OPTYMALIZACJA ZANIECZYSZCZEŃ POWIETRZA W KANIONACH ULICZNYCH PRZEZ STEROWANIE RUCHEM DROGOWYM W OPARCIU O ZAAWANSOWANY MODEL KANIONU

dr hab. inż. Andrzej Adamski Prof. PK #*, dr Maciej M. Duras ##,*(doctoral student)

 # Division of Transport Organization, Department of Civil Engineering,
Cracow University of Technology, J. Pawla II37, 31-864 Cracow, Poland.
** Institute of Automatics, Cracow University of Mining and Metallurgy,*
Al. Mickiewicza 30, 30-059 Cracow, Poland.
Institute of Physics, Cracow University of Technology, Podchorążych 1, 31-084 Cracow, Poland.

Streszczenie

W pracy przedstawiono propozycję systemowego zintegrowanego podejścia do problemów pro-ekologicznego zarządzania i sterowania ruchem drogowym w miastach. W tym kontekście sformułowano i rozwiązano problem optymalnego, w sensie minimalizacji zanieczyszczeń powietrza, sterowania ruchem drogowym w kanionach ulicznych. Dla potrzeb tego problemu stworzono zaawansowany hydrodynamiczny model kanionu ulicznego w którym reprezentowany jest dwukierunkowy, wielopasmowy ruch wielu typów emisyjnych pojazdów i estymowanych jest wiele typów zanieczyszczeń powietrza. Rozwiązano numerycznie 12 przykładów dla rzeczywistego kanionu w Krakowie i podano optymalne sterowania dla trzech kryteriów sterowania ruchem w kanionie tj. globalnego czasu podróży, natężenia emisji i koncentracji zanieczyszczeń

ADVANCED MODEL-BASED AIR POLLUTION OPTIMAL TRAFFIC CONTROL IN STREET CANYONS

Andrzej Adamski and Maciej M. Duras

Abstract

In this paper a system analysis integrated approach to the pro-ecological urban traffic management and control problems is presented. In this context the problem aimed at air pollution dependent optimal traffic road control in the street canyon is formulated and solved. A general traffic control idea for the street canyon is proposed with emphasis placed on the development of advanced hydrodynamic control model of the street canyon including: multi-lane, 1-D bi-directional model of movement of several emission types of vehicles and of emitted pollutants. The optimal in the sense of total travel time, pollutant emission and concentration pro-ecological control problems for one of the street canyons in Kraków are formulated and illustrated by 12 numerical examples.

Introduction

Increasing social costs of road transport due to air and noise pollution and lack of safety, motivate first of all the need for a more efficient use the existing transportation facilities and services. In the most developed countries this costs are approximately estimated to a few percent of GDP and show an increasing non-linear tendency. The forecast of increase road traffic in Europe (between 80 and 150% by the year 2025 [11]) pose difficult challenges to keep the transport related social costs within sensible bounds (e.g. "sustainable mobility" paradigm [9]). The scientific highly distributed research are concentrated presently on identification and evaluation of different aspects of transportation-environment interactions by simulation, empirical and analytical models for tactical/ strategical transportation planning DSS or short/medium term prediction purposes. Research projects are concerned with proposals of technological innovations (e.g. alternative fuels, efficient silent engines, catalytic converters), socio-economic measures based network evaluation and management tools, impacts analysis of transport measures in terms of pollutant and energy consumption [11]. Several general-purpose predictive dispersion models have been developed (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 in urban streets (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, among others with:
- Oversimplified representation of the main determinants which influence the pollutant concentration in the streets vicinity e.g. traffic road processes which create the emission source and physical processes which proceed in the street canyons. For example, it is common to assume a straight line emission source with constant rate of emission over the length of road (HIWAY, CALINE) or user defined road segments (PREDCO). In EMAM models, vehicle operating modes representation seems to be oversimplified, especially in the

cases when the "fluid" vehicle homogeneous queuing 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.

- High uncertainties in the estimates of the model input parameters e.g. meteorological parameters.
- Poor real-time measurements data and data-based experimental knowledge of temporal and spatial pollutant concentration distributions in various types of street canyons.

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

General traffic control idea for street canyon

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 have 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 data equipped 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 the 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 knowledge base which organise and use rich bodies of data [13] available for analysis and tools capable of dealing with and efficiently searching through a practically 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 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 the 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 the adverse environmental impacts) actions with a short reaction time to an 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 terms of both demand and supply side effects. Demand reduction in 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 characterised by overall reduction in delay, emissions and energy consumption for the same traffic volume and decreasing the 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:

I. <u>Planning Layer</u>

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:

<u>Data and Knowledge Bases</u> which are generated, verified and up-dated automatically by modern AI tools [11,13]

<u>Methods and Tool Bases</u> equipped with family of application dedicated models and methods.

II **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 summarised 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 $g_i \in [g_{min}, g_{max}]$ and cycle times $C \in [C_{min}, C_{max}]$ on the entrance and exit signalised junctions. The availability of video-detectors makes it possible to use direct environmental measures in the single and multicriteria control problems [8]. The entrance control is a general gating type of control which, by selection of entrance traffic signals parameters, controls the number of vehicles entering the street canyon. Similarly, exit control determines 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 $F \in [0, C)$. The 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 the real-time estimated parameters p_e / p_d as well as activates (if it is 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 off-line prepared traffic scenarios according to on-line calculated set of markers describing 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 vehicles 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 of a model parameters p_e and p_d during model updating process is forming 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 the 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 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 the simple connection algebra is an advantageous representation of various network problems and enables us to concentrate on the solution of the “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:

G1. 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 $y = 0, y = b$ and 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_R right ones (the traffic is bi-directional).

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

P1. 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_2O, 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 the 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 the combustion the heat produced is neglected.

P4. The gaseous mixture is treated as polytropic, compressible, Newtonian, and viscous fluid. We assume that also the components of the mixture are polytropic, compressible, Newtonian, and viscous fluids. The components do not interact with each other. The i^{th} component possesses individual velocity $\vec{v}_i(x,y,z,t)$, density $\rho_i(x,y,z,t)$, and preassure $p_i(x,y,z,t)$, whereas the mixture possesses the total velocity $\vec{v}(x,y,z,t)$, density $\rho(x,y,z,t)$, and preassure $p(x,y,z,t)$ .We assume that

$$\vec{v}(x,y,z,t) = \sum_{i=1}^{N} \frac{\rho_i(x,y,z,t)}{\rho(x,y,z,t)} \vec{v}_i(x,y,z,t), \rho(x,y,z,t) = \sum_{i=1}^{N} \rho_i(x,y,z,t), p(x,y,z,t) = \sum_{i=1}^{N} p_i(x,y,z,t).$$

In order to make less complex the set of equations governing the dynamics of mixture we assume that the total velocity is equal to the velocities of the components

$$\vec{v}(x,y,z,t) = \vec{v}_i(x,y,z,t), i = 1..N.$$

Hence, we can restrict our attention to the equations of conservation of total mass of mixture **E2**, of total momentum of mixture **E1**, and of the conservation of mass of components **E3**. We assume that the equation of state for mixture **E4** is averaged over the components.

We study the motion of this mixture. The turbulence 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 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. The chemical reactions are neglected with exception of combustion of oxygen.

P8. The dependence of the processes on temperature is neglected.

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

The following set of descriptive dynamic **model variables A1-A9** together with their **boundary B1-B7 (for t≥0)** and **initial conditions C1-C7 (for t=0)** , and with the set of equations **E1-E6** that governs their dynamics, is assumed:

A. Variables.

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

$$\vec{v}(x,y,z,t) = \sum_{i=1}^{N} \frac{\rho_i(x,y,z,t)}{\rho(x,y,z,t)} \vec{v}_i(x,y,z,t).$$

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

$$\rho(x,y,z,t) = \sum_{i=1}^{N} \rho_i(x,y,z,t).$$

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

$$c_i(x,y,z,t) = \frac{\rho_i(x,y,z,t)}{\rho(x,y,z,t)}, i = 1..N.$$

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

$$p(x,y,z,t) = \sum_{i=1}^{N} p_i(x,y,z,t).$$

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

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

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

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

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

A7b. $e^R_{r,ct,vt}(x,t), ct = 1..CT, vt = 1..VT, r = 1..n_R$ 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 $F \in [F_{min}, F_{max}]$. 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

$$U^{adm} = \{(g_1, C_1, g_2, C_2, F): C_j \in [C_{jmin}, C_{jmax}], g_j \in [g_{jmin}, C_j - g_{j,orth}], F \in [F_{min}, F_{max}]\}$$

A9a. $G^L_{out}(C_1, g_1, F, t)$, the signal at $x = a$ for all left lanes.

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

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. $\frac{\partial \rho}{\partial y}(x, 0, z, t) = \frac{\partial \rho}{\partial y}(x, b, z, t) = \frac{\partial \rho}{\partial z}(x, y, 0, t) = 0$.

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. $\frac{\partial c_i}{\partial y}(x, 0, z, t) = \frac{\partial c_i}{\partial y}(x, b, z, t) = \frac{\partial c_i}{\partial z}(x, y, 0, t) = 0, i = 1..N$.

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. $\frac{\partial p}{\partial y}(x, 0, z, t) = \frac{\partial p}{\partial y}(x, b, z, t) = \frac{\partial p}{\partial z}(x, y, 0, t) = 0$.

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. $\vec{u}^L_{l,vt}(a, t) = \vec{u}^L_{l,vt,out}(t), vt = 1..VT, l = 1..n_L$.

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: $\sum_{i=1}^{N} c_{iIb} = \sum_{i=1}^{N} c_{iIIb} = \sum_{i=1}^{N} c_{iIIIb} = 1$.

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: $\sum_{i=1}^{N} c_{i0} = 1$.

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 $z = 0$:

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

$Set_{N_E}(x,y,z,t)$, 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 $Set_{N_E}(x,y,z,t) = ONOX \cdot Set_{N_E-1}(x,y,z,t)$, 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 ($\eta = 18.1 \cdot 10^{-6}[\frac{kg}{s \cdot m}]$ for air at temperature $T = 293[K]$), ξ is second viscosity coefficient ($\xi = 15.6 \cdot 10^{-6}[\frac{kg}{s \cdot m}]$ 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 ($\vec{g} = (0,0,-9.81)[\frac{m}{s^2}]$). 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. $$\rho(\frac{\partial c_i}{\partial t} + \vec{v}\nabla c_i) = Set_i - c_i S + \sum_{m=1}^{N-1}(D_{im} - D_{iN})[\rho\Delta c_m + (\nabla\rho)(\nabla c_m)], i = 1..N_E,$$

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

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 ($p_0 = 1[atm], \rho_0 = 1.293[\frac{kg}{m^3}]$). We assume that the gaseous mixture is polytropic.

E5. Conservation of Vehicles - Equation of continuity.

E5a. $$\frac{\partial k^L_{l,vt}}{\partial t} + div(k^L_{l,vt}\vec{u}^L_{l,vt}) = 0, l = 1..n_L, vt = 1..VT.$$

E5b. $$\frac{\partial k^R_{r,vt}}{\partial t} + div(k^R_{r,vt}\vec{u}^R_{r,vt}) = 0, r = 1..n_R, vt = 1..VT.$$

E6. Technical parameters.

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

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

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

where
$|\vec{u}^L_{l,ct,vt}(x,t)| \in (v_{ct,vt,i_l}, v_{ct,vt,i_l+1}), |\vec{u}^R_{r,ct,vt}(x,t)| \in (v_{ct,vt,i_r}, v_{ct,vt,i_r+1}), l = 1..n_L, ct = 1..CT, vt = 1..VT,$
$v_{ct,vt,i_l}, v_{ct,vt,i_l+1}, v_{ct,vt,i_r}, v_{ct,vt,i_r+1}$, are experimental velocities and $e_{ct,vt,i_l}, e_{ct,vt,i_r}$ are experimental emissions of ct^{th} exhaust gas from single vehicle of vt^{th} type at velocity v_{ct,vt,i_l}, 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. $\inf_{u \in U^{adm}} J_{TTT}(u)$, where $J_{TTT}(u) = \sum_{l=1}^{n_L}\sum_{vt=1}^{VT}\int_0^T\int_0^a k^L_{l,vt}(x,t)dtdx + \sum_{r=1}^{n_R}\sum_{vt=1}^{VT}\int_0^T\int_0^a k^R_{r,vt}(x,t)dtdx$,

F2. $\inf_{u \in U^{adm}} J_E(u)$ where $J_E(u) = \sum_{l=1}^{n_L}\sum_{ct=1}^{CT}\sum_{vt=1}^{VT}\int_0^T\int_0^a e^L_{l,ct,vt}(x,t)dtdx + \sum_{r=1}^{n_R}\sum_{ct=1}^{CT}\sum_{vt=1}^{VT}\int_0^T\int_0^a e^R_{r,ct,vt}(x,t)dtdx$,

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

Remark: J_{TTT} is measured in [s], J_E is measured in [kg], and J_C is measured in [kg * s].
The density of vehicles, the emissions and concetrations in **F1**, **F2**, **F3** are the solutions of equations **E1**-**E6** with given boundary **B1**-**B7** and initial conditions **C1**-**C7**, and the sources **D1**-**D2**. The functionals in **F1**, **F2**, **F3** depend on the control u through the conditions given in the next section.

Numerical examples

We solve the set of nonlinear partial differential equations **E1**-**E6** with given boundary **B1**-**B7** and initial conditions **C1**-**C7** by finite difference method using the C language program written by one of authors (Maciej Duras). We solve this set in the cuboid starting from intial conditions and we iterate it over the time period $[0,T]$ using the direct finite difference method taking into account the boundary **B1**-**B7** conditions and the sources **D1**-**D2** and initial conditions at each time step. The functionals in **F1**, **F2**, **F3** are iterated with the same steps that the equations **E1**-**E6**.

We assumed the following data from the canyon in Krasiñski street in Kraków:

- $VT = 4, n_L = n_R = 2$; $CT = N_E - 1 = 3$; $a = 300[m], b = 30[m], c = 20[m], T = 90[s]$,
- $\delta_x = 30[m], \delta_y = 6[m], \delta_z = 4[m], \delta_t = 7.2[s]$, the steps in x, y, z, t, directions,
- $\delta_{C_1} = 22.5[s], \delta_{g_1} = 5.625[s], \delta_{C_2} = 22.5[s], \delta_{g_2} = 5.625[s], \delta_F = 5.625[s]$, 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 $C_{j,\max} = T$, $g_{j,\max} = C_i - g_{i,orth}$, $F_{\max} = F - \delta_F$ the maximal values..

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

$k^L_{l,vt,in}(t) = k^L_{l,vt,arrival}$ if $G^R_{out}(C_2, g_2, F, t) = GREEN$, and there is no queue at $x = 0$,
$k^L_{l,vt,in}(t) = k^L_{l,vt,sat}$ if $G^R_{out}(C_2, g_2, F, t) = GREEN$, and there is queue at $x = 0$,
$k^L_{l,vt,in}(t) = k^L_{l,vt,jam}$ if $G^R_{out}(C_2, g_2, F, t) = RED$,
$k^R_{r,vt,in}(t) = k^R_{r,vt,arrival}$ if $G^L_{out}(C_1, g_1, F, t) = GREEN$, and there is no queue at $x = a$,
$k^R_{r,vt,in}(t) = k^R_{r,vt,sat}$ if $G^L_{out}(C_1, g_1, F, t) = GREEN$, and there is queue at $x = a$,
$k^R_{r,vt,in}(t) = k^R_{r,vt,jam}$ if $G^L_{out}(C_1, g_1, F, t) = RED$,
$k^L_{l,vt,out}(t) = k^L_{l,vt,arrival}$ if $G^L_{out}(C_1, g_1, F, t) = GREEN$, and there is no queue at $x = a$,
$k^L_{l,vt,out}(t) = k^L_{l,vt,sat}$ if $G^L_{out}(C_1, g_1, F, t) = GREEN$, and there is queue at $x = a$,
$k^L_{l,vt,out}(t) = k^L_{l,vt,jam}$ if $G^L_{out}(C_1, g_1, F, t) = RED$,
$k^R_{r,vt,out}(t) = k^R_{r,vt,arrival}$ if $G^R_{out}(C_2, g_2, F, t) = GREEN$, and there is no queue at $x = 0$,
$k^R_{r,vt,out}(t) = k^R_{r,vt,sat}$ if $G^R_{out}(C_2, g_2, F, t) = GREEN$, and there is queue at $x = 0$,
$k^R_{r,vt,out}(t) = k^R_{r,vt,jam}$ if $G^R_{out}(C_2, g_2, F, t) = RED$,
$l = 1..n_L, r = 1..n_R, vt = 1..VT.$
The existence of the 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
$k^L_{l,vt}(-\delta_x, t) = k_{GREEN}$ for $t \in [0, g_1) \cup [C_1, C_1 + g_1) \cup ...,$
$k^L_{l,vt}(-\delta_x, t) = k_{RED}$ $k^L_{l,vt,in}(t) = k_{RED}$ for $t \in [g_1, C_1) \cup [C_1 + g_1, 2C_1) \cup ...,$
$k^R_{r,vt}(a + \delta_x, t) = k_{GREEN}$ $k^R_{r,vt,in}(t) = k_{GREEN}$ for $t \in [F, F + g_2) \cup [F + C_2, F + C_2 + g_2) \cup ...,$
$k^R_{r,vt}(a + \delta_x, t) = k_{GREEN}$ $k^R_{r,vt,in}(t) = k_{RED}$ for $t \in [0, F) \cup [F + g_2, F + C_2 + g_2) \cup ...,$
where $k_{GREEN} = 0.133[veh/m], k_{RED} = 0.067[veh/m]$,
$k^L_{l,vt,sat}, k^R_{r,vt,sat}, k^L_{l,vt,arrival}, k^R_{r,vt,arrival}, k^L_{l,vt,jam}, k^R_{r,vt,jam}$, 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 **B1a**, **B1b**, **B1c**, **C1**, 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 **F1**, **F2**, **F3**, we select the 12 given in Table 1.
In the 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 $yL = 300 / yR = 300$ stands for the initial left /right queues filling whole canyon. $VX = 0$ is meant for no initial and boundary velocity of mixture, while $VX = 1$ is put for the velocity of 1[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 nonhomogeneous (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 time travel J_{TTT} **F1**, $(C_{1E}, g_{1E}, C_{2E}, g_{2E}, F_E)$ is the 5-tuple for optimal emissions J_E **F2**, and $(C_{1C}, g_{1C}, C_{2C}, g_{2C}, F_C)$ is the 5-tuple for optimal concentrations J_C **F3**.
From the results indicated in the Table 1 we infer that:
I1.If there are no vehicles on left and right lanes optimal total time travel and emissions are equal to zero, however optimal concentrations J_C **F3** are not equal to zero since the pollutants are dispersed in the air even in the absence of vehicles (background pollutant concentrations).
I2.The optimal 5-tuples for the cases **F1**, **F2**, **F3**, are non-identical (no degeneration of 5-tuples), 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**.
I3. The optimal offset parameter is a nontrivial parameter.
I4. Due to co-ordination of traffic intersections by means of offsets and boundary conditions, the opposite (antiparallel) directions of the wind and traffic flow do not cause decreasing of pollutant concentrations.
I5. The $g_{1E}, g_{2E}, g_{1C}, g_{2C}$ parameters tend to be minimal with only one exception. The cycles C_{1TTT}, C_{1E}, C_{1C}, are always greater or equal to C_{2TTT}, C_{2E}, C_{2C}, respectively. This is result of co-ordination trade-offs between the traffic demands on the left and right lanes.

Conclusions

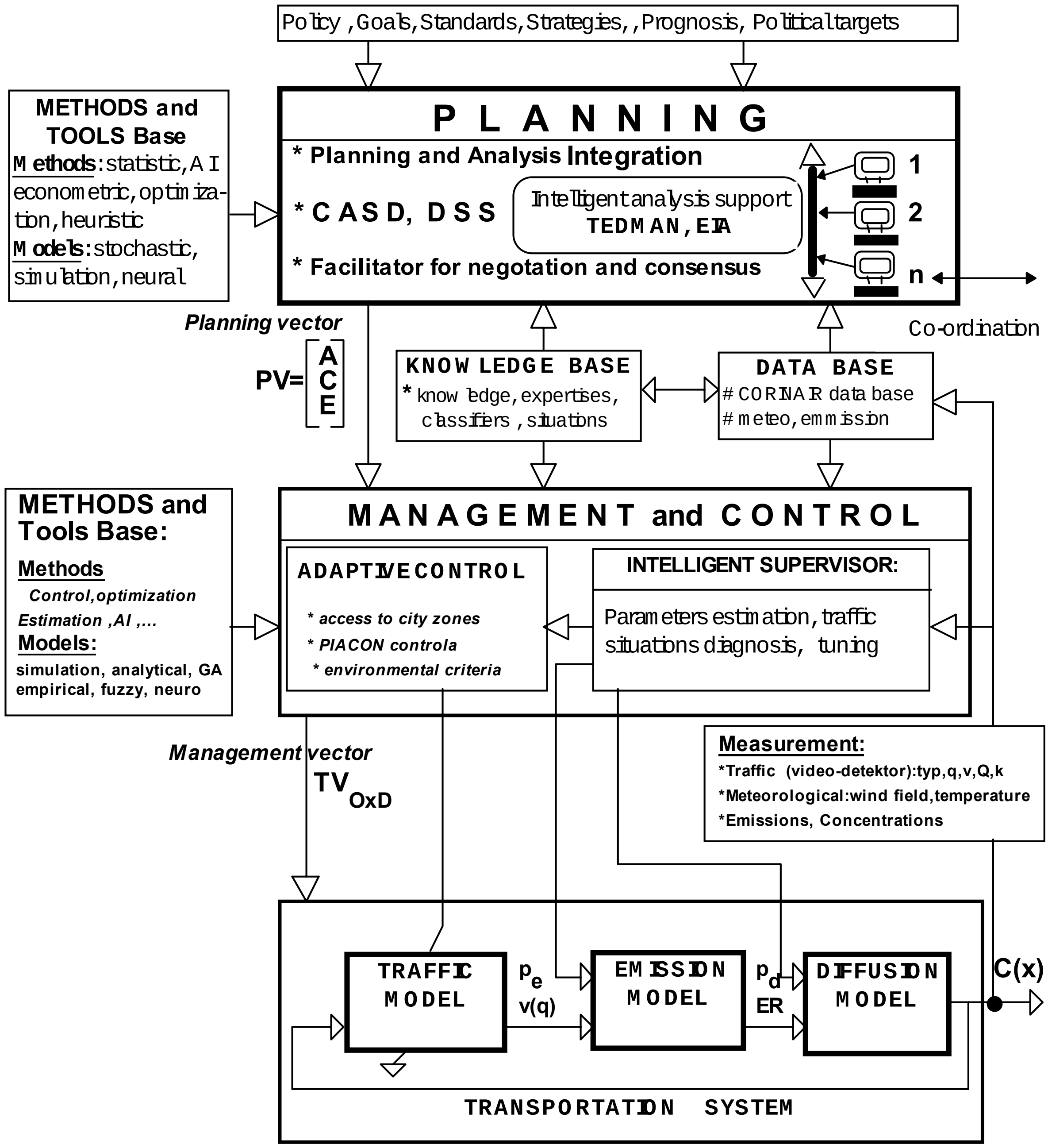
The pro-ecological traffic control idea and advanced model of the street canyon have been presented in this paper. It was found that the proposed model is reasonably tractable and represents the essential features of the very complex air pollution phenomena As numerical results shows the pro-ecological 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 the real-time traffic road control purposes.

References

[1] Adamski A. ”Environmental criteria in Integrated Urban Traffic Control and Management Systems” Polish Journal of Environmental Studies, vol. 2, no.2, pp. 7-11, 1993.
[2] Adamski A. ”Multicriterial Approach to Traffic Adaptive Control at a Signalized Traffic Intersection”. Foundations of Computing and Decision Sciences, Kluwier Press, 20(2): 77-97, 1994.
[3] Adamski A.”Polyoptimal integrated traffic road control on an intersection with feedback realized by video-detectors”. Elektrotechnika, 14(3): 143-156, 1995a.
[4] Adamski A. ”IVHS approach to environment protection in transport” Proc.1-st Polish Conf. Environment Protection in Transport and Transportation Building, Zakopane'95 pp 11-22 1995b

[5] Adamski A "Multicriteria Traffic Control with Video Feedback" Applications of Advanced Technologies in Transportation Engineering. ASCE Publ. ,Eds. Y.J. Stephanedes and Filippi, pp. 620-627, 1996.
[6] Adamski A., A. Rudnicki, E. Goras, T. Kopta "Protection tools against traffic road air pollution" (chapter 2 with 5 appendixes) in the book Principles of environment protection in traffic road design, construction and maintenance. Polish General Directorate of Public Roads, pp. 198-270.
[7] Adamski A. and M.M. Duras "Environmental traffic control issues in street canyons". Polish Journal of Environmental Studies, vol. 6, no. 1, pp. 13-20, 1997.
[8] Adamski A. and K. Florek "TEDMAN System Analysis Approach for Traffic Control at Signalized Junction". AUTOMATICS, vol. 1, no.1, pp.443-456, 1997.
[9] Ambrosino G., M. Bielli, P. Carotenuto, M. Romanazzo, P. Sassali "A modelling framework for impact assesment of urban transportation systems" IFAC /IFIP/IFORS Symposium 16-18 June , Chania, Grecee, pp. 1037-1041,1997
[10] Benson P.E. "CALINE-4 a dispersion model for predicting air pollution concentrations near roadways". FHWA/CA/TL-84/15, 1989.
[11] Bieli M., P. Carotenuto, V.DelleSite "Advanced research on transport environment interactions". IFAC /IFIP/IFORS Symposium 16-18 June , Chania, Grecee, pp. 1029-1036,1997.
[12] Chapman S. and T.G. Cowling "The mathematical theory of non-uniform gases" Cambridge University Press (Table no. 22, pp. 263, Table no. 24, pp. 266, Table no. 25, pp.267), 1970.
[13] Eggleston H.S, Gaudioso D, Gorissen H, Joumard R, Rijkeboer R.C, Samaras Z, Zierock K.H "CORINAIR Working Group on emission factors for calculating 1990 emissions from road traffic Final Report CEC Bruxelles.
[14] Eringen A.C. and Maugin G.A. "Electrodynamics of Continua" Springer Verlag N.Y. vol. I Chapters 3,5, vol. II Chapters 9, 10, 1990.
[15] Greenshields B.D. "A study of traffic capacity" Proc. Hwy. Res. Board, 14:448-477, 1934.
[16] Hickman A.J. and Colwill D.M. "The estimation of air pollution concentrations from road traffic" TRRL report 1052, 1982.
[17] Johnson W.B., Ludwig F.L., Dabbert W.F. Allen R.J. "An urban diffusion simulation model for carbon monoxide" J. Air Pollut. Contr. Assoc., 23:490-498, 1973.
[18] Joumard R et al. "Model of exhaust and noise emissions and fuel consumption of traffic in urban areas" Manual INRETS-LEN Rep. 912, Bron.
[19] Kanafani A, A. Khattak, J. Dahlgren "A planning, methodology for intelligent urban transportation systems. Transpn. Res.-C, vol. 2, no. 6, pp. 197-215.
[20] Kono H. and Ito S. "A micro-scale dispersion model for motor vehicle exhaust gas in urban areas - OMG volume-source model" Atmospheric Environment, 24B(2): 243-251, 1990.
[21] Landau L.D. and Lifshits E.M. "Hydrodynamics" Nauka Moscow, Chapters 2,6, 1986.
[22] Matzoras A. and Van Vliet D. "A model of air pollution from road traffic, based on the characteristics of interrupted flow and junction control: Part1 - Model description" Transpn. Res., 26A(4): 315-330, 1992.
[23] Matzoras A. and Van Vliet D. "A model of air pollution from road traffic, based on the characteristics of interrupted flow and junction control: Part2 - Model results" Transpn. Res., 26A(4): 331-355, 1992.
[24] Michalopoulos P. G., Beskos D. E., and Lin J. -K. "Analysis of Interrpted Traffic Flow by Finite Difference Methods," Transpn. Res. -B, 18B (4/5): 409-421, 1984:.
[25] Petersen W.B. "A highway air pollution model" HIWAY-2. U.S.-EPA-600/8-80-018, Ressearch Triangle Park NC 27711, 1980.

[26] Prangsma G. J., Alberga A. H, and Beenakker J. J. M. ”Ultrasonic determination of the volume viscosity of N2, CO, CH4, and CD4 between 77 and 300K”,Physica 64(2): 278-288, 1973.
[27] Qin Y. and Kot S.C. ”Dispersion of vehicular emission in street canyon” Guangzhou city PRC. Atmos. Environ., 27B:286-295, 1993.
[28] Tokyo Metropolitan Government ”Study on the air quality models for prediction on the vicinity of streets” 22-25, 35-40, 1983.



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 Methodology

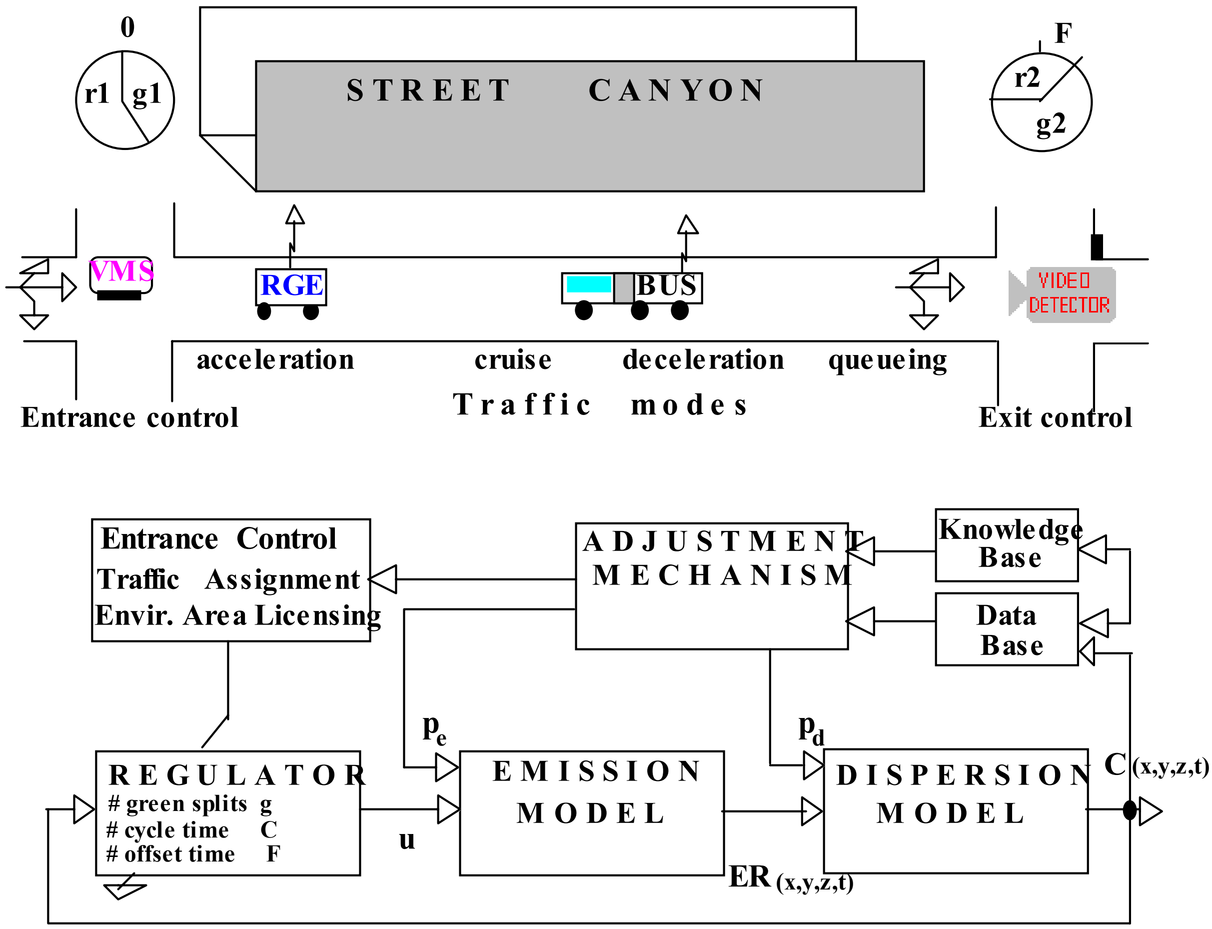


Fig. 2. Illustration of the pro-ecological control idea for the street canyon

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	300	0	300	0	300	0	300	0	0	0	0
yR [m]	0	300	0	300	0	0	0	0	0	0	300	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]	75.0	75.0	52.5	75.0	52.5	75.0	52.5	75.0	52.5	75.0	52.5	30.0
C2TTT [s]	52.5	52.5	52.5	52.5	52.5	52.5	52.5	52.5	52.5	52.5	52.5	30.0
g1TTT [s]	55.0	55.0	32.5	55.0	32.5	55.0	32.5	55.0	32.5	55.0	32.5	10.0
g2TTT [s]	10.0	10.0	32.5	10.0	32.5	10.0	32.5	10.0	32.5	10.0	32.5	10.0
FTTT [s]	33.750	33.750	5.625	33.750	5.625	33.750	5.625	33.750	5.625	33.750	5.625	0.0
JTTTx 10^2 [s]	9.7181	8.4806	3.5972	4.8590	1.5558	4.2403	1.7986	4.8590	1.5558	4.2403	1.7986	0.0
C1E [s]	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	30.0
C2E [s]	30.0	30.0	30.0	30.0	75.0	30.0	30.0	30.0	75.0	30.0	30.0	30.0
g1E [s]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
g2E [s]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
FE [s]	16.875	0.000	5.625	16.875	0.000	0.000	5.625	16.875	0.000	0.000	5.625	0.0
JE [kg]	2.0824	5.5325	17.029	1.0412	5.4769	2.7662	8.5147	1.0412	5.4769	2.7662	8.5147	0.0
C1C [s]	52.5	75.0	75.0	75.0	75.0	75.0	52.5	52.5	75.0	75.0	75.0	30.0
C2C [s]	30.0	30.0	30.0	30.0	75.0	30.0	52.5	30.0	75.0	30.0	30.0	30.0
g1C [s]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
g2C [s]	10.0	10.0	10.0	10.0	10.0	10.0	32.5	10.0	10.0	10.0	10.0	10.0
FC [s]	5.625	0.000	5.625	11.250	0.000	0.000	0.000	5.625	0.000	0.000	5.625	0.0
JC x 10^3 [kgs]	5.9408	5.9449	5.9714	7.9176	5.9509	7.9203	5.9560	5.9385	101.84	34.735	94.711	7.9157