Expert Systems with Applications 41 (2014) 4245–4258

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Green logistic vehicle routing problem: Routing light delivery vehicles in urban areas using a neuro-fuzzy model

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ARTICLE INFO

Keywords:
Environmentally friendly vehicles
Vehicle routing
Green logistics
Neuro-fuzzy
Simulated annealing

ABSTRACT

Today's growth in the level of traffic in cities is leading to both congestion and environmental pollution (exhaust emissions and noise), as well as increased costs. Traffic congestion makes cities less pleasant places to live in, a particular problem being the negative impact on health as a result of increased exhaust emissions. In addition to these emissions, another major effect of transport which can lead to serious health problems is noise (EEA, 2013a, 2013b). There is a strong tendency in the world towards the development of "clean" motor vehicles that do not pollute the environment, that is, that do not emit harmful substances in their exhaust fumes and which create less noise without causing other types of pollution. The growth in the influence of transport on the environment has resulted in planners formulating procedures which take into account the effect of traffic on the quality of life in urban areas. This paper presents a model for the routing of light delivery vehicles by logistics operators. The model presented takes into account the fact that logistics operators have a limited number of environmentally friendly vehicles (EFV) available to them. When defining a route, EFV vehicles and environmentally unfriendly vehicles (EUV) are considered separately. For solving the problem of routing in the model, an adaptive neural network was used which was trained by a simulated annealing algorithm. An adaptive neural network was used for assessing the performance of the network branches. The input parameters of the neural network were the logistics operating costs and environmental parameters (exhaust emissions and noise) for the given vehicle route. Each of the input parameters of the neural network was thoroughly examined. The input parameters were broken down into elements which further describe the state of the environment, noise and logistics operating costs. After obtaining the performance of the network links for calculating the route for EFV and EUV vehicles a modified Clark–Wright algorithm was used. The proposed model was tested on a network which simulates the conditions in the very centre of Belgrade. All of the input parameters of the model were obtained on the basis of 40 automatic measuring stations for monitoring the air quality (SEA, 2012).

1. Introduction

In its simplest possible form, logistics can be described as the process of delivering a product (service) in the required quantities, in good condition, to the appointed place at the appointed time, to a specific customer at an agreed price. The expansion of logistics came along with the growing trend of globalization and decentralization of production, the functioning of which depends significantly on the quality of logistics activities. The area of logistics has constantly expanded and developed, adapting to the demands of technology and the environment. Today, logistics is present in all areas of society. At the same time as its development, there has been a growth in environmental awareness, and it is indeed noticeable that in the 21st century environmental problems occupy an important place in the priority list of the world's problems.

Today it is difficult to imagine any system without logistics support. However, the realization of key logistics processes (transport, handling, storage) conflicts with the requirements for environmental protection, with transport being characterized as one of the major environmental pollutants. For precisely this reason, this paper focuses on the organization of the transport process, more specifically on green transport within the framework of

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http://dx.doi.org/10.1016/j.eswa.2014.01.005

green logistics, which during the implementation of the logistics process, uses an approach involving environmental preservation.

According to research carried out in Japan and Great Britain (Murphy & Poist, 2003), heavy goods vehicles generate noise between 88 and 92 dB, and light goods vehicles between 79 and 81 dB. If we bear in mind that noise which exceeds 60 dB is harmful to human health, then it is not difficult to conclude that on this basis road transport is the greatest cause of adverse effects on the environment. Traffic noise, as the main source of noise in urban areas, is a very significant ecological problem in terms of its serious damage to the health of the population, also causing a reduction in labor productivity. Recent data on the threat of environmental noise to the population was obtained after the first round in the production of strategic noise maps for agglomerations in European Union countries. Data from the European Environment Agency (2013a, 2013b) indicate that in urban areas 54% of the population (56,001,200 people) are exposed to full-day noise levels exceeding 55 dB(A) and 15% of the population (15,754,500 individuals) full-day noise levels greater than 65 dB(A). In addition, away from the agglomeration another 33,437,244 residents live in areas where the full-day noise level is greater than 55 dB(A), of whom 7,657,083 residents are in areas where the full-day noise level is greater than 65 dB(A). From a total of 89,438,444 residents who are subject to full-day levels of noise greater than 55 dB(A) almost 89 million are exposed to noise generated by traffic (road, rail and air). The number of people exposed to full-day levels of noise greater than 55 dB(A) arising from road traffic is almost 68 million, indicating road traffic to be the dominant source of noise. A report by the European Environment Agency (2013a, 2013b) showed that in most European cities, three out of five people are exposed to harmful levels of traffic noise. Research carried out by Schreyer et al. (2004) has shown that in the European Union the external costs of traffic accidents occurring as a result of the deterioration of air quality and an increase in noise level amounts to between 0.5% and 3.7% of the gross domestic product of EU countries.

Many industrialized countries and developing countries have adopted different regulations to define the maximum permissible level of noise emissions of motor vehicles, the noise inside the vehicle as well as noise emissions in urban areas. However, even with very "quiet" motor vehicles and laws favoring their use, it will be many years before existing outdated fleets are completely replaced. Bearing this in mind, the model presented in this paper recognises the fact that logistics operators in urban zones use not only EFV but also EUV vehicles.

Besides noise, another significant consequence of transport that can lead to serious health problems is harmful exhaust emissions (EEA, 2013a; EEA, 2013b). Transport is responsible for about 14% of the total carbon dioxide emissions (CO_2) (Yazan, Petruzzelli, & Albino, 2011). Of the total amount of harmful substances emitted 50% is caused by traffic, while in urban areas its share can be as high as 90%. Road traffic, as a specific branch of traffic, significantly contributes to air pollution. This type of transport causes 86% of the carbon monoxide (CO), 33% of the hydrocarbon (CH) and 42% of the nitrogen oxide (NO_x) pollution. In addition, petrol engines are the main sources of lead pollution, and diesel engines emit large amounts of soot and smoke. Moreover, different types of transport have different rates of energy consumption (and thus different fuel emissions) for carrying out the same transport task. The largest consumer is road transport, which accounts for 82% of the total energy consumption in transport, followed by air with 13%, rail with 3% and river with 2% (Bapna, Thakur, & Nair, 2002).

The increased demand placed on logistics distribution systems has led to the construction of distribution centers and terminals near or within urban areas. By developing the "just in time" concept, many production systems have almost lost their storage function which not only required investment, but also generated significant running costs. This has resulted in the transfer of certain stock to the transport system. Part of the stock is actually in transit, which causes greater congestion and pollution in cities, with the environment and society bearing the cost. This has been confirmed by empirical research in the UK, where out of a sample of 87 companies a 39% reduction in the number and capacity of storage facilities was recorded, while 1/3 of the companies recorded an increased volume of delivery transport (McKinnon, 2008).

A large concentration of logistics activities in populated areas causes a great deal of air pollution as well as noise. One of the solutions to this for logistics operators is the introduction of EFV. These vehicles have found their place in the prevention of global warming and reduction of pollution caused by CO, CO_2, CH, NO_x, SO_2 (sulfur dioxide) and particulate emissions (PM_{10} and $PM_{2.5}$). In addition, EFV are especially important in terms of reducing the emission of vibrations and noise as specific forms of environmental pollution which are especially prevalent in urban areas. EFV vehicles are characterized by reduced emissions of harmful substances and are fuelled by gas, liquefied petroleum gas, ethanol, methanol, biodiesel, hydrogen, hybrid and electrical energy.

Based on the environmental directives promoted by the European Union, logistics operators in cities have begun to renew their fleets by introducing EFV. As the number of these vehicles is currently limited, implementation needs to be carried out together with the existing vehicles in such a way to maximize the impact on reducing pollution. The dramatic increase in the impact of traffic on air quality in cities has influenced the emergence of new procedures that will take into account the impact of transport on the quality of the environment in urban areas. There is no single solution for all urban problems, but city authorities insist that logistics operators focus on an integrated approach in order to respond in the best possible way to the problems that arise. This is achieved by combining knowledge from various areas of technology such as the development of new vehicles, economic incentives and new procedures for the creation of green EFV routes. In this paper, the term EFV of logistics operators is understood as light delivery vehicles with reduced emission levels.

Several ecologically oriented extensions of the VRP have been introduced which aim at minimizing fuel consumption or the amount of CO_2 emissions. For any of these problems, the evaluation of transportation plans relies on an estimation of the quantity of fuel consumed while completing the required task. There are a variety of methods for estimating the fuel consumption and emissions of road transportation which depend on a whole range of parameters. For an overview on methods see for example Frey, Zhang, and Rouphail (2010). Most of the estimation methods are based on analytical emission models, and they differ in terms of the principles on which they are based and the parameters they take into account for estimation. A comparison of several vehicle emission models for road freight transportation can be found in Demir, Bektas, and Laporte (2011). In addition to comparing different methods for estimating fuel consumption and pollution, Demir et al. (2011) analyze the discrepancies between the results yielded by the models on the one hand and the results recorded for the on-road consumption of real vehicles on the other hand.

Kara, Kara, and Yetis (2007) present a model for the problem that minimizes the load weight carried by the vehicles. They claim that their model aims at minimizing the energy required for the routed vehicles. More recent models are based on methods for estimating fuel and pollution which depend on specific parameters