic assignment problem or selection of off-line prepared traffic scenarios according to an on-line calculated set of markers describing the current traffic situation. In practice these strategies are usually implemented by means of VMS (Variable Message Signs) and RGE (On-board Route Guidance Equipment) tools.

The feedback control loop at the bottom level includes the macroscale vehicle emission model that relates spatio-temporal traffic driving modes (i.e. acceleration, cruise, deceleration, queueing) with spatio-temporal traffic source emmission rates ER(x,y,z,t) of air pollutants (denoted in model by S for abbreviation). The detailed adaptive control loop information about flow of vehicles in the street canyon which is necessary to estimate a model parameters p_e and p_d during the model updating process is formed from data and knowledge bases. The main data sources in the vicinity of junctions are video-detectors, whereas in the outlying junction zones of the street canyon there are messages from "marked vehicles" (i.e. Route Guidance and Public Transport vehicles equipped with on-board computers and communications means which create the "distributed traffic detector") which drive inside the traffic stream. The microscale pollutant dispersion model that relates source emission rates to i-th pollutant concentration at a given point of the street canyon C_i(x,y,z,t) is presented in the next section. The extension of the control idea from one street canyon to a network of street canyons arises in a natural way. The street canyon may be treated as an elementary operational unit EU described in terms of parameters representative for particular local conditions. The street arteries and networks are an aggregation of EU modules realized by means of simple aggregation and connection rules. The control plant module-based representation together with simple connection algebra is an advantageous representation of various network problems and enables us to concentrate on the solution of "small" control problems for modules (i.e. street canyon).

Model of the Street Canyon

In this section the mathematical model of the street canyon is developed (see Fig. 1).

The **geometrical assumptions** of this model are as follows:

Gl. The street canyon is represented by a cuboid of dimensions *a,b,c*. The structure of the canyon is simplified by assuming that the walls of the buildings and the road surface are rectangles. If we put the origin of the co-ordinate system in cuboid's corner then we have two walls at and $y = 0$, $y = b$ road surface at $z = 0$. The remaining three non-solid open surfaces of air have the co-ordinates $x = 0$, $x = a$, $z = c$. respectively.

G2. There are neither holes in the walls nor vegetation alongside the road. The remaining three surfaces of the cuboid also do not have holes since they simulate non-solid open rectangles of air.

G3. The road sections which constitute the bottom of the street canyon are rectilinear.

G4. At each end of the street canyon there are entrance and exit junctions *(M = 2)* with traffic signals (their co-ordinates are $x = 0$, $x = a)$.

G5. The vehicles of *VT* distinguishable emission types are material points. The vehicles are treated as hydrodynamical fluid. There are n_L left lanes and n_K right ones (the traffic is bi-directional).

The **physical assumptions** of this model are as follows:

PI. The considered mixture of gases which consists of $N, N_E - 1 + N_A = N$ gases. The first $(N_E - 1) = 3$ gases are the exhaust gases emitted by vehicle engines during combustion *(CO, CH, NO$_X$,* we neglect the presence of *SO$_2$)*. The remaining $N_A = 9$ gases are the components of air *(O$_2$, N$_2$, Ar, CO$_2$, Ne, He, Kr, Xe, H$_2$,* we neglect the presence of *H$_2$O, O$_3$)*.

P2. The walls of the canyon and the surface of the road are impervious for all gases of the mixture. The remaining three surfaces of the cuboid are pervious for external fluxes of exhaust gases and air components.

P3. The internal sources of air components are not present with the exception of oxygen i.e. N_E^{th} component of the gaseous mixture. There are internal mobile sources of exhaust gases (passenger cars, lorries, with many types of engines: diesel or petrol, and with mixed ages of engines). During combustion the engine consumes oxygen, therefore with each internal mobile source of exhaust gases a negative source of oxygen (sink) is connected. We assume that during combustion the heat produced during combustion is neglected.

P4. The gaseous mixture is treated as polytropic, compressible and viscous fluid. We study the motion of this mixture. The turbulences of the mixture caused by the motion of vehicles are neglected, since vehicles are dimensionless. The components of mixture are reflected by the three impervious surfaces. We assume that the gaseous mixture can be transmitted through the three open surfaces of the cuboid.

P5. The molecular process of diffusion of all components is considered; however, the diffusion tensor is a constant diagonal matrix.

P6. All vehicles emit exhaust gases at given rates depending on their velocities (i.e. modes).

P7. Chemical reactions are neglected with the exception of the combustion of oxygen.

P8. The dependence of the processes on temperature is neglected, because the equations of motion presented below are neither overdetermined nor underdetermined.

P9. The rate of combustion of oxygen for a given type of engine is known.

The following set of descriptive dynamic **model variables** together with their **boundary** ($t \geq 0$) and **initial conditions** is assumed:

A. Variables.

A1. $\vec{v}(x,y,z,t)$ velocity of gaseous mixture.

A2. $\rho(x,y,z,t)$ density of gaseous mixture.

A3. $c_i(x,y,z,t)$ concentration of ith component of gaseous mixture, $i = 1..N$ (let us note that due to $\sum_{i=1}^{N} c_i = 1$ one concentration component is the dependent variable).

A4. $p(x,y,z,t)$ pressure of gaseous mixture.

A5a. $k_{l,vt}^L(x,t)$, $vt = 1..VT$, $l = 1..n_L$ density of vehicles of type vt on l^{th} left lane measured in [veh / m].

A5b. $k_{r,vt}^R(x,t)$, $vt = 1..VT$, $r = 1..n_R$ density of vehicles of type vt on r^{th} right lane measured in [veh / m].

A6a. $\vec{u}_{l,vt}^L(x,t)$, $vt = 1..VT$, $l = 1..n_L$ velocity of vehicles of type vt on l^{th} left lane.

A6b. $\vec{u}_{r,vt}^R(x,t)$, $vt = 1..VT$, $r = 1..n_R$ velocity of vehicles of type vt on r^{th} right lane.

A7a. $e_{l,ct,vt}^L(x,t)$, $ct = 1..CT$, $vt = 1..VT$, $l = 1..n_L$ emissivity of ct^{th} component of exhaust gases from vehicles of type vt on l^{th} left lane measured in [kg / (m · s)].

A7b. $e_{r,ct,vt}^R(x,t)$, $ct = 1..CT$, $vt = 1..VT$, $r = 1..n_R$ emissivity of ct^{th} component of exhaust gases from vehicles of type vt on r^{th} right lane measured in [kg / (m · s)].

A8a. $u_j = (g_j, C_j)$ control on j^{th} junction $j = 1..M$, $M = 2$, which contains traffic signals green $g_j \in [g_{j,min}, C_j - g_{j,orth}]$ and cycle $C_j \in [C_{j,min}, C_{j,max}]$ times.

A8b. The traffic signals control co-ordination variable for the street canyon is the offset time $F \in [F_{min}, C_2 - \delta_F]$. These control variables form a 5-tuple of control: $u = (g_1, C_1, g_2, C_2, F)$. The admissible control domain set for this 5-tuple in the simulation time period T > 0 is for j = 1,2. $U^{adm} = \{(g_1, C_1, g_2, C_2, F): C_j \in [C_{j,min}, C_{j,max}], g_j \in [g_{j,min}, C_j - g_{j,orth}], F \in [F_{min}, C_2 - \delta_F]\}$.

A9a. $G_{out}^L(C_1, g_2, F, t)$ the signal at $x = a$ for all left lanes (outgoing vehicles) and all right lanes (incoming vehicles).

A9b. $G_{out}^R(C_2, g_2, F, t)$ the signal at $x = 0$ for all right lanes (outgoing vehicles) and all left lanes (incoming vehicles). Between both signals there is offset time F. In the signals we assume Boolean values: GREEN and RED.

To represent the emission process we assume two internal sources.

D. Sources.

D1. $S(x,y,z,t)$, the volume density of internal sources of gaseous mixture consisting of exhaust gases and oxygen measured in [kg / (m^3 · s)].

D2. $Set_{ct}(x,y,z,t)$, $ct = 1..CT$, the volume density of internal sources (the emission rate) of ct^{th} component of exhaust gases emitted by all vehicles in the canyon measured in [kg / (m^3 · s)].

We assume that the sources of exhaust gases are situated in n_L left lanes at $y = y_l, l = 1..n_L$, and n_R right ones at $y = y_r$, $r = 1..n_R$ at the level of the road $z = 0$:

$$Set_{ct}(x,y,z,t) = [\sum_{l=1}^{n_L}\sum_{vt=1}^{VT} e_{l,ct,vt}^L(x,t)\cdot\delta(y - y_l)\cdot\delta(z) +$$
$$+ \sum_{r=1}^{n_R}\sum_{vt=1}^{VT} e_{r,ct,vt}^R(x,t)\cdot\delta(y - y_r)\cdot\delta(z)] / (bc), \; ct = 1..CT,$$

$Set_{NE}(x,y,z,t)$, the volume density of negative internal sources (the emission rate) of oxygen absorbed by all vehicles in the canyon measured in [kg/(m^3 · s)]. We assume that $Set_{NE}(x,y,z,t) = ONOX \cdot Set_{NE-1}(x,y,z,t)$, where $ONOX = -0.5308$.

The following relation holds:

$$S(x,y,z,t) = \sum_{ne=1}^{N_E} Set_{ne}(x,y,z,t).$$

Under the above model specifications the complete set of equations of dynamics of the model may be formulated as follows: (we follow the general idea presented in [14, 21]).

E. Equations of dynamics.

E1. Balance of Momentum – Navier Stokes equation.

$$\rho(\frac{\partial\vec{v}}{\partial t} + (\vec{v}\nabla)\vec{v}) + S\vec{v} = -\nabla p + \eta\Delta\vec{v} + (\xi + \frac{\eta}{3})\nabla(\nabla\circ\vec{v}) + \vec{F}$$

where η is first viscosity coefficient ($\eta = 18.1\cdot10^{-6}[kg/s \cdot m]$ for air at temperature $T = 293[K]$), ξ is second viscosity coefficient ($\xi = 15.6\cdot10^{-6}[kg/s \cdot m]$ (for air at temperature $T = 293[K]$, [26]), $\vec{F} = \rho\vec{g}$ is gravitational body force density, $\vec{g}$ is gravitational acceleration of Earth ($\vec{g} = (0,0,-9.81)[m/s^2]$). We assume that the gaseous mixture is compressible and viscous fluid.

E2. Conservation of Mass – Equation of continuity.

$$\frac{\partial\rho}{\partial t} + div(\rho\vec{v}) = S.$$

We have assumed the source **D1**.

E3. Conservation of Mass of Components – Diffusion equations.

E3a. $\rho(\frac{\partial c_i}{\partial t} + \vec{v}\nabla c_i) = Set_i - c_iS + \sum_{m=1}^{N-1}(D_{im} - D_{iN})[\rho\Delta c_m + (\nabla\rho)(\nabla c_m)]$, $i = 1..N_E$,

E3b. $\rho(\frac{\partial c_i}{\partial t} + \vec{v}\nabla c_i) - c_iS + \sum_{m=1}^{N-1}(D_{im} - D_{iN})[\rho\Delta c_m + (\nabla\rho)(\nabla c_m)]$, $i = (N_E + 1)..N$,

where $D_{im} = D_{mi}$ is the diffusivity coefficient from component i to m, and D_{ii} is the autodiffusivity coefficient of component i. The diffusivity coefficients are constant and known (see [12]). In **E3a** we have assumed the sources **D1-D2**. In **E3b** only the source **D1** is taken into account. Since the mixture is in motion we cannot neglect the convection term: $\vec{v}\nabla c_i$. We assume that the thermodiffusion coefficient and the barodiffusion coefficient are equal to zero.

E4. Equation of state – Constitutive equation.

$$\frac{p}{p_0} = (\frac{\rho}{\rho_0})^\gamma,$$

where $\gamma = \frac{c_p}{c_v} = 1.4$ is adiabatic exponent of gas (air), c_p is the specific heat at constant pressure, c_v is specific heat at constant volume, subscript 0 refers to normal pressure and

density of air ($p_0 = 1[atm]$, $\rho_0 = 1.293$ [kg/m³]). We assume that the gaseous mixture is polytropic.

E5. Conservation of Vehicles – Equation of continuity.

E5a. $\dfrac{\partial k_{l,vt}^L}{\partial t} + div(k_{l,vt}^L \vec{u}_{l,vt}^L) = 0$, $l = 1..n_L$, $vt = 1..VT$.

E5b. $\dfrac{\partial k_{r,vt}^R}{\partial t} + div(k_{r,vt}^R \vec{u}_{r,vt}^R) = 0$, $r = 1..n_R$, $vt = 1..VT$.

E6. Technical parameters.

The dependence of the emissivity on density and velocity of vehicles is taken in the form:

$$e_{l,ct,vt}^L(x,t) = k_{l,vt}^L(x,t)\left(\frac{|\vec{u}_{l,ct,vt}(x,t)| - v_{ct,vt,i_l}}{v_{ct,vt,i_l+1} - v_{ct,vt,i_l}} + e_{ct,vt,i_l}\right),$$
$$l = 1..n_L, \ ct = 1..CT, \ vt = 1..VT,$$

$$e_{r,ct,vt}^R(x,t) = k_{r,vt}^R(x,t)\left(\frac{|\vec{u}_{r,ct,vt}(x,t)| - v_{ct,vt,i_r}}{v_{ct,vt,i_r+1} - v_{ct,vt,i_r}} + e_{ct,vt,i_r}\right),$$
$$r = 1..n_R, \ ct = 1..CT, \ vt \ 1..VT,$$

where

$$|\vec{u}_{l,ct,vt}^L(x,t)| \in (v_{ct,vt,i_l}, v_{ct,vt,i_l+1}), |\vec{u}_{r,ct,vt}^R(x,t)| \in (v_{ct,vt,i_r}, v_{ct,vt,i_r+1}),$$
$$l = 1..n_L, \ r = 1..n_R, \ ct = 1..CT, \ vt = 1..VT,$$

$v_{ct,vt,i_l}, v_{ct,vt,i_l+1}, v_{ct,vt,i_r}, v_{ct,vt,i_r+1}$, are experimental velocities and $e_{ct,vt,i_l}, e_{ct,vt,i_r}$ are experimental emis-sions of ct^{th} exhaust gas from single vehicle of vt^{th} type at velocity v_{ct,vt,i_p} measured in [kg/(s · veh)].

E7. Control.
$u = (u_1, u_2, F) \in U^{adm}$ where U^{adm} is a set of admissible control variables.

F. Optimization problems.
Our control task is the minimization of the measures of the total travel time TTT [24], emissions E, and concentrations C of exhaust gases in the street canyon, therefore the appropriate optimization problems may be formulated as follows:

F1. $\inf\limits_{u \in U^{adm}} J_{TTT}(u)$, where

$$J_{TTT}(u) = \sum_{l=1}^{n_L}\sum_{vt=1}^{VT}\int_0^T\int_0^a k_{l,vt}^L(x,t)dtdx + \sum_{r=1}^{n_R}\sum_{vt=1}^{VT}\int_0^T\int_0^a k_{r,vt}^R(x,t)dtdx,$$

F2. $\inf\limits_{u \in U^{adm}} J_E(u)$, where

$$J_E(u) = \sum_{l=1}^{n_L}\sum_{ct=1}^{CT}\sum_{vt=1}^{VT}\int_0^T\int_0^a e_{l,ct,vt}^L(x,t)dtdx + \sum_{r=1}^{n_R}\sum_{ct=1}^{CT}\sum_{vt=1}^{VT}\int_0^T\int_0^a e_{r,ct,vt}^R(x,t)dtdx,$$

F3. $\inf\limits_{u \in U^{adm}} J_C(u)$, where $J_C(u) = \sum\limits_{i=1}^{N_E-1}\int_0^T\int_0^a\int_0^b\int_0^c c_i(x,y,z,t)dtdxdydz,$

F4. $\inf\limits_{u \in U^{adm}} J_{TTT,ext}(u)$, where

$$J_{TTT,ext}(u) = J_{TTT}(u) + \alpha_{TTT,ext}^1(Ta\sum_{r=1}^{n_R}\sum_{vt=1}^{VT}k_{l,vt,jam}^L)(C_1 - g_1) +$$
$$+ \alpha_{TTT,ext}^2(Ta\sum_{l=1}^{n_L}\sum_{vt=1}^{VT}k_{r,vt,jam})(C_2 - g_2),$$

F5. $\inf\limits_{u \in U^{adm}} J_{E,ext}(u)$, where

$$J_{E,ext}(u) = J_E(u) + \alpha_{E,ext}^1(Ta\sum_{r=1}^{n_R}\sum_{ct=1}^{CT}\sum_{vt=1}^{VT}e_{l,ct,vt,jam}^L)(C_1 - g_1) +$$
$$+ \alpha_{E,ext}^2(Ta\sum_{r=1}^{n_r}\sum_{ct=1}^{CT}\sum_{vt=1}^{VT}e_{r,ct,vt,jam}^R)(C_2 - g_2),$$

F6. $\inf\limits_{u \in U^{adm}} J_{C,ext}(u)$, where

$$J_{C,ext}(u) = J_C(u) + (Tabc\sum_{i=1}^{N_E-1}c_{i,STP})(\alpha_{C,ext}^1(C_1 - g_1) +$$
$$+ \alpha_{c,ext}^2(C_2 - g_2)).$$

Remark: J_{TTT} and $J_{TTT,ext}$ are measured in [s], J_E and $J_{E,ext}$ are measured in [kg], and J_C and $J_{C,ext}$ are measured in [kg · s]. Moreover, $k_{l,vt,jam}^L$, $k_{r,vt,jam}^R$ are the jam vehicles' densities, $e_{l,vt,jam}^L$, $e_{r,vt,jam}^R$, are the jam vehicles' emissions, and $c_{i,STP}$ are the pollutants' concentrations at standard temperature and pressure STP. In the last three optimization problems **F4, F5, F6** we defined the additional cost functions ascribed to the nearest neighbour previous and next street canyon assuming that in these canyons there are full jams. Hence, by these additional terms we modelled the remaining canyons of the city.

Numerical Examples

We assumed the following data:

- $VT = 4$, $n_L = n_R = 2$; $CT = N_E - 1 = 3$; $a = 762[m]$, $b = 50[m]$, $c = 100[m]$, $T = 50[s]$,
- $\delta_x = 76.2[m]$, $\delta_y = 10[m]$, $\delta_z = 20[m]$, $\delta_t = 4[s]$, the steps in x,y,z,t directions,
- $\delta_{C_1} = 12.5[s]$, $\delta_{g_1} = 3.125[s]$, $\delta_{C_2} = 12.5[s]$, $\delta_{g_2} = 3.125[s]$, $\delta_F = 1.5625[s]$, are the steps in C_1, g_1, C_2, g_2, F, directions,
- $C_{j,min} = 30[s]$, $g_{j,min} = 10[s]$, $j = 1,2$, $F_{min} = 0[s]$, the minimal values of control variables C_1, g_1, C_2, g_2, F and $C_{j,max} = T$, $g_{j,max} = C_j - g_{j,orth}$, $j = 1,2$; $F_{max} = C_2 - \delta_F$ the maximal values, $g_{j,orth} = 15[s]$, $j = 1,2$, are the green lights' lengths on the orthogonal canyons to the one studied.
- $\alpha_{TTT,ext}^1 = 1$; $\alpha_{TTT,ext}^2 = 1$; $\alpha_{E,ext}^2 = 1$; $\alpha_{C,ext}^2 = 1$;

According to [24] we assumed the boundary conditions **B5a, B5b, B5c, B5d**, in the form:

$k_{l,vt,in}^L(t) = k_{l,vt,arrival}^L$ if $G_{out}^R(C_2,g_2,F,t) = GREEN$, and there is no queue at $x = 0$,

$k_{l,vt,in}^L(t) = k_{l,vt}^L$ if $G_{out}^R(C_2,g_2,F,t) = GREEN$, and there is queue at $x = 0$,

$k_{l,vt,in}^L(t) = k_{l,vt,jam}^L$ if $G_{out}^R(C_2,g_2,F,t) = RED$,

$k_{r,vt,in}^R(t) = k_{r,vt,arrival}^R$ if $G_{out}^L(C_1,g_1,F,t) = GREEN$, and there is no queue at $x = a$,

$k_{r,vt,in}^R(t) = k_{r,vt,sat}^R$ if $G_{out}^L(C_1,g_1,F,t) = GREEN$, and there is queue at $x = a$,

$k_{r,vt,in}^R(t) = k_{r,vt,jam}^R$ if $G_{out}^L(C_1,g_1,F,t) = RED$,

$k_{l,vt,out}^L(t) = k_{l,vt,arrival}^L$ if $G_{out}^L(C_1,g_1,F,t) = GREEN$, and there is no queue at $x = a$,

$k_{l,vt,out}^L(t) = k_{l,vt,sat}^L$ if $G_{out}^L(C_1,g_1,F,t) = GREEN$, and there is queue at $x = a$,

$k_{l,vt,out}^L(t) = k_{l,vt,jam}^L$ if $G_{out}^L(C_1,g_1,F,t) = REED$,

$k_{r,vt,out}^R(t) = k_{r,vt,arrival}^R$ if $G_{out}^R(C_2,g_2,F,t) = GREEN$, and there is no queue at $x = 0$,

$k_{r,vt,out}^R(t) = k_{r,vt,sat}^R$ if $G_{out}^R(C_2,g_2,F,t) = GREEN$, and there is queue at $x = 0$,

$k_{r,vt,out}^R(t) = k_{r,vt,jam}^R$ if $G_{out}^R(C_2,g_2,F,t) = RED$,

$l = 1..n_L, \ r = 1..n_R, \ vt = 1..VT.$

The existence of queues at the entrances to the canyon (at $x = 0$, for the left lanes, and at $x = a$, for the right lanes) is determined by the values of the vehicles' densities changing in the following way:

$$k^L_{l,vt}(-\delta_x, t) = k_{GREEN} \text{ for } t \in [0, g_1) \cup [C_1, C_1 + g_1) \cup ...,$$

$$k^L_{l,vt}(-\delta_x, t) = k_{RED} \; k^L_{l,vt,in}(t) = k_{RED} \text{ for } t \in [g_1, C_1) \cup$$
$$[C_1 + g_1, 2C_1) \cup ...,$$

$$k^R_{r,vt}(\alpha + \delta_x, t) = k_{GREEN} \; k^R_{r,vt,in}(t) = k_{GREEN} \text{ for } t \in [F, F + g_2)$$
$$\cup [F + C_2, F + C_2 + g_2) \cup ...,$$

$$k^R_{r,vt}(\alpha + \delta_x, t) = k_{GREEN} \; k^R_{r,vt,in}(t) = k_{RED} \text{ for } t \in [0, F)$$
$$\cup [F + g_2, F + C_2 + g_2) \cup ...,$$

where, $k_{GREEN} = 0.030 [veh/m]$, $k_{RED} = 0.006 [veh/m]$, $k^L_{l,vt,sat}, k^R_{r,vt,sat}, k^R_{r,vt,arrival}, k^R_{r,vt,arrival}, k^L_{l,vt,jam}, k^R_{r,vt,jam}$, are saturation, arrival or jam vehicles' density.

The Greenshields equilibrium u-k model is assumed [15]:

$$\vec{u}^L_{l,vt}(x,t) = (u^L_{l,vt,f}(1 - \frac{k^L_{l,vt}(x,t)}{k^L_{l,vt,jam}}), 0, 0), \; l = 1..n_L, \; vt = 1..VT,$$

$$\vec{u}^R_{r,vt}(x,t) = (-u^R_{r,vt,f}(1 - \frac{k^R_{r,vt}(x,t)}{k^R_{r,vt,jam}}), 0, 0), \; r = 1..n_R, \; vt = 1..VT,$$

In the boundary and initial conditions Bla, Bib, Blc, CI, we assumed that the only nonzero co-ordinates of velocities of mixture are the x- co-ordinates and they are equal to given constant *VX* (compare Table 1).

In the boundary and initial conditions B3a, B3b, B3c, C3, we assumed that all the concentrations are the same as the ones for air at standard temperature and pressure STP conditions. In the calculations we omitted the boundary conditions B3d, B3e, B3f.

From hundreds of performed optimizations Fl, F2, F3, F4, F5, F6 we select the 12 given in Table 1.

In Table 1 $yL = 0$ / $yR = 0$ means that the lengths of all queues on left/right lanes at the beginning were equal to zero, whereas $yL = 762$ / $yR = 762$ stands for the initial left/right queues filling whole canyon. $VX = 0$ is meant for zero initial and boundary velocity of mixture, while $VX - 1$ is put for the velocity of l[m/s]. If the latter holds then the left lanes are leeward and the right ones windward. If there are no vehicles on left or right lanes then $LON = 0$ or, $RON = 0$, respectively. *UNIFORM* $= 0$ stands for non-homogeneous (different) values of maximum free flow speed, jam, and saturation densities for $VT = 4$ types of vehicles (passenger cars, 8-, 12-, and 16-ton trucks).

$(C_{1TTT}, g_{1TTT}, C_{2TTT}, g_{2TTT}, F_{TTT})$ is the 5-tuple for optimal total travel time J_{TTT} F1, $(C_{1E}, g_{1E}, C_{2E}, g_{2E}, F_E)$ is the 5-tuple for optimal emissions J_E F2, and $(C_{1G}, g_{1G}, C_{2G}, g_{2G}, Fc)$ is the 5-tuple for optimal concentrations J_c F3.

$(C_{1TTText}, g_{1TTText}, C_{2TTText}, g_{2TTText}, F_{TTText})$ IS the 5-tUple for optimal total travel time $J_{TTT,ext}$ F4, $(C_{1Eext}, g_{1Eext}, C_{2Eext}, g_{2Eext}, F_{Eext})$ is the 5-tuple for optimal emissions $J_{E,ext}$ F5, and $(C_{1Cext}, g_{1Cext}, C_{2Cext}, g_{2Cext}, Fc_{ext})$ is the 5-tuple for optimal concentrations Jc_{ext} F6.

From the results presented in the Table 1 we infer that:

II. The optimal pollutant emissions and concentrations are the lowest if there are no vehicles on left (leeward) and right (windward) lanes; then they are greater if the vehicles are on both left and right lanes, next they are again greater if there are vehicles on right lanes; finally, they are the greatest if there are vehicles only on left lanes.

12. In cases Fl, F2, F3 if there are no vehicles on left and right lanes optimal total travel time and emissions are equal to zero, whereas optimal concentrations are not equal to zero since the pollutants are dispersed in the air even in the absence of vehicles (background pollutant concentrations). In the F4, FS, F6 cases all values are nonzero.

I3. The optimal 5-tuples in the Fl, F2, F3 cases are always different (no degeneration) with only one exception for the absence of vehicles (triple degeneration of 5-tuples). In some cases there is double degeneration between 5-tuples for F2 and F3.

I4. The optimal 5-tuple for total travel time is symmetrical and the offset is zero: ($C_{1TTT} = C_{2TTT}$, $g_{1TTT} = g_{2TTT}$, $F_{TTT} = 0$). C_{1TTT}, g_{1TTT}, tend to be minimal (the minimal capacity on both left and right lanes), only in the absence of vehicles on both lanes. In all other cases the optimal 5-tuple for total travel time is asymmetrical and the offset is nonzero. For the right lanes the cycle time is minimal whereas the green signal is short but not minimal. For the left lanes the cycle and green times are essentially longer than for right lanes. This is a result of co-ordination trade-offs between the traffic demands on the left and right lanes.

I5. If the optimal 5-tuples for F2, F3 cases are different from the 5-tuple for total travel time Fl, then they are asymmetrical and the offset is nonzero: the cycles and green times are not equal $(C_{1TTT} \neq C_{2TTT})$- and $(g_{1TTT} \neq g_{2TTT})$- The optimal offset F_{TTT} IS nontrivial parameter.

16. The optimal 5-tuples in the F4, F5, F6 cases are always different with the one exception for the absence of vehicles, however the green signals are short but not minimal. In some cases there is double degeneration between 5-tuples for F5 and F6.

I7. The optimal 5-tuple for total travel time (F4 case) is symmetrical when the offset is zero. The cycle times tend to be minimal, whereas the green signals are short but not minimal (only in the case of absence of vehicles on both lanes). In all other cases the optimal 5-tuple for total travel time F4 is asymmetrical and the offset is nonzero. For the right lanes the cycle time is minimal whereas the green signals are short but not minimal. For the left lanes the cycle and green times are essentially longer than for right lanes. This is a result of co-ordination trade-offs between the traffic demands on the left and right lanes.

18. If the optimal 5-tuples for FS, F6 cases are different from the 5-tuple of F4, then they are asymmetrical and the offset is nonzero: the cycles and green times are not equal and the optimal offset is a nontrivial parameter.

19. The 5-tuples for Fl and F4 are identical with the exception of the absence of vehicles (see 17).

110. The 5-tuples for F2 and F5 as well as F3 and F6 are not always identical.

111. The optimal total travel time values for F4 case are always greater than for Fl case.

Table 1.

Case		1	2	3	4	5	6	7	8	9	10	11	12
UNIFORM		0	0	1	1	0	0	1	1	0	1	1	0 or 1
yL	[m]	0	762	0	762	0	762	0	762	0	0	0	0
yR	[m]	0	762	0	762	0	0	0	0	0	0	762	0
VX	[m/s]	1	1	1	1	1	1	1	1	1	1	1	1
LON		1	1	1	1	1	1	1	1	0	0	0	0
RON		1	1	1	1	0	0	0	0	1	1	1	0
C1TTT	[s]	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	30.0
C2TTT	[s]	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
g1TTT	[s]	25.625	25.625	25.625	25.625	25.625	25.625	25.625	25.625	25.625	25.625	25.625	10.000
g2TTT	[s]	13.125	13.125	13.125	13.125	13.125	13.125	13.125	13.125	13.125	13.125	13.125	10.000
FTTT	[s]	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	0
JTTTx 10^2	[s]	6.4911	6.3818	1.1678	3.2456	0.5610	3.1741	0.5839	3.2456	0.5610	3.1741	0.5839	0
C1E	[s]	30.0	30.0	42.5	42.5	42.5	30.0	42.5	30.0	42.5	30.0	42.5	30.0
C2E	[s]	42.5	42.5	30.0	30.0	30.0	30.0	30.0	42.5	42.5	42.5	30.0	30.0
g1E	[s]	10.000	10.000	25.625	13.125	25.625	10.000	25.625	10.000	25.625	10.000	25.625	10.000
g2E	[s]	25.625	22.500	13.125	13.125	13.125	13.125	13.125	25.625	16.250	22.500	13.125	10.000
FE	[s]	40.625	3.125	0	25.000	0	25.000	0	40.625	0	3.125	0	0
JE	[kg]	0.1012	0.4709	6.4074	0.4083	1.4393	0.6837	3.2190	0.0506	1.4225	0.2355	3.2037	0
C1C	[s]	30.0	30.0	42.5	42.5	42.5	30.0	42.5	30.0	42.5	30.0	42.5	30.0
C2C	[s]	42.5	42.5	30.0	30.0	30.0	30.0	30.0	42.5	42.5	42.5	30.0	30.0
g1C	[s]	10.000	10.000	25.625	10.000	25.625	10.000	25.625	10.000	25.625	10.000	25.625	10.000
g2C	[s]	25.625	25.625	13.125	10.000	13.125	10.000	13.125	25.625	10.000	25.625	13.125	10.000
FC	[s]	40.625	40.625	0	25.000	0	25.000	0	40.625	0	40.625	0	0
JC × 10^3	[kgs]	10.789	10.789	10.789	10.789	10.791	10.789	10.794	10.789	10.791	10.789	10.794	10.789
C1TTText	[s]	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	42.5	30.0
C2TTText	[s]	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
g1TTText	[s]	25.625	25.625	25.625	25.625	25.625	25.625	25.625	25.625	25.625	25.625	25.625	13.125
g2TTText	[s]	13.125	13.125	13.125	13.125	13.125	13.125	13.125	13.125	13.125	13.125	13.125	13.125
FTTText	[s]	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	0
JTTT × 10^2	[s]	11.891	11.748	6.568	8.646	5.961	8.574	5.984	8.646	5.961	8.574	5.984	5.400
C1Eext	[s]	30.0	30.0	42.5	30.0	42.5	30.0	42.5	30.0	42.5	30.0	42.5	30.0
C2Eext	[s]	42.50	42.5	30.0	30.0	30.0	30.0	30.0	42.5	30.0	42.5	30.0	30.0
g1Eext	[s]	13.125	10	25.625	13.125	25.625	13.125	25.625	13.125	25.625	13.125	25.625	13.125
g2Eext	[s]	25.625	25.625	13.125	13.125	13.125	13.125	13.125	25.625	13.125	25.625	13.125	13.125
FEext	[s]	40.625	7.8125	0	25.000	0	25.000	0	40.625	0	3.125	0	0
JEext	[kg]	0.8660	1.6017	7.4421	1.1452	2.1706	1.7517	4.2537	0.7986	2.1542	1.3530	4.2384	0.7313
C1Cext	[s]	30.0	30.0	42.5	30.0	42.5	30.0	42.5	30.0	42.5	30.0	42.5	30.0
C2Cext	[s]	42.50	42.5	30.0	30.0	30.0	30.0	30.0	42.5	30.0	42.5	30.0	30.0
g1Cext	[s]	13.125	13.125	25.625	13.125	25.625	13.125	25.625	13.125	25.625	13.125	25.625	13.125
g2Cext	[s]	25.625	25.625	13.125	13.125	13.125	13.125	13.125	25.625	13.125	25.625	13.125	13.125
FCext	[s]	35.938	40.625	0	21.875	0	21.875	0	34.375	1.563	40.625	0	0
JCext × 10^3	[kgs]	18.439	18.439	18.448	18.440	18.441	18.440	18.444	18.440	18.441	18.440	18.443	18.400

112. The optimal emission values for F5 case are always greater than for F2 case.

113. The optimal pollutant concentration values for F6 case are always greater than for F3 case.

Conclusions

The pro-ecological traffic control idea and advanced model of the street canyon have been presented in this paper. It was found that the proposed model is reasonably tractable and represents the essential features of very complex air pollution phenomena. As numerical results show, pro-ecological control actions may be in some cases highly beneficial. It can be argued that this control model of the street canyon may be in a simple way extended to the practically observed situations of 3-D representations of vehicles, multilevel streets and junctions as well as cases with nonhomogeneous canyon walls. Finally, let us note that until now the air pollution models have not been used directly for real-time traffic road control purposes.

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APPENDIX I. NOTATION

The following symbols are used in this paper:
a,b,c = street canyon dimensions
α = pre-factors of functional
c = concentration
C = cycle time
δ = numerical step

e = emissivity
F = offset time
g = green time
G = traffic signal
J = functional to be minimized
k = vehicles density
p = pressure
ρ = mixture density
σ = heat production rate
T = temperature
u = control variable
$\vec{u}$ = vehicles velocity
U^{adm} = set of admissible control variables
Sets of indices:
0 = initial condition index
$ct = 1...CT$ concentration type index
$i = 1...N$ mixture constituent index
in / out = entrance/exit junction quantity index
$j = 1...m$ traffic junction number
$l = 1...n_L$ left lane number
$n_e = 1...N_E$ emission number
$r = 1...n_R$ right lane number
TTT, E, C, ext = control performance indices
$vt = 1...VT$ vehicle type index

APPENDIX II.

B. Boundary conditions.

B1a. $\vec{v}\,(0,y,z,t) = \vec{v}_{Ib}\,(y,z,t).$
B1b. $\vec{v}\,(a,y,z,t) = \vec{v}_{IIb}\,(y,z,t).$
B1c. $\vec{v}\,(x,y,c,t) = \vec{v}_{IIIb}\,(x,y,t).$
B1d-B1f. $\vec{v}\,(x,0,z,t) = \vec{v}\,(x,b,z,t) = \vec{v}\,(x,y,0,t) = \vec{0}.$
B2a. $\rho\,(0,y,z,t) = \rho_{Ib}\,(y,z,t).$
B2b. $\rho\,(a,y,z,t) = \rho_{IIb}\,(y,z,t).$
B2c. $\rho\,(x,y,c,t) = \rho_{IIIb}\,(x,y,t).$

B2d-B2f. $\dfrac{\partial \rho}{\partial y}\,(x,0,z,t) = \dfrac{\partial \rho}{\partial y}(x,b,z,t) = \dfrac{\partial \rho}{\partial z}(x,y,0,t) = 0.$

B3a. $c_i\,(0,y,z,t) = c_{iIb}\,(y,z,t),\ i = 1..N.$
B3b. $c_i\,(a,y,z,t) = c_{iIIb}\,(y,z,t),\ i = 1..N.$
B3c. $c_i\,(x,y,c,t) = c_{iIIIb}\,(x,y,t),\ i = 1..N.$

B3d-B3f. $\dfrac{\partial c_i}{\partial y}\,(x,0,z,t) = \dfrac{\partial c_i}{\partial y}\,(x,b,z,t) = \dfrac{\partial c_i}{\partial z}\,(x,y,0,t) = 0,$
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad i = 1..N.$

B4a. $p(0,y,z,t) = p_{Ib}(y,z,t).$
B4b. $p(a,y,z,t) = p_{IIb}(y,z,t).$
B4c. $p(x,y,c,t) = p_{IIIb}(x,y,t).$

B4d-B4f. $\dfrac{\partial p}{\partial y}\,(x,0,z,t) = \dfrac{\partial p}{\partial y}\,(x,b,z,t) = \dfrac{\partial p}{\partial z}(x,y,0,t) = 0.$
B5a. $k^L_{l,vt}(0,t) = k^L_{l,vt,in}(t),\ vt = 1..VT,\ l = 1..n_L.$
B5b. $k^L_{l,vt}(a,t) = k^L_{l,vt,out}(t),\ vt = 1..VT,\ l = 1..n_L.$
B5c. $k^R_{r,vt}(0,t) = k^R_{r,vt,out}(t),\ vt = 1..VT,\ r = 1..n_R.$
B5d. $k^R_{r,vt}(a,t) = k^R_{r,vt,in}(t),\ vt = 1..VT,\ r = 1..n_R.$
B6a. $\vec{u}^L_{l,vt}\,(0,t) = \vec{u}^L_{l,vt,in}\,(t),\ vt = 1..VT,\ l = 1..n_L.$
B6b. $\vec{u}^L_{l,vt}\,(a,t) = \vec{u}^L_{l,vt,in,out}\,(t),\ vt = 1..VT,\ l = 1..n_L.$
B6c. $\vec{u}^R_{r,vt}\,(0,t) = \vec{u}^R_{r,vt,out}\,(t),\ vt = 1..VT,\ r = 1..n_R.$
B6d. $\vec{u}^R_{r,vt}\,(a,t) = \vec{u}^R_{r,vt,in}\,(t),\ vt = 1..VT,\ r = 1..n_R.$
B7a. $e^L_{l,ct,vt}\,(0,t) = e^L_{l,ct,vt,in}\,(t),\ ct = 1..CT,\ vt = 1..VT,$
$l = 1..n_L.$
B7b. $e^L_{l,ct,vt}\,(a,t) = e^L_{l,ct,vt,out}\,(t),\ ct = 1..CT,\ vt = 1..VT,$
$l = 1..n_L.$
B7c. $e^R_{r,ct,vt}\,(0,t)=e^R_{r,ct,vt,out}\,(t),\ ct = 1..CT,\ vt = 1..VT,$
$r = 1..n_R.$
B7d. $e^R_{r,ct,vt}\,(a,t) = e^R_{r,ct,vt,in}\,(t),\ ct = 1..CT,\ vt = 1..VT,$
$r = 1..n_R.$

Conditions **B1d-B1f** result from viscosity of the gaseous mixture since the velocity of viscous fluid on immobile and impervious surface is zero. Similarly, conditions **B2d-B2f**, **B3d-B3f**, **B4d-B4f** result from the fact that the walls and the surface of the road are impervious solid bodies.

Remark: The functions: $\vec{v}_{Ib}, \vec{v}_{IIb}, \vec{v}_{IIIb}, \rho_{Ib}, \rho_{IIb}, \rho_{IIIb}, c_{iIb}, c_{iIIb}, c_{iIIIb},\ i = 1..N,\ p_{Ib}, p_{IIb}, p_{IIIb}, k^L_{l,vt,in}, k^L_{l,vt,out}, k^R_{r,vt,in}, k^R_{r,vt,out}, \vec{u}^L_{l,vt,in}, \vec{u}^L_{l,vt,out}, \vec{u}^R_{r,vt,in}, \vec{u}^R_{r,vt,out}, e^L_{l,ct,vt,in}, e^L_{l,ct,vt,out}, e^R_{r,ct,vt,in}, e^R_{r,ct,vt,out}, ct = 1..CT,\ vt = 1..VT,\ l = 1..n_L,\ r = 1..n_R,$ are given and fulfil the natural constraints: $\sum\limits_{i=1}^{N} c_{iIb} = \sum\limits_{i=1}^{N} c_{iIIb} = \sum\limits_{i=1}^{N} c_{iIIIb} = 1.$

C. Initial conditions.

C1. $\vec{v}\,(x,y,z,0) = \vec{v}_0\,(x,y,z).$
C2. $\rho\,(x,y,z,0) = \rho_0\,(x,y,z).$
C3. $c_i\,(x,y,z,0) = c_{i0}\,(x,y,z),\ i = 1..N.$
C4. $p\,(x,y,z,0) = p_0(x,y,z).$
C5a. $k^L_{l,vt}(x,0) = k^L_{l,vt,0}(x),\ vt = 1..VT,\ l = 1..n_L.$
C5b. $k^R_{r,vt}(x,0) = k^R_{r,vt,0}(x),\ vt = 1..VT,\ r = 1..n_R.$
C6a. $\vec{u}^L_{l,vt}\,(x,0) = \vec{u}^L_{l,vt,0}\,(x),\ vt = 1..VT,\ l = 1..n_L.$
C6b. $\vec{u}^R_{r,vt}\,(x,0) = \vec{u}^R_{r,vt,0}\,(x),\ vt = 1..VT,\ r = 1..n_R.$
C7a. $e^L_{l,ct,vt}(x,0) = e^L_{l,ct,vt,0}\,(x),\ ct = 1..CT,\ vt = 1..VT,\ l = 1..n_L.$
C7b. $e^R_{r,ct,vt}(x,0) = e^R_{r,ct,vt,0}\,(x),\ ct = 1..CT,\ vt = 1..VT,\ r = 1..n_R.$

Remark: The functions $\vec{v}_0, \rho_0, c_{i0},\ i = 1..N,\ p_0, k^L_{l,vt,0}, k^R_{r,vt,0}, \vec{u}^L_{l,vt,0}, \vec{u}^R_{r,vt,0}, e^L_{l,ct,vt,0}, e^R_{r,ct,vt,0}, ct = 1..CT,\ vt = 1..VT,\ l = 1..n_L, r = 1..n_R,$ are given and fulfil the constraint: $\sum\limits_{i=1}^{N} c_{i0} = 1.$