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Impact of intersection type and a vehicular fleet's hybridization level on energy consumption and emissions

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ABSTRACT

A vehicle's energy consumption and emissions are two major constraints in sustainable development. Both of them have proportionally raised in recent decades with the exponential growth of world traffic demands. The reduction of road traffic-generated energy consumption and emissions have thus become unprecedentedly challenging and worth examining. This paper investigates energy consumption and environmental problems present at roundabout and signalized intersection to analyze the impact of the hybridization level's fleet and intersection type on vehicle consumption and pollution. Instantaneous fuel consumption and emission models coupled with simulation of urban mobility (SUMO) are in this study. The authors started with modeling energy consumption. Then, an emission model emissions from traffic (EMIT) was implemented to quantify vehicle emissions of CO_2, CO and NO_x. These models help investigate the influence of intersection type on energy consumption and environmental conditions. The authors implemented a signalized intersection and roundabout using SUMO. The input data are collected from the roundabout of Sousse (Tunisia) using video data collection. Since there is a lack of econometric models that emulate hybridized stream behavior near intersections, two energy consumption models for the roundabout and crossroad are developed using traffic flow and hybridization level as the input variables. Compared to crossroads, a roundabout can obtain more environmental improvements and substantial reductions in energy consumption and road traffic emissions.

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1. Introduction

Road traffic encounters several problems, such as air pollution and energy consumption, which result in a major constraint for sustainable mobility. With increasing concern over urban air pollution from motor vehicles, it is imperative that vehicles take energy consumption and emission into consideration. One of the focal questions in transportation science is the evaluation of environmental and energetic impacts of vehicular traffic (Chen and Borken-Kleefeld, 2014; Sekhar et al., 2013).

Emission rates and consumption depend on road traffic characteristics, vehicle type, and road intersection type (Pandian et al., 2009). In fact, the intersection type can play a substantial role in reducing vehicle emissions. Research shows that emissions are generated in greater quantities at intersections with traffic signals than at roundabouts. Therefore, replacing a signalized intersection with a roundabout results in fuel consumption and emissions decreasing (Ahn et al., 2009; Mandavilli et al., 2008).

This paper aims to study the energy and emission problems of road traffic at intersection using computer micro simulation modeling tools (Coelho et al., 2006; Zamboni et al., 2015). Since many consumption models depend on microscopic variables, such as velocity and acceleration, one must start by modeling road traffic for simulation. The kinematic variables of traffic flow are obtained by the simulation of urban mobility (SUMO) tool (Krajzewicz et al., 2002, 2012). Thus, the authors have implemented an instantaneous energy consumption model (Demir et al., 2011) and emissions model (EMIT) (Cappiello et al., 2002).

This work contributes the integration of a microscopic simulation traffic tool with an instantaneous energy consumption and emission model. Secondly, using data collected at the roundabout of Sousse (Tunisia) the authors have studied how intersection type and traffic state influences energy consumption at a roundabout and a crossroad. Finally, this paper introduces a statistic model at a roundabout and crossroad that enables authors to estimate energy consumption while taking into account the hybridization level and traffic demand.

Since increasing traffic congestion causes complications at intersection, the authors have compared the fuel consumption and vehicle emission at a roundabout and crossroad for both congested and uncongested cases. Moreover, they have studied the influence of traffic flow on the two intersections and implemented two energy consumption models for the roundabout and crossroad that combines traffic flow and hybridization level. The hybridization level reflects the percentage of Hybrid Electric Vehicle (HEV) among the total fleet.

This work analyzes microscopic energy consumption and emission traffic models. Secondly, this work describes the implementation's geometry and vehicles dynamic of the crossroad and the roundabout. Thirdly, results are presented to illustrate the influence of intersection type on fuel consumption and emissions in both congested and uncongested cases. Also presented are details about the development of energy consumption models, which take in consideration the traffic flow and hybridization level, for the roundabout and crossroad. Finally, this study's main findings and potential for future research are summarized.

2. Related work

Many studies have investigated energy consumption and the environmental effects present at signalized intersections and roundabouts, but very few researchers have used instantaneous traffic simulation models in conjunction with microscopic energy and emission models. The main contribution of this study is the quantification of energy consumption and emissions using instantaneous models coupled with a microscopic traffic simulator at both a roundabout and crossroad intersection. Authors developed a multiple linear regression model that estimates energy consumption at two types of intersection (i.e., crossroad and roundabout) using the traffic demand and the hybridization level as input variables.

The principal objectives of this paper include studying the influence of intersection type on energy consumption and environmental effects, as well as showing the relevance of hybridization level at an intersection. A study by Mustafa and Vougias (1993) demonstrates that vehicle emissions at signalized intersections exceed emissions at roundabouts by about 50%. In fact, the hydrocarbons (HC) emitted at a signalized intersection is twice as high as what is emitted at a roundabout.

In Sweden, a study of the environmental impacts of roundabouts found that vehicle emissions of carbon monoxide (CO) and nitrogen oxides (NO_x) at roundabouts are 20%–29% less than emissions produced at signal controlled intersections (Hyden and Varhelyi, 2000).

Varhelyi (2002) demonstrated that replacing a signalized intersection with a roundabout generates a reduction in vehicle emissions of CO and NO_x by 29% and 21%, respectively. Fuel consumption is also reduced by 28% at roundabouts.

Mandavilli et al. (2008) used the signalized and unsignalized intersection design and research aid (SIDRA) software to study the environmental impacts of roundabouts. They concluded that HC, CO, NO_x, and CO_2 emissions can be reduced by 65%, 42%, 48%, and 59%, respectively, by converting stop-controlled intersections to roundabouts.

Another study by Ahn et al. (2009) shows that roundabouts do not usually lead to a reduction in vehicle emissions and energy consumption compared to other types of intersection.

Chamberlin et al. (2011) applied the Paramics microsimulation model in combination with the motor vehicle emission simulator (MOVES) and the comprehensive modal emission model (CMEM) to estimate levels of CO and NO_x emissions at intersections. They concluded that, under congested traffic conditions, a pre-timed traffic signal can reduce vehicle emissions compared to a roundabout.

The study by Gastaldi et al. (2014) used a traffic microsimulation tool (S-Paramics) combined with an instantaneous emission estimator (AIRE) to investigate the environmental performance of two intersection types (i.e., roundabout and fixed-time signal control). The authors concluded that a roundabout can decrease pollutants more than a fixed-time signal control.