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Transport spatial model for the definition of green routes for city logistics centers

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ABSTRACT

This paper presents a transport spatial decision support model (TSDSM) for carrying out the optimization of green routes for city logistics centers. The TSDSM model is based on the integration of the multi-criteria method of Weighted Linear Combination (WLC) and the modified Dijkstra algorithm within a geographic information system (GIS). The GIS is used for processing spatial data. The proposed model makes it possible to plan routes for green vehicles and maximize the positive effects on the environment, which can be seen in the reduction of harmful gas emissions and an increase in the air quality in highly populated areas. The scheduling of delivery vehicles is given as a problem of optimization in terms of the parameters of: the environment, health, use of space and logistics operating costs. Each of these input parameters was thoroughly examined and broken down in the GIS into criteria which further describe them. The model presented here takes into account the fact that logistics operators have a limited number of environmentally friendly (green) vehicles available. The TSDSM was tested on a network of roads with 127 links for the delivery of goods from the city logistics center to the user. The model supports any number of available environmentally friendly or environmentally unfriendly vehicles consistent with the size of the network and the transportation requirements.

1. Introduction

Today it is hard to imagine any system without logistics support. However, the implementation of key logistics processes (transport, handling, storage) is contradictory to the requirements of environmental protection, since transport is characterized as one of the main pollutants. This is the reason why the research in this paper focuses on the organization of the transport process, that is, on green transport in the framework of green logistics, which apart from the logistics approach, also uses an approach of environmental protection and minimization of the adverse impacts of transport on the quality of life in cities.

City logistics centers (CLC) are situated in favorable traffic locations, at the edge of cities or just inside them, and they connect inbound and outbound flows, coordinating the flow of goods being supplied to and transported from the city area. With the development of the "just in time" concept, many production systems have almost lost their storage functions, which generated significant investment and maintenance costs. This has resulted in the transfer of part of the stock to the transport system. Part of the stock is actually in transit, which brings greater congestion and pollution in cities, and the environment and society bear the cost. This was confirmed in a study conducted by McKinnon and Woodburn (2008) in London in which in a sample of 87 companies, a 39% reduction in the number of warehouses and their capacity was identified while at the same time 1/3 of the companies recorded an increased volume of delivery of transport.

Large cities have special settings for logistics terminals for the domain of city logistics, so that logistics centers have become the central element of the system for the supply of goods. In research into systems of cooperation and consolidation conducted by Murphy and Poist (2003) in the US it can be seen that by using logistics terminals it is possible for a growing number of companies to reduce their costs from 5 to 20%. According to this study, by using logistics terminals in urban areas, the number of vehicle kilometers is reduced by 60%. Research carried out by the SEA (2014) in collaboration with the STSA (2014) confirms the results of the previous study. It also states that due to the increased use of the CLCs in Belgrade and Novi Sad the use of delivery vehicles has been reduced by 30–60%. The result of this is a reduction in the fleet for the same number of transport tasks. In research carried out by the SEA (2014) and STSA (2014) it was observed that in Belgrade the volume of deliveries has increased by 15% with a parallel decrease in the negative effects of the transport (a reduction in the noise and gas emissions).

As a result of the logistics activities of CLCs, traffic congestion occurs, which is highly pronounced in the so-called peak periods. Traffic congestion is very harmful to the environment and has many negative

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consequences, such as additional fuel consumption, air pollution, late arrival at work or school, problems in supply, a reduction in turnover, the effects of the vehicles and others. So far, hundreds of different pollutants have been identified, and it should be noted that there is a possibility of new previously unknown ones being formed under the influence of solar radiation and electrical discharge (EEA, 2014). According to the EEA (2014), the pollutants in urban areas in the European Union that have the most harmful effects on humans on the environment (plants and animals) are sulfur dioxide, nitrogen oxides, carbon monoxide and ozone. A study by Bapna et al (2002) shows that in the US state of Ohio up to 90% of the total pollutants emitted in urban areas are a result of logistics activities, public transport and individual vehicles. In addition to this, research carried out by Ćirović et al. (2014) in Serbia shows that in Belgrade transport is responsible for around 14% of the total amount of carbon dioxide emitted. One of the answers for logistics operators is the introduction of environmentally friendly vehicles. These vehicles have found their place in the prevention of global warming and reduction in air pollution. In addition, environmentally friendly vehicles (EFV) are particularly important in terms of reducing the secondary consequences of air pollution, for example by reducing the number of those suffering from asthma, bronchitis and respiratory infections. In this paper, the term EFV of logistics operators means delivery vehicles with reduced exhaust emissions which carry out transport from a CLC to the users in urban areas.

Preventing pollution and rehabilitating already polluted air, and thus restoring the environment to its original natural state requires a number of activities. In addition to having the appropriate knowledge about the state of the environment, the emission of pollutants, emitters, the distribution of pollutants in the atmosphere, their reactions and climatic conditions, it is necessary to develop an appropriate strategy for protection. Research and monitoring of air quality in urban and industrial areas is just one of the first steps towards a solution for this problem of air pollution, so as to protect public health and the environment. Therefore, the local authorities in cities make an effort to include as many vehicles as possible with reduced emissions and to move logistics processes as far away as possible from central city zones. However, there is an evident lack of reliable methodologies that would support such implementation.

This paper presents a new model for determining vehicle routes that takes into account the parameters of the environment, health, use of space and logistics operating costs. The advantage of the TSDSM can be seen in its potential for designing routes for the EFV and EUF vehicles of logistics operators in urban zones. The model takes into account the real state of the fleets of logistics operators and the fact that they have a limited number of EFVs. TSDSM is based on the integration of the modified WLC method and the modified Dijkstra algorithm within the framework of a GIS. In the first phase of the TSDSM using the modified WLC method and GIS, the parameters and criteria that affect the vehicle routes are processed. In the TSDSM four parameters are identified (the environment, health, use of space and logistics operating costs) that are broken down into a total of 21 criteria. The weight coefficients of the parameters/criteria are obtained by surveying experts who have a minimum of ten years' experience of managing transport processes. A final map of the benefits of the transport network is obtained as a result of the first phase. In the second phase the routes of the EFV and EUF vehicles are determined using the modified Dijkstra algorithm. The traditional Dijkstra algorithm does not provide the opportunity for simultaneously making the routes for EFV and EUF vehicles, which is why in this research the traditional Dijkstra algorithm was modified.

The paper is organized in five sections. The opening section introduces the effects of the transport process on the environment and the quality of life in urban areas. In the following section is an overview of relevant models which have been developed over the last few years for routing green vehicles (Section 2), and the phases of the TSDSM are presented (Section 3). After this, Section 4 presents the testing of the TSDSM under real conditions, and concluding considerations are given.

2. Overview of the models for routing green vehicles

Routing vehicles and their scheduling is a well-known organizational problem. From when the Vehicle Routing Problem (VRP) was raised until today there has been no dominant model for solving it. Many different approaches have been developed for solving the VRP that are based on heuristics, meta-heuristic procedures and approaches that involve the use of various tools for processing spatial data. The following section presents the models that have been developed so far for routing green vehicles that are based on heuristic and meta-heuristic procedures, models of linear programming and models that involve the use of a GIS for processing spatial data.

Table 1 is a presentation of studies which consider the problem of routing on the basis of heuristic and meta-heuristic procedures and models of linear programming. They are categorized based on the objectives used and solution methods involved. In terms of their objectives, travel time/cost related objectives have received the most attention. In addition, a significant number of studies discuss the capacity of vehicles and the length of routes which achieve the minimum exhaust emissions. Some studies have the minimization of both fuel consumption and CO_2 emissions as their objective. However, it evident that not many studies consider the impact of environmental parameters (Noise, CO_2, NO_x, SO_x) and traditional parameters (Reserve capacity, Total vehicle miles, Total travel time/cost) at the same time when defining the vehicle routes.

There are a number of GIS-based methodologies for solving green transport problems. Transport planning is usually related to network analysis. Table 2 shows the models that use GIS to process spatial data and create the vehicle routes.

The majority of the studies presented here (Table 2) consider the environmental and economic aspects of vehicle route planning. Some of them also consider the social impact of vehicle route planning while it is rare to find studies that consider economic and social components and environmental impacts at the same time.

Most of these models for routing green vehicles consider quite a small number of parameters without looking at the complex influence of sub-parameters on the algorithms for routing vehicles and on the final decision. For example, to reduce the energy requirements of vehicle routing, Bektas and Laporte (2011) described a comprehensive emissions model that takes into account load and speed. Kara et al. (2007) defined an energy-minimizing VRP that minimizes the weighted load rather than a distance based objective function. Kuo (2010) proposed a model to calculate the total fuel consumption for the time-dependent VRP. Xiao et al. (2012) extended the capacitated vehicle routing problem by taking into account travel distance and load impacts on fuel costs. Ćirović et al. (2014) and Jovanović et al. (2014) took into account the logistics operating costs and environmental parameters, and so on.

An analysis of the available literature (Tables 1 and 2) has led to the conclusion that so far, authors have not considered the problem of routing EFVs by applying spatial analysis and the modified Dijkstra algorithm, which takes into account the parameters of the environment, health, use of space and logistics operating costs when defining routes. The advantage of the TSDSM is its complex consideration of the parameters of the environment, health, use of space and logistics operating costs on the final decision regarding establishing green routes. The impact of these parameters is processed in a GIS using the modified WLC method and the modified Dijkstra algorithm. Traditional vehicle routing algorithms consider either route for EFV or for EUF vehicles. The advantage of the modified Dijkstra algorithm developed in this study can be seen in the fact that in addition to planning routes for EFV it can also be used to plan routes for EUV vehicles. This becomes even more significant when the TSDSM is used by operators with a heterogeneous fleet, that is, with a limited number of EFV. We believe that this work provides a unique, highly relevant and usable decision support