

ANALYZING THE IMPACTS OF THE TRAVELER INFORMATION PROVISION SERVICES AND THE SPEED LIMIT CONTROL ON VEHICULAR EMISSIONS AND CONGESTION

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ABSTRACT

Recent studies have indicated that lower urban speed limits result in lower vehicular emissions. With the implementation of traveler information provision services, travelers with better information about a transport network may change their route choice behavior and this may affect the impacts of the speed limit control on vehicular emissions as well as congestion. With this consideration, in this paper, we studied the impacts of the traveler information provision services and the speed limit control on the vehicular emissions and congestion. We model the route choice behaviour of the equipped and unequipped travellers as following a mixed-Stochastic User Equilibrium (SUE) with elastic market penetration. This mixed-equilibrium problem with elastic market penetration is modelled as a nonlinear complementary problem (NCP). Results indicate that both higher and lower speeds do not lead to lower vehicular emissions. It is largely dependent on the service charges of traveller information services. Additionally, the information quality has different effects on vehicular emissions and congestion with varied speed limits.

Keywords: Traveler Information Provision Services, Speed Limit Control, Vehicular Emissions

INTRODUCTION

The exhausted vehicular emissions depend on the driving speed of a vehicle (1). Therefore, the speed limit control would have a significant impact on the vehicular emissions. However, very few studies were focused on studying the impacts of the speed limit control on vehicular emissions (2, 3, 4, 5, 6, and 7). W.A.M. (1) and Fergusson (5) indicated that lower urban speed limits result in lower emissions. Rietveld and Shefer (4) claimed that at higher speeds the emissions are higher. However, with the implementation of traveler information services in many urban cities, travelers with better information about a transport network may change their route

choice behavior and this may affect the impacts of the speed limit control on vehicular emissions as well as congestion. Actually, the speed limit on each route decides the free flow travel time of this route in the network. And the average travel time on the route dependent on the free flow travel time affects the average travel speed once a travel distance is fixed. This means that the speed limit indirectly affects the average speed on the route, therefore emissions. Intuitively speaking, it seems that a higher speed limit allowed on the transport network would result in a lower Total System Travel Time (TSTT). However, this higher speed limit allowed would lead to a rise in the vehicular emissions. So when travelers are guided to travel on a route with the higher speed limit to save their travel times, consequently, this may lead to an increase in the vehicular emissions. Additionally, as Szeto et al. (8) have concluded that the service charge of traveler information provision services, the dominant of the level of market penetration, also affects the vehicular emissions. Therefore, there may a significant impact of the joint implementation of the speed limit control and traveler information provision services on vehicular emissions and congestion.

Yet so far, there is no research studying the impacts of the joint implementation of traveler information provision services and the speed limit control on vehicular emissions and congestion. Szeto et al. (8) have found out some paradoxical phenomena with the traveler information provision services regarding vehicular emissions and congestion in terms of TSTT. Nevertheless, the estimation of vehicular emissions in our study was based on a relationship derived from emissions models developed by the National Environmental Protection Agency (NEPA) that the volume of emissions is equal to the product of an emission factor and the link load, where the speed limit control was not considered. To incorporate the speed limit control in our study, we adopt the macroscopic emissions estimation relationship used in TRANSYT 7-F model which belongs to the domain of average speed models. In this case, the speed limit indirectly decides the average speed which is dominant to the volume of emissions. This model can be applied to estimate fuel consumption, carbon monoxide (CO) emissions, hydrocarbon emissions, and nitrogen oxide emissions. It is decided that in our study only CO emissions rates are calculated. Reasons are as follows: Firstly, as it is indicated in Rilett and Benedek (9), the assignment results obtained on the basis of all the pollutants would be similar due to the similarity in the form of the production functions. Secondly, according to (10), Alexopoulos et al. (11) pointed out that CO may be considered as the best tracer to determine the traffic contribution to the overall atmospheric pollution of the area since CO is almost solely emitted by vehicles. Thirdly, CO is dangerous to human health, particularly to those with heart disease, because it reduces the blood's ability to carry oxygen. With the above considerations, in this paper, we studied the impacts of the traveler information provision services and the speed limit control together on the vehicular emissions, specifically CO emissions, and congestion in terms of TSTT. We model the route choice behaviour of the equipped and unequipped travellers as following a mixed-Stochastic User Equilibrium (SUE) with elastic market penetration. But equipped drivers are considered to have a lower perception variation due to provided traveller information, and unequipped drivers have a higher perception variation due to the lack of current traffic information. Elastic market penetration is also considered. This mixed-equilibrium problem with elastic market penetration is modelled as a nonlinear complementary problem (NCP). To capture the elastic behavior of demands for the services, the multi-class mixed SUE model includes a proposed multinomial logit-based market penetration model, in which the demand of each class of drivers depends on the negative average generalized travel costs of all classes of drivers. The model then can be solved by any existing optimization program. In our study, the model is solved using the

Generalized Reduced Gradient (GRG) method (12). Results demonstrate that both higher and lower speed limits do not lead to lower emissions. It is largely dependent on the service charges of traveller information services. With a lower speed limit, TSTT is higher when the service charge is lower, which implies a higher market penetration. This means when the speed limit is low, higher market penetration would lead to the increase in total system travel time. Therefore, government has to control the speed limit and service charges with caution when traveller information provision services are implemented so as to balance the conflict between vehicular emissions and TSTT. Moreover, we found out that the information quality has different effects on vehicular emissions and congestion with varied speed limits. It indicates that it is essential to consider the speed limit while evaluating the impacts of traveller information provision services on vehicular emissions and TSTT. The rest of this paper is organized as follows: Section Two depicts the NCP formulation of the multi-class mixed SUE assignment model with elastic market penetrations and performance measures, such as TSTT and vehicular emissions. Section Three provides numerical studies. Finally, Section Four summarizes concluding remarks.

FORMULATION AND PERFORMANCE MEASURES

NCP formulation of the multi-class mixed SUE equilibrium problem

The traveler information provision service is a navigational measure to provide drivers information of road network situations to assist travelers to make decision of their route choices. Lo and Szeto (2002) pointed out that assumption in many previous studies (e.g., Yang, 1998; Lo et al., 1999) has been made to consider equipped travelers to have perfect information and unequipped travelers to have imperfect information. The level of information provided can be reflected by the parameter of travel time perception variation. In this paper, we model the multi-class route choice behavior of equipped and unequipped travelers to follow the principle of Stochastic User Equilibrium by only varying travel time perception variation, which implies that all the equipped travelers have a lower travel time perception variation and all the unequipped travelers have a higher travel time perception variation. It is assumed there are M information service providers (ISP) who provide traffic information service over the whole road network for the corresponding M equipped driver classes, who only pay for the information from one service provider. There is an unequipped driver class who do not pay for any information service. Therefore, this problem has $M+1$ driver classes. We model this multi-class equilibrium problem as a Nonlinear Complementarity Problem (NCP) and consider a network $[N, A]$ where N is the set of nodes and A the set of directed links. The SUE conditions are formulated using the logit model:

$$f_{p,i}^{rs} - w_{p,i}^{rs} \cdot q_i^{rs} = 0, \forall rs, p, i, \quad (1)$$

$$w_{p,i}^{rs} = \frac{\exp(-\theta_i \cdot \eta_{p,i}^{rs})}{\sum_k \exp(-\theta_i \cdot \eta_{k,i}^{rs})}, \forall rs, p, i, \quad (2)$$

where $f_{p,i}^{rs}$, $w_{p,i}^{rs}$, and $\eta_{p,i}^{rs}$ are respectively the route flows, the proportion, and the generalized travel cost of class i drivers on route p between origin-destination (OD) pair rs ; θ_i is the parameter representing the travel cost perception variation of class i drivers, interpreted as the information quality available to them or interpreted as the accuracy of traffic information

provided by an information service provider (ISP) to equipped drivers; q_i^{rs} is the demand of class i drivers between OD pair rs .

Equation (1) simply means that the demand of each class is loaded into each route according to the proportion defined by the logit model (2). As shown in (2), the difference between all classes is on the travel cost perception variation, represented by θ_i . A higher θ_i means a smaller travel cost perception variation and therefore better information quality. In general, we expect that the equipped vehicles have a higher θ_i than the unequipped ones. The value of θ_{M+1} , on the other hand, represents people's familiarity with the network conditions without traveler information services. All these parameters can be calibrated to the quality of information available by the methodology proposed in Lo and Szeto (2002).

The generalized route travel costs $\eta_{p,i}^{rs}$ in (2) are functions of link travel times, which in turn are functions of the link flow v_a . The link flow v_a can be determined by summing up all the route flows on that link:

$$v_a = \sum_{p \in P^{rs}} \sum_i f_{p,i}^{rs} \cdot \delta_a^p, \forall a, \quad (3)$$

where δ_a^p is the link-route incidence indicator — $\delta_a^p = 1$ if link a is on route p ; $\delta_a^p = 0$ otherwise, and P^{rs} is the set of paths between OD pair rs .

The link travel time t_a in this study is obtained from the link flow v_a based on the Bureau of Public Roads (BPR) type performance function:

$$t_a = t_a^0 \left[1 + \alpha \left(\frac{v_a}{c_a} \right)^\beta \right], \forall a, \quad (4)$$

$$t_a^0 = \frac{l_a}{s_a}, \forall a, \quad (5)$$

where c_a is its capacity; α, β are parameters of the BPR function, whose typical values are $\alpha = 0.15, \beta = 4$; t_a^0 , the link's free flow travel time, can be calculated in equation (5) when the distance of the link a and the speed limit of this link, l_a and s_a , are given. Equation (4) is a monotonic and continuous link travel time function, which is adopted for illustrative purposes. Other continuous link travel time functions can be used in this problem.

Once link travel time is known, the generalized route travel cost can be computed as follows:

$$\eta_{p,i}^{rs} = C_{ISP,i} + \sum_a (Bt_a + \rho_a) \cdot \delta_a^p, \forall rs, p, i, \quad (6)$$

where ρ_a is the toll on link a , which equals zero for a toll-free link and equals $C_{TO,a}$ if the toll link is maintained and operated by toll road operator a . B is the value of time. $C_{ISP,i}$ is the information service charge for class i drivers. It is the average service charge per trip derived from the monthly charge, and is zero when i is $M+1$ (i.e., when the drivers are unequipped). The term in the brackets is the travel cost on link a , which is the sum of the travel time cost Bt_a and

its toll ρ_a . The generalized route travel cost is simply the sum of the travel costs of the links on that route and the service charge.

The demand q_i^{rs} in (1) is modeled through the newly proposed multinomial logit market penetration model:

$$q_i^{rs} = \tilde{q}^{rs} e_i^{rs}, \forall rs, i, \quad (7)$$

$$e_i^{rs} = \frac{\exp(\rho \phi_i^{rs})}{\sum_{k=1}^{M+1} \exp(\rho \phi_k^{rs})}, \forall rs, i, \quad (8)$$

where $\tilde{q}^{rs}$ is the total travel demand between OD pair rs , which is fixed; and e_i^{rs} is the proportion of class i drivers between OD pair rs ; ρ is the scale parameter; ϕ_i^{rs} is the systematic utility received by class i drivers between OD pair rs , which is simply assumed to be equal to the driver-class-specific constant ω_i minus average generalized route travel cost of those drivers:

$$\phi_i^{rs} = \omega_i - \left(\sum_p w_{p,i}^{rs} \cdot \eta_{p,i}^{rs} \right), \forall rs, i. \quad (9)$$

The driver-class-specific constant ω_i is actually a parameter capturing benefits other than travel time saving such as convenience of having the device. The market penetration model (7)-(8) is the generalization of the special case in Lo and Szeto (2002). This model is reduced to the special case when there is only one information service provider and $\rho = 1$. Under this situation, the systematic utility received by class i drivers is:

$$\phi_i^{rs} = -C_{ISP,i} + \omega_i - B \left\{ \sum_p \left[w_{p,i}^{rs} \left(\sum_a (t_a \cdot \delta_a^p) \right) \right] \right\}, i = 1, 2, \forall rs. \quad (10)$$

The term in the parentheses in (10) is the travel time on route p . The term in braces is the average route travel time of class i drivers between OD pair rs . The first and second terms in equation (10) are zero for unequipped drivers. From (10), we can determine the difference of systematic utilities as follows:

$$\phi_2^{rs} - \phi_1^{rs} = C_{ISP,1} - \omega - B \left\{ \sum_p \left[w_{p,2}^{rs} \left(\sum_a (t_a \cdot \delta_a^p) \right) \right] - \sum_p \left[w_{p,1}^{rs} \left(\sum_a (t_a \cdot \delta_a^p) \right) \right] \right\}, \forall rs. \quad (11)$$

The term in the braces in (11) is the travel time saving defined in Lo and Szeto (2002). Since there is only one information provider and the demand for the service can be expressed as a function of the difference of systematic utilities:

$$q_1^{rs} = \tilde{q}^{rs} e_1^{rs} = \tilde{q}^{rs} \frac{\exp(\phi_1^{rs})}{\exp(\phi_1^{rs}) + \exp(\phi_2^{rs})} = \tilde{q}^{rs} \frac{1}{1 + \exp(\phi_2^{rs} - \phi_1^{rs})}, \forall rs. \quad (12)$$

By substituting (11) into (12), we can obtain the elastic market penetration model proposed in Lo and Szeto (2002). Hence, the market penetration model (7)-(8) is the generalization of the one there.

To obtain an NCP formulation, we multiply the corresponding route flows by the SUE conditions

(1), substitute (7) into the resultant expression, and add the non-negativity conditions to obtain the following:

$$\begin{cases} f_{p,i}^{rs} (f_{p,i}^{rs} - w_{p,i}^{rs} \tilde{q}^{rs} e_i^{rs}) = 0 \\ f_{p,i}^{rs} \geq 0 \\ f_{p,i}^{rs} - w_{p,i}^{rs} \tilde{q}^{rs} e_i^{rs} \geq 0 \end{cases}, \forall rs, p, i. \quad (13)$$

According to (13), if $f_{p,i}^{rs} > 0$, the term $(f_{p,i}^{rs} - w_{p,i}^{rs} \tilde{q}^{rs} e_i^{rs})$ must be zero; (1) must be satisfied, and $f_{p,i}^{rs}$ is apportioned according to the logit split expressions (2) and (8). If $f_{p,i}^{rs} = 0$, the term $(f_{p,i}^{rs} - w_{p,i}^{rs} \tilde{q}^{rs} e_i^{rs})$ can take any value. However, this will never happen because theoretically, the SUE assignment assigns positive flows to each route. Finally, the constraint $f_{p,i}^{rs} - w_{p,i}^{rs} \tilde{q}^{rs} e_i^{rs} \geq 0$ is added for mathematical completeness. At the SUE solution, as contended above, the term $(f_{p,i}^{rs} - w_{p,i}^{rs} \tilde{q}^{rs} e_i^{rs})$ becomes zero, and hence satisfies this last constraint automatically.

We put everything together and let:

$$\mathbf{y} = \begin{bmatrix} \theta_i, i = 1, \dots, M \\ C_{ISP,i}, i = 1, \dots, M \end{bmatrix}, \quad (14)$$

$$\mathbf{x}(\mathbf{y}) = [f_{p,i}^{rs}, \forall rs, p, i], \text{ and} \quad (15)$$

$$\mathbf{F}(\mathbf{x}) = [f_{p,i}^{rs} - w_{p,i}^{rs} \tilde{q}^{rs} e_i^{rs}, \forall rs, p, i], \quad (16)$$

the NCP (13) can then be expressed as finding $\mathbf{x}^* \geq 0$ such that:

$$\mathbf{F}(\mathbf{x}^*) \geq 0, \mathbf{x}^*(\mathbf{y})^\top \cdot \mathbf{F}(\mathbf{x}^*) = 0, \quad (17)$$

where $w_{p,i}^{rs}$ and e_i^{rs} are defined by (2)-(9).

In this study, it is assumed that a congestion problem is a primary concern of decision makers (governments). Traveller information services are provided to guide equipped travellers from congested areas to the less congested ones together with the speed limit control. It is anticipated that the provision of traveller information services could possibly relieve the congested problem. In addition, government also considers the impact of traveller information provision on vehicular emissions. With the above NCP formulation, we can solve for route flow patterns of equipped travelers and unequipped travelers, and hence evaluate the impacts of traveler information provision on traffic incurred congestion and emissions respectively under different speed limits. In the following, the functions of system performance regarding congestion and vehicular emissions are defined.

Performance measures

The total system travel time (TSTT)

The total system travel time (TSTT) is calculated to measure system performance regarding congestion and it is the sum of the travel times of all drivers on all links, expressed as:

$$TSTT = \sum_a v_a t_a. \quad (18)$$

According to (18), TSTT is a function of link flows, and hence is a function of route flows based on (3).

Vehicular emissions

In our study, we adopt the macroscopic emissions estimation relationship used in TRANSYT 7-F model which belongs to the domain of average speed models. The general function of the model used in (9 and 13) to calculate CO emissions is expressed as follows:

$$ROP_a = 3.3963 \frac{e^{0.01456 \bar{s}_a}}{1000 \bar{s}_a}, \forall a, \quad (19)$$

where ROP_a is the production rate of CO emissions (grams/veh·ft), $\bar{s}_a$ is the average speed of a vehicle on link a (ft/sec), which is obtained by dividing the link distance l_a with the average travel time of link a , t_a in equation (4). In our study, the unit of speed is converted into km/hr. So the production rate of CO emissions is in grams/veh·km. The converted function of CO emissions is not expressed here. The overall vehicular emissions can be calculated as follows:

$$Q = \sum_a Q_a = \sum_a ROP_a l_a v_a, \forall a, \quad (20)$$

where Q_a is the vehicular emissions on link a ; l_a is the link distance; v_a represents the hourly traffic flow on link a . Q_a , the vehicular emissions on link a are the production of the CO production rate on this link, the distance of the link and the link load. The overall vehicular emissions Q can be obtained as in equation (20) by summing of the vehicular emissions on each link.

NUMERICAL STUDIES

In this study, we study the impacts of traveller information provision services and speed limit control on TSTT and overall vehicular emissions in a two-class mixed SUE assignment problem where one class of drivers are equipped drivers and they can obtain pre-trip traveller information, and another class of drivers are not equipped. They follow the mixed SUE assignment, in which they have different perception variations. Market penetration of traveller information provision services is elastic here, because travellers decide their choices to buy or not to buy services based on quality and service charges of traveller information. It is assumed all drivers are homogeneous, and they have the same value of time. The example network shown in figure 1 is broadly based upon an existing section of the road network in Ireland between North of Balbriggan and Dundalk in Co. Louth, which consists of two links, two nodes and one OD pair, where link 1 is a highway link and link 2 is a road link. Government can control both the speed limits on the highway link and the information service charges for information provision. It is assumed that the speed limit on each route is uniform and the compliance rate of the speed limits is 100%, also the speeds of vehicles are constant along each link with 0% grade on all roads. The parameters adopted are as follows: a) demand parameters: $\tilde{q}^{13} = 4250$ vph; b) route choice parameters: value of time $B = \text{€ } 15/\text{hr}$; travel cost perception variation parameter: unequipped drivers $\theta_1 = 0.15 \text{ €}^{-1}$; equipped

drivers $\theta_2 = 2 \text{ €}^{-1}$; convenience of having the device: $\omega = 1.5 \text{ €}$; c) toll operation parameter: toll $\rho_1 = \rho_2 = 0 \text{ €}$; d) information service parameter: service charge $C_{ISP} = 0 - 8 \text{ €}$; e) Network parameters: $c_1^0 = 2500 \text{ vph}$; $c_2^0 = 2000 \text{ vph}$; $\alpha_0 = 1$; $\alpha_1 = 0.15$, $\alpha_2 = 4$; $s_1 = 50 - 110 \text{ km/hr}$; $s_2 = 60 \text{ km/hr}$; $l_1 = 55 \text{ km}$; $l_2 = 30 \text{ km}$. They are assumed to be fixed and selected for illustrative purposes. In general, they should correspond to network characteristics and a real situation.

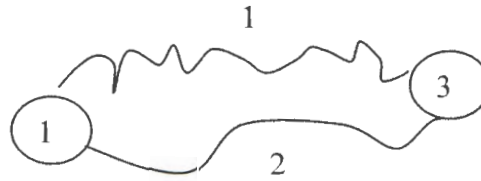


Figure 1. The example network

Figures 2 and 3 below respectively plot changes in overall vehicular emissions and TSTT against service charges of information provision under varied values of speed limits. Results indicate that both higher and lower speed limits do not lead to lower vehicular emissions. It is largely dependent on the service charges of traveller information services. For example, when the speed limit is 50km/hr, the level of vehicular emissions varies when the service charge changes. When the service charge is low which results in a high market penetration, the vehicular emissions are at a high value. With the increase of the service charge, the vehicular emissions fall. When the service charge is smaller than 2.2euros, the speed limit of 50km/hr brings about the highest vehicular emissions than any other given speed limit. However, after the service charge is greater than 2.2euros, the speed limit of 110km/hr leads to the highest value of vehicular emissions. It is observed in figure 2 that intermediate speed limits, such as 70 and 80 km/hr, maintain a lower level of emissions. When the service charge is below 2.2 euros, the lowest vehicular emissions occur when the speed limit is at 80km/hr. Nevertheless, this does not always occur after the service charge is over 2.2euros, where the lowest vehicular emissions are exhausted when the speed limit is at 70km/hr. these findings implied that both higher and lower speed limits do not lead to a lower level of vehicular emissions. In this case, it depends on the value of service charges, which directly affects the market penetration. In figure 3, we found out the higher the speed limits, the lower the TSTT. However, when the speed limit is low at 50km/hr, TSTT decreases when the service charge rises. As we know, a lower level of service charges results in a high market penetration. This means when the speed limit is low, higher market penetration would lead to the increase in total system travel time. But when the higher speed limit is implemented, there are very minor changes in TSTT when the service charges alter. Therefore, it is concluded that government has to control the speed limit and service charges with caution when traveller information provision services are implemented so as to balance the conflict between vehicular emissions and TSTT.

Figure 4 illustrates the impacts of information quality on overall vehicular emissions and TSTT when speed limits are 50 and 110km/hr respectively. In this case, the sensitivity analysis is carried out to change travel time perception variation, θ . A higher value of θ means a lower perception variation and better information quality. It is found out that the information quality has different effects on vehicular emissions and congestion with varied speed limits. For instance, when the speed limit is at 50km/hr, the information quality has major impacts on both vehicular

emissions and TSTT. When the information quality is better, both vehicular emissions and TSTT increase. However, when the speed limit is at 110km/hr, only the vehicular emissions rise slightly with the increase in θ . There is almost no effect on TSTT when θ increases. This finding implied that it is important to consider the speed limit control while evaluating the impact of traveller information services on the system performance in terms of vehicular emissions and TSTT.

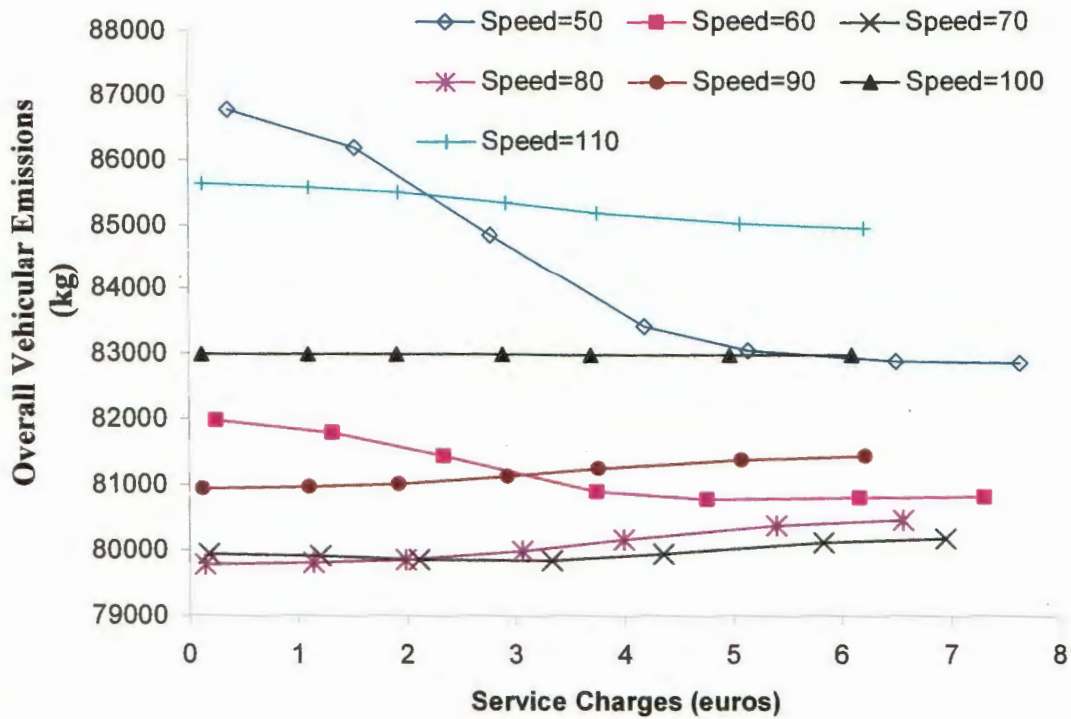


Figure 2. The impact of service charges and the speed limit on overall vehicular emissions.

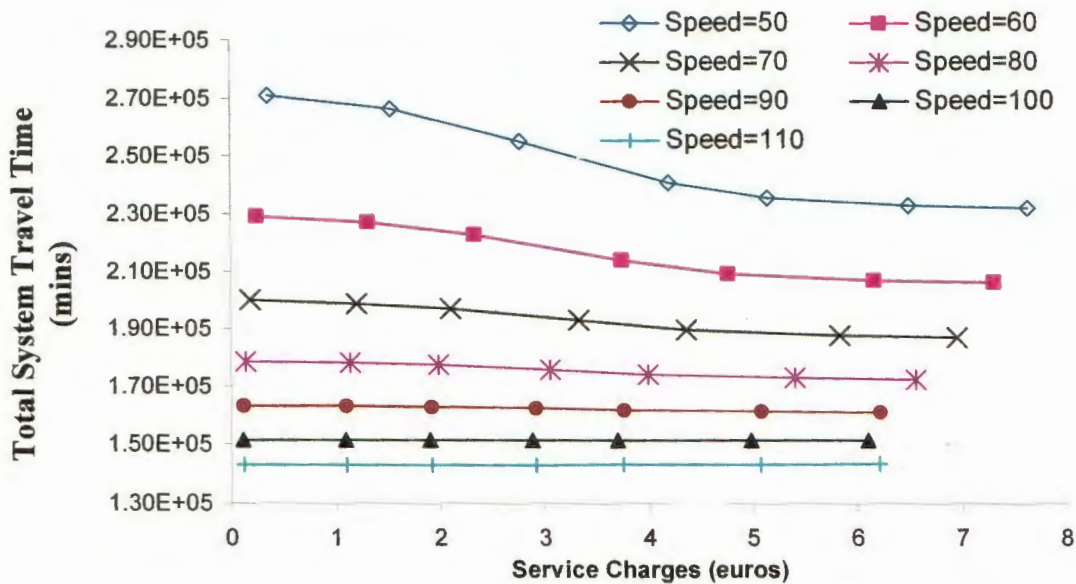


Figure 3. The impact of service charges and the speed limit on TSTT.

emissions and TSTT. When the information quality is better, both vehicular emissions and TSTT increase. However, when the speed limit is at 110km/hr, only the vehicular emissions rise slightly with the increase in θ . There is almost no effect on TSTT when θ increases. This finding implied that it is important to consider the speed limit control while evaluating the impact of traveller information services on the system performance in terms of vehicular emissions and TSTT.

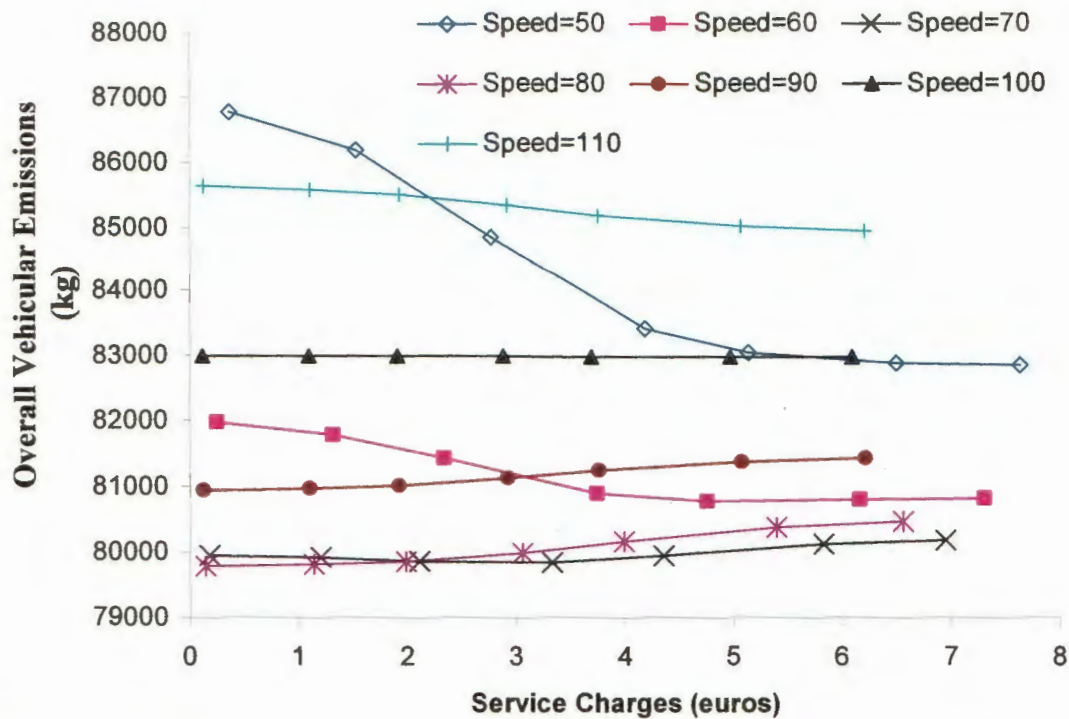


Figure 2. The impact of service charges and the speed limit on overall vehicular emissions.

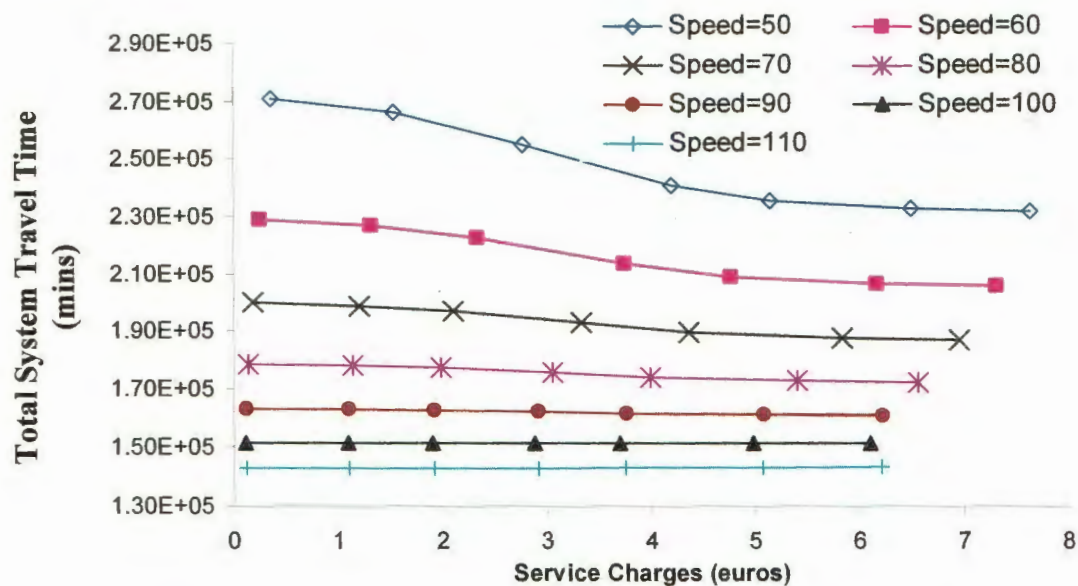


Figure 3. The impact of service charges and the speed limit on TSTT.

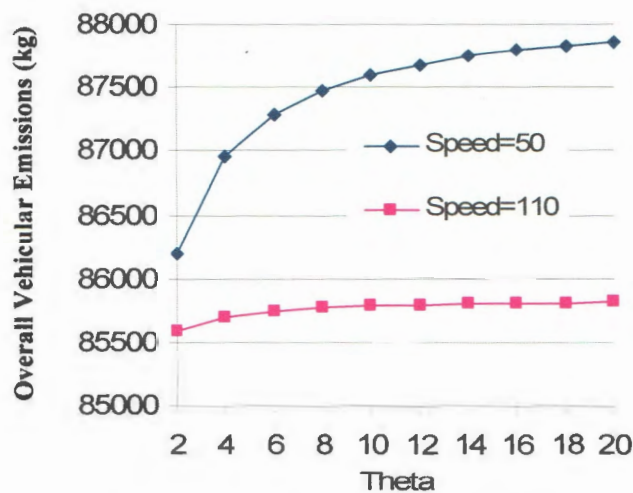


Figure 4a.

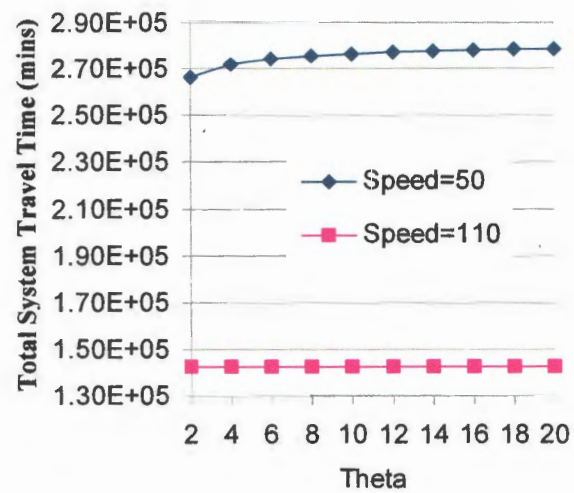


Figure 4b.

Figure 4. The impact of information quality on overall vehicular emissions and TSTT when speed limits are 50 and 110km/hr respectively.

CONCLUSIONS

In the literature, no one has attempted to incorporate the speed limit control when studying the impacts of traveller information services on vehicular emissions and TSTT. However, the speed of a vehicle plays an important role in the volume of vehicular emissions. To address this important issue, in this paper, we adopt the macroscopic emissions estimation relationship used in TRANSYT 7-F model which belongs to the domain of average speed models to consider the effect of the speed limit control while analyzing the impacts of traveller information provision services on TSTT and overall vehicular emissions. We model the route choice behaviour of the equipped and unequipped travellers as following a mixed-Stochastic User Equilibrium (SUE) where elastic market penetration is captured. This mixed SUE problem is modelled through the Nonlinear Complementarity Problem (NCP) approach and solved by Generalized Reduced Gradient (GRG) method. Results indicate that both higher and lower speed limits do not lead to lower emissions. It is largely dependent on the service charges of traveller information services. Additionally, when the speed limit is low, TSTT rises when the service charge decreases. A low service charge implies a higher market penetration. This means when the speed limit is low, the higher market penetration would lead to a rise in TSTT. Therefore, government has to control the speed limit and service charges with caution when traveller information provision services are implemented so as to balance the conflict between vehicular emissions and TSTT. Furthermore, it is observed that the information quality has different effects on vehicular emissions and congestion with varied speed limits. It shows that it is important to capture the effect of the speed limit control while evaluating the impacts of traveller information provision services on vehicular emissions and TSTT.

There are following extensions raised in this research. Firstly, it is assumed in our study, a uniform speed limit is applied on each route, and all drivers have the same value of time. However, people with a higher value of time will travel faster than other people (see, for example,

4 and 14). Rietveld and Shefer (4) have pointed out with a uniform speed limit, it is impossible to consider the variety among drivers. Without any difficulty, our model can be extended to consider various speed limits on the same route in the transport system where drivers have different value of times. Secondly, we assumed that the compliance rate of the speed limit is 100%, but in the real world drivers are not completely obedient to the speed limit. It is thus rather important to capture this driver behaviour when studying the impacts of the speed limit control and traveller information provision services on TSTT and vehicular emissions. Besides, extending the existing model to incorporate travel time, cost and network uncertainties would be another meaningful but challengeable research direction.

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