A Model for an Integrated Intelligent Decision Support System for Environmental Urban Traffic Management

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Abstract. Intelligent Transport Systems (ITSs) and traffic management are two of the many approaches that can improve traffic efficiency, reduce traffic congestion and pollution, and enhance safety. Through managing traffic flows in urban transport networks, ITSs can provide a response to the today's major challenges regarding the minimization of traffic congestion and its negative effects on the environment. In this research, a model of an Integrated Intelligent Decision Support System (IIDSS) for environmental traffic management in urban areas is presented. The proposed model consists of three operational layers: wireless sensor network layer, intelligent agent layer, and routing coordinator, while using information about traffic congestion and pollution in the decision-making process. The main objective of the proposed model is to provide a solid basis for future development of IIDSS and its implementation in urban networks that correspond to city areas that exhibit significant congestion and pollution problems. The system will enable travelers to move around the central city areas avoiding congested and polluted roads.

Keywords: Intelligent Transport Systems · Wireless Sensor Networks · Intelligent Agent · Traffic Congestion · Air Pollution.

1 Introduction

Nowadays urban areas are home to more than half of the world's population, thus they are facing a number of challenges related to road transport. Most significant problems include: (i) frequent and long-lasting traffic congestions; (ii) difficulties with the vulnerable categories of passengers; (iii) decreased reliability of the public transport system; (iv) ever-increasing parking demands; (v) air pollution originating from the vehicles of the road transport.

Transport-related emissions are the dominant source of urban air pollution. The primary air pollutants emitted by motor vehicles are carbon monoxide (CO), nitrogen oxides (NOx including NO and NO_2) and particulate matter (PM) [1]. Urban transport is a major consumer of fossil fuels, which generate large amounts of CO_2. Thus, the transport is responsible for 40% of CO_2 emissions and 70% of another pollutants [2]. According to the data from the European Environment Agency (EEA), road transport accounts for 72% of the total greenhouse gas emissions of the sector [3]. Due to high levels of fine particulate matter (PM10), air pollution in 2005 has been estimated to have caused 1,031 accelerated deaths and 1,088 respiratory hospital admissions in London [4]. It can be concluded that the transport sector has a significant, yet a negative impact on the air pollution and is considered as one of the major threats of the 21st century to health and human well-being.

There is no just one and universal solution for reducing road transport sector emissions, but three Intelligent Transport Systems (ITS) major areas have the potential for reducing air pollution. They are: Vehicle Systems, Traffic Management Systems and Traveler Information Systems [5-8].

Intelligent Transport Systems (ITSs) and traffic management are one of the many approaches that can cope successfully with above-mentioned problems [9-11]. Based on the information about traffic congestion and air quality of urban areas, efficient routes can be deduced through the deployment of an Integrated Intelligent Decision Support System (IIDSS) [12]. In this research, a model of an IIDSS for environmental traffic management in urban areas is presented. The proposed model consists of three operational layers: (i) Wireless sensor network layer, (ii) Intelligent agent layer and (iii) Routing coordinator, and uses information about the traffic congestion and pollution during the decision-making process. For the purposes of developing a model we analyse the road traffic pollution data for the City of Skopje, Republic of Macedonia, which like every larger urban environment, has faced continuing problems with air quality and traffic congestion during recent years.

The rest of this article is organized as follows. The second section gives an overview of traffic-related air pollution in the city of Skopje. The third section describes the structure of the proposed IIDSS model. The paper ends with relevant conclusions and a discussion about the future research.

2 Identification of road traffic pollution in the City of Skopje

The City of Skopje, like other urban environments, is a subject to frequent fluctuations in the air quality. With approximately one-third of the total population of the Republic of Macedonia being concentrated in the city, Skopje is not only the capital but also it is the country's largest city. The assessed number of people traveling to Skopje every day exceeds 90,000. The existing traffic network is a favorable combination of ring roads, as well as radial and orthogonal infrastructural sub-segments around the very core of the city. The lack of some infrastructural backbone traffic corridors (express streets) forces the emergence of an unwanted interference including both transit and non-transit traffic. The major internal road network in Skopje accounts for a total length of 211 km. In combination with a somewhat inconvenient concentration of administrative and other service activities in the city's center, it gathers most of the usual appearances of fast-growing and dynamic cities: saturations, bottlenecks, queues, longer travel times, high energy consumption and air pollution.

According to a study made by World Health Organization, published at the beginning of 2017, Skopje is among the 10 most polluted cities in Europe [13]. During the winter period the situation becomes often critical, since the concentration of PM10 particles in the air reaches levels up to 20 times higher than the maximum levels measured in the past. Many sources and causes for the severe air quality problem have been already identified, among which emissions from road transport have a considerable contribution. The emissions from road transport depend on multiple factors: the vehicle category (passenger cars, light goods vehicles and heavy goods vehicles), vehicle technology (Euro 1, Euro 2), quality of the fuels, etc.

According to the Macedonian Ministry of Internal Affairs, the number of the registered vehicles in Skopje in 2014 was 161,474. More than 40% of the vehicles are categorized as conventional, Euro 1 or Euro 2, which have the greatest negative impact on the air quality. Additionally, 31% of heavy goods vehicles are very old and are categorized as conventional or Euro 1. In terms of PM10, the oldest classes of vehicles (conventional, Euro 1 and Euro 2) contribute with almost 70% in the total emissions from passenger cars. In terms of CO and NOx pollutants, the class of conventional vehicles is responsible for the most emissions. Furthermore, the majority of the passenger vehicles in Skopje (65%) use petrol as fuel and about 30% use diesel [14]. According to the data calculated for each vehicle category, the total amount of emissions for the road transport is summarized in Table 1, which shows that passenger cars have a dominant impact regarding pollutant emissions.

Table 1. Total emissions from road transport sector (t/year)

	Pollutant emission (t/year)					
Vehicle category	CO	NH_3	NMVOC	NO_x	PM	SO_2
Passenger cars	3166	37	309	572	43	197
Light goods vehicles	270	2	27	105	12	21
Heavy goods vehicles	805	0	83	294	13	30
Buses	137	0	34	577	25	16
Motorcycles	50	0	11	2	0	2
Total emissions	**4378**	**39**	**453**	**1547**	**93**	**263**

In order to respond to the problems being elaborated previously, in this paper we propose an IIDSS for Environmental Urban Traffic Management (EUTM).

3 Model of an Integrated Intelligent Decision Support System

The model of an IIDSS for EUTM (see Fig. 1) consists of three operational layers: (i) Wireless Sensor Network (WSN) layer, (ii) Intelligent Agents (IAg) layer and (iii)Routing Coordinator (RCo).

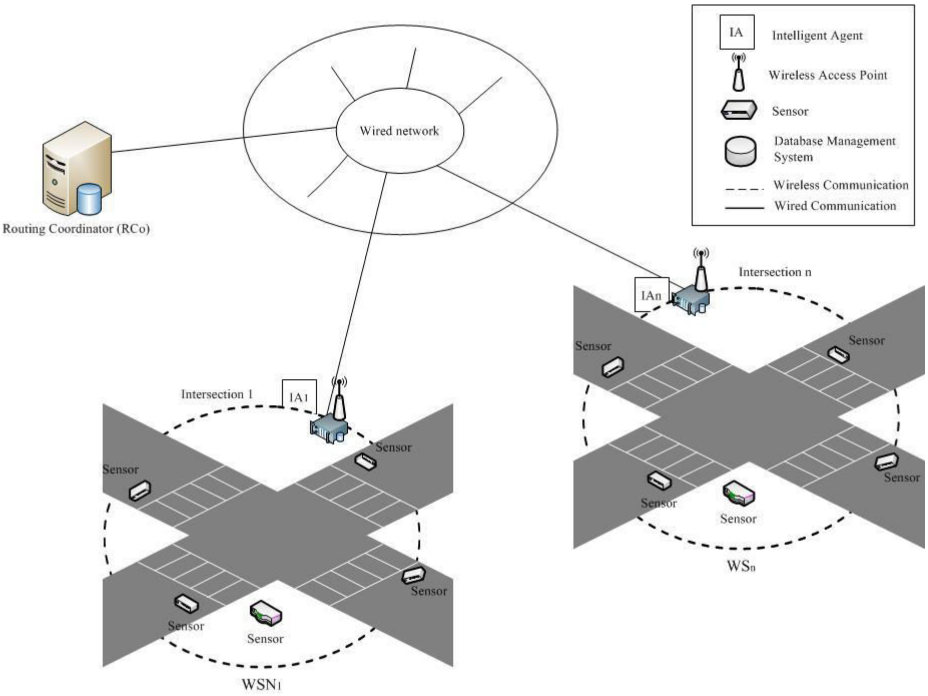

Fig. 1. Model of an Integrated Intelligent Decision Support System

WSN layer comprises of WSNs installed at each traffic intersection. It is composed of multiple interconnected wireless sensor nodes intended to measure air pollution and real-time traffic data, i.e. the type and number of vehicles that pass through the corresponding intersection.

IAg layer comprises of IAgs installed at each intersection of the selected urban traffic segment. The roles of a single IAg are to:

- Collect real-time traffic data from the WSN of the corresponding intersection;
- Collect atmospheric pollution data from the existing Pollution measurement station that measures the air pollution in the area of the corresponding intersection;
- Assign a Route Priority (RP) value to every route direction for the referred intersection, based on the previously collected data, and forward the RP values to the Routing Coordinator.

For the purpose of processing the real-time traffic data acquired from the WSN, we assume that the IAg uses an existing protocol or traffic analysis algorithm. As a result of the traffic data processing, the IAg assigns a predefined Traffic Congestion (TC) index to each route direction on a given intersection. A variety of congestion measures are used throughout the traffic engineering literature. Traffic congestion measures may vary depending on the needs, from traditional volume-to-capacity ratio to more complicated empirical equations.

Traffic status can be determined by the traffic intensity i.e. the volume-to-capacity ratio, or simply by the use of level of service rating expressed in grades, ranging from A (best) to F (worst). For signalized intersections, the Highway Capacity Manual [15] measures congestion in terms of average delay per vehicle, and 'levels of service' are defined based on the average amount of delay. Furthermore, congestion is a nonlinear function, so as a road approaches its maximum capacity, small changes in traffic volumes can cause proportionately larger changes in congestion delays [16].

For the purposes of this research, traffic status can be determined by traffic intensity that is the volume-to-capacity ratio (1):

$$\varepsilon_{ij} = \left(V_{ij} / C_{ij} \right) \quad (1)$$

The description of ratio thresholds is given as follows:

- $\varepsilon_{ij} \leq 0.85$ - The intersection is operating under its capacity. There is no congestion state;
- $0.85 \leq \varepsilon_{ij} \leq 0.95$ - The intersection is operating near its capacity. Higher delays may be expected, but continuously increasing queues should not occur;
- $0.95 \leq \varepsilon_{ij} \leq 1$ - Unstable traffic state;

$\varepsilon_{ij} \geq 1$ - Demand exceeds the available capacity of the intersection. There is oversaturation (Spillback and Residual queues are anticipated).

For the purpose of simplicity, we define four possible TC indexes, as presented in Table 2.

Table 2. Possible TC indexes and their meaning

TC index	Traffic volume ratio	Description (Traffic state)
T1	$\varepsilon_{ij} \leq 0.85$	Intersection operate under capacity
T2	$0.85 \leq \varepsilon_{ij} \leq 0.95$	Intersection operate near capacity
T3	$0.95 \leq \varepsilon_{ij} \leq 1$	Intersection operate at capacity
T4	$\varepsilon_{ij} \geq 1$	Intersection operate over capacity

Besides the calculation of TC indexes, based on the data received from the corresponding Pollution measurement station, the IAg assigns one of the predefined Pollution indexes to the route directions of the referred intersection. The possible pollution indexes are given in Table 3.

Besides the assignment of TC and pollution indexes, another IAg's function is to assign an *RP value* to each route direction of the referred intersection based on previously assigned indexes. The IAg's decision is based on predefined *RP tables*, presented in Table 4 and Table 5. Each table is optimized for different types of traffic participants (drivers, bicycle riders, and pedestrians). Table 4 defines the RP values optimized for drivers, where the priority for defining the RP value is the congestion index. However, the pedestrians and/or bicycle riders are not directly affected by the vehicle congestion at the intersection. Instead, they are more concerned with the pollution that, besides other factors, increases during traffic congestions. Table 5 defines RP values giving priority to the pollution index. In each table of RP values, the value of 1 means that the referred road direction is the most preferable one.

Table 3. Pollution indexes

Air Pollution Index	Index Value	Description
P1	0 - 25	Very low pollution
P2	25 – 50	Low pollution
P3	50 - 75	Medium pollution
P4	75 - 100	High pollution
P5	> 100	Very high pollution

Table 4. RP values with preference on congestion index

Route priority value	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Traffic congestion index	T1	T1	T1	T2	T2	T2	T3	T3	T3
Pollution index	P1	P2	P3	P1	P2	P3	P1	P2	P3

Table 5. RP values with preference on pollution index

Route priority value	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Pollution index	P1	P1	P1	P2	P2	P2	P3	P3	P3
Traffic congestion index	T1	T2	T3	T1	T2	T3	T1	T2	T3

In a predefined time intervals, after detecting the changes in the pollution and traffic indexes, all the IAgs in the network forward the RP values for each route direction to the Routing Coordinator (RCo). In this manner, the RCo 'knows' the route priority values for each direction of the multiple intersections that belong to the urban traffic segment of interest.

The RCo keeps a table of predefined possible routes as a connection between each pair of surface points of the urban traffic segment of interest (see Fig. 2). Based on the RP values received from the IAg layer, the RCo proposes a preferable route to the interested user whose intention is to travel between any selected pairs of surface points. For the purpose of selection of a preferable route, the RCo can use some of the existing traffic routing protocols or a modification of a certain network routing protocol that uses a known algorithm for selection of the best path, such as the Dijkstra's algorithm [17]. Additionally, the RCo provides an interface for other applications or existing intelligent traffic systems.

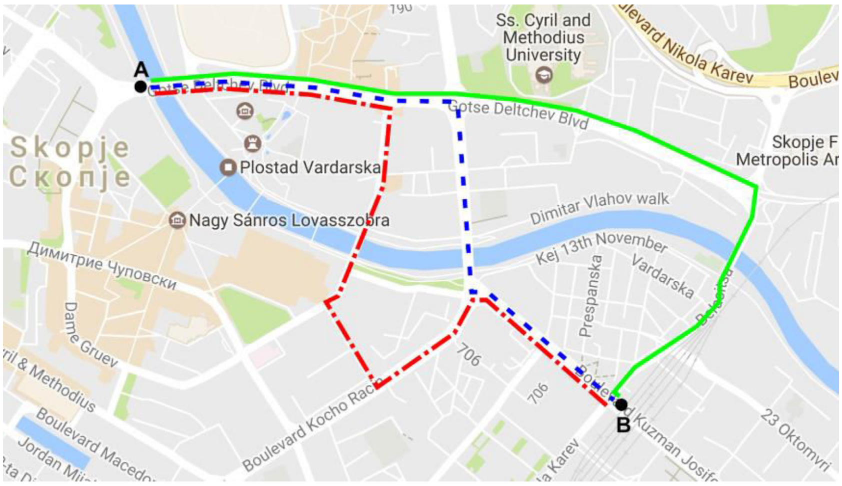

Fig. 2. Example of the RCo predefined routes

4 Discussion and conclusions

Contemporary times impose the need for the development of efficient methods and technologies aimed at pollution reduction, in general. This is especially important for urban areas where the air quality is mostly degraded due to various types of pollutants emitted from road vehicles. One of the approaches that can improve air condition is by enhancing traffic efficiency, which is usually conveyed using Intelligent Transport Systems (ITSs) and traffic management. Through the management of traffic flows in urban transport networks, ITSs are able to respond to one of the major issues regarding minimization of traffic congestion and its negative effects on the environment. Using the positive experiences of already established ITSs, in this research, we developed a model of an IIDSS intended to achieve efficient environmental traffic management in urban areas. The main objective of the proposed model is to enable travelers to move around the central city areas avoiding network congestion, thus avoid the most air-polluted areas. The system that we present consists of three operational layers, i.e. a WSN layer, an IAg layer and an RCo. The WSN layer is a network layer that is used to connect various network endpoints that measure traffic congestion and air pollution. The IAg layer consists of intelligent agents placed at each intersection, which collect and analyze data from the WSN layer. The RCo is a single entity that gathers all the information from the interconnected IAg nodes and, using a specified algorithm, proposes the best (the least polluted or the least congested) route, depending on the traveler's preferences.

Our future work is directed towards the development and implementation of a system based on the presented model, including analyses of its behavior and the effects that would be gained from its implementation. Considering the preliminary observations, we are quite confident that such system would provide significant benefits to the congested urban areas, and especially for the citizens as the most affected segment by the ubiquitous pollution.

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