PARADOXES WITH THE TRAVELLER INFORMATION PROVISION SERVICES

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ABSTRACT

Conventionally, it is intended that providing travellers with the dissemination of traffic information would allow equipped vehicles to spread from the congested to the less congested areas. Hence the travel times of both equipped drivers and the total system travel time (TSTT) would be reduced. However, the provision of traveller information services may not be able to reduce TSTT and the total vehicular emissions simultaneously. With this consideration, we model the route choice behaviour of the equipped and unequipped travellers as following a mixed-Stochastic User Equilibrium (SUE). Elastic market penetration is also considered. This mixed-equilibrium problem with elastic market penetration is modelled as a nonlinear complementary problem (NCP). Results demonstrate that the provision of traveller information services cannot reduce total system travel time (TSTT) and emissions simultaneously. More importantly, improving information quality of the service can raise total emissions in addition to TSTT. In addition, we found out that a range of service charge of information provision can lead to the occurrence of these paradoxical phenomena. This implies that the government has to control the charges and information quality so as to avoid the increases in both TSTT and total vehicular emissions.

INTRODUCTION

Over the last two decades, there has been a considerable interest in the transportation area in analyzing the effects of providing traveller information. Many research works have been undertaken to evaluate the impacts of traveller information provision in terms of some welfare economic considerations (Emmerink et al., 1998; Chmura et al., 2007), potential travel time savings (Wunderlich, 1998; Levinson, 2003; Abdalla and Abdel-Aty, 2006; Toledo et al., 2006), driver response (Kantowitz et al., 1995; Chatterjee et al., 2000), safety implications (Al-Deek et al., 1993; Al-Deek et al., 1998), route choice behavior (Abdel-Aty et al., 1995; Li and Huang, 2004; Jou et al., 2005; Gan et al., 2006), and system performance (Emmerink, 1995; Hall, 1996; Stern 1996; Al-Deek et al., 1998), and so on. Only very few studies were focused on studying environmental impacts of traveler information provision, particularly from increased vehicular emissions. For example, Al-Deek et al. (1995) proposed an analytical method for evaluating the impact of Advanced Traveler Information System (ATIS) on air quality in a simple network where traffic experienced incident congestion. Kanninen (1996) discussed the congestion relief and environmental impacts expected of Intelligent Transportation Systems (ITS). It was mentioned that ITS might induce latent travel demand which probably would increase vehicular emissions. Kaysi et al. (2004) assessed implications for vehicle-induced emissions in a congested city where traveler information is provided for incident management.

To our best knowledge, the impact of traveler information on vehicular emissions requires more evaluation, because any underestimation and overestimation of environmental impacts of traveler information provision would lead to an unexpected outcome. Conventionally, it is intended that providing travellers with the dissemination of traffic information would allow equipped vehicles to spread from the congested to the less congested areas. Hence the travel times of both equipped drivers and the total system travel time (TSTT) would be reduced. However, diverted traffic may impose extra environmental externalities, such as air pollution, noise pollution, and accidents, on existing drivers and residents living in the neighbourhood. And the increased pollution is hazardous to human health. In this case, the aim of implementing traveler information provision is not only to enhance the mobility of a transportation system but also to maintain the system to sustain in an environment-friendly way. Al-Deek et al. (1995) pointed out that under different market penetration levels, ATIS may have different impacts on vehicular emissions. Actually the market penetration level, the proportion of the number of drivers who buy the service and the total number of drivers in the system, is determined by the cost for purchasing the information system, the value of time of drivers as well as the level of information quality provided to drivers. Therefore, the key to understand the impacts of traveler information provision on vehicular emissions lies on these parameters, and how they determine the level of market penetration, and consequently resulting in changes in vehicular emissions. Similarly, these parameters are also determinants of the system performance in terms of TSTT due to the changes in market penetration. However, the provision of traveller information services may not be able to reduce TSTT and the total vehicular emissions simultaneously. Therefore, in this study, our objectives are to: 1). analyze the occurrence of paradoxes regarding TSTT and

vehicular emissions in the transportation system with the provision of traveler information; 2). study the impacts of information service charges and the level of information quality on the occurrence of paradoxes in terms of TSTT and vehicular emissions. In this study, we assume all drivers are homogeneous, and they have an identical value of time. So the impact of the value of times on the occurrence of paradoxes is not our concern at this stage. Nonetheless, a future analysis in a multi-class, multi-criteria (cost versus time) road network can utilize the framework proposed by Huang and Li (2007).

In this study, we model the route choice behaviour of the equipped and unequipped travellers as following a mixed-Stochastic User Equilibrium (SUE). 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. This market penetration model can be reduced to the one proposed in Lo and Szeto (2002) when there is only one class of equipped 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 (Abadie and Carpentier, 1969). Results demonstrate that there are paradoxical phenomena regarding TSTT and overall vehicular emissions and the provision of traveller information services cannot reduce total system travel time (TSTT) and emissions simultaneously. More importantly, improving information quality of the service can raise total emissions in addition to TSTT. Furthermore, we found out that a range of service charge of information provision can lead to the occurrence of these paradoxical phenomena. This implies that the government has to control the charges and information quality so as to avoid the increases in both TSTT and total vehicular emissions.

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:

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

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

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

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

where t_a^0 is the link's free flow travel time; c_a is its capacity; α, β are parameters of the BPR function, whose typical values are $\alpha = 0.15, \beta = 4$. This monotonic and continuous link travel time function 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:

$$\eta_{p,i}^{rs} = C_{ISP,i} + \sum_a \left(Bt_a + \rho_a \right) \cdot \delta_a^p, \forall rs, p, i, \tag{5}$$

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:

$$q_i^{rs} = \tilde{q}^{rs} e_i^{rs}, \forall rs, i, \tag{6}$$

$$e_i^{rs} = \frac{\exp\left(\rho \phi_i^{rs} \right)}{\sum_{k=1}^{M+1} \exp\left(\rho \phi_k^{rs} \right)}, \forall rs, i, \tag{7}$$

where $\tilde{q}^{rs}$ is the total travel demand between OD pair rs, which is fixed; and e_j^{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:

$$\phi_i^{rs} = \omega_i - \left(\sum_p w_{p,i}^{rs} \cdot \eta_{p,i}^{rs} \right), \forall rs, i. \tag{8}$$

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 (6)-(7) 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:

$$\phi_i^{rs} = -C_{ISP,i} + \omega_i - B\left\{\sum_p\left[w_{p,i}^{rs}\left(\sum_a\left(t_a \cdot \delta_a^p\right)\right)\right]\right\}, i = 1, 2, \forall rs. \tag{9}$$

The term in the parentheses in (9) 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 (9) are zero for unequipped drivers. From (9), we can determine the difference of systematic utilities as follows:

$$\phi_2^{rs} - \phi_1^{rs} = C_{ISP,1} - \omega - B\left\{\sum_p\left[w_{p,2}^{rs}\left(\sum_a\left(t_a \cdot \delta_a^p\right)\right)\right] - \sum_p\left[w_{p,1}^{rs}\left(\sum_a\left(t_a \cdot \delta_a^p\right)\right)\right]\right\}, \forall rs. \tag{10}$$

The term in the braces in (10) 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:

$$q_1^{rs} = \tilde{q}^{rs}e_1^{rs} = \tilde{q}^{rs}\frac{\exp\left(\phi_1^{rs}\right)}{\exp\left(\phi_1^{rs}\right) + \exp\left(\phi_2^{rs}\right)} = \tilde{q}^{rs}\frac{1}{1 + \exp\left(\phi_2^{rs} - \phi_1^{rs}\right)}, \forall rs. \tag{11}$$

By substituting (10) into (11), we can obtain the elastic market penetration model proposed in Lo and Szeto (2002). Hence, the market penetration model (6)-(7) is the generalization of the one there.

To obtain an NCP formulation, we multiply the corresponding route flows by the SUE conditions (1), substitute (6) into the resultant expression, and add the non-negativity conditions to obtain the following:

$$\begin{cases} f_{p,i}^{rs}\left(f_{p,i}^{rs} - w_{p,i}^{rs}\tilde{q}^{rs}e_i^{rs}\right) = 0 \\ \qquad\qquad f_{p,i}^{rs} \geq 0 \qquad\quad, \forall rs, p, i. \\ f_{p,i}^{rs} - w_{p,i}^{rs}\tilde{q}^{rs}e_i^{rs} \geq 0 \end{cases} \tag{12}$$

According to (12), if $f_{p,i}^{rs} > 0$, the term $\left(f_{p,i}^{rs} - w_{p,i}^{rs}\tilde{q}^{rs}e_i^{rs}\right)$ must be zero; (1) must be satisfied, and $f_{p,i}^{rs}$ is apportioned according to the logit split expressions (2) and (7). If $f_{p,i}^{rs} = 0$, the term $\left(f_{p,i}^{rs} - w_{p,i}^{rs}\tilde{q}^{rs}e_i^{rs}\right)$ 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 $\left(f_{p,i}^{rs} - w_{p,i}^{rs}\tilde{q}^{rs}e_i^{rs}\right)$ becomes zero, and hence satisfies this last constraint automatically.

We put everything together and let:

$$\mathbf{y} = \begin{bmatrix} \theta_i, i = 1,...,M \\ C_{ISP,i}, i = 1,...,M \end{bmatrix}, \tag{13}$$

$$\mathbf{x(y)} = \left[f_{p,i}^{rs}, \forall rs, p, i \right], \text{ and} \tag{14}$$

$$\mathbf{F(x)} = \left[f_{p,i}^{rs} - w_{p,i}^{rs} \tilde{q}^{rs} e_i^{rs}, \forall rs, p, i \right], \tag{15}$$

the NCP (12) can then be expressed as finding $\mathbf{x}^* \geq 0$ such that:

$$\mathbf{F(x^*)} \geq \mathbf{0}, \ \mathbf{x}^* (\mathbf{y})^{\mathrm{T}} \cdot \mathbf{F(x^*)} = 0, \tag{16}$$

where $w_{p,i}^{rs}$ and e_i^{rs} are defined by (2)-(8).

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. 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. 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:

$$TSTT = \sum_a v_a t_a. \tag{17}$$

According to (17), TSTT is a function of link flows, and hence is a function of route flows based on (3).

Vehicular emissions

There are two types of vehicular emissions: link and network (or overall). The link vehicular emission is defined through the link emission factor approach. The key of estimating vehicular emissions is the relationship that volume of emissions is equal to the product of an emission factor and link load (DeCorla-Souza et al., 1995). This emission factor obtained using MOBILE model proposed by the Environmental Protection Agency (EPA) is based on the federal test procedure (FTP), typical driving conditions for an urban vehicle trip (DeCorla-Souza et al., 1995). This link emission factor approach adopted by Nagurney *et al*. (1998) and others can be expressed as follows:

$$Q_a = \sum_m Q_a^m = \sum_m h_a^m v_a^m, \forall a, \tag{18}$$

where Q_a^m is the vehicular emissions for traffic mode m on link a; v_a^m represents the hourly traffic flow for mode m on link a; h_a^m is the emission factor for mode m on link

a, which is assumed to be given for all links. The factors affecting the value of h_a^m are discussed in Nagurney (2000). The overall vehicular emissions can be calculated as follows:

$$Q_\tau = \sum_a Q_{a,\tau}, \forall \tau .$$ (19)

According to (18), the vehicular emissions for mode m on a particular link is the product of the link flows of mode m and the corresponding emission factor, and the total vehicular emissions on this link is the sum of vehicular emissions for all modes traveling on this link. And the overall vehicular emissions can be obtained as in equation (19) by summing of the vehicular emissions on each link.

NUMERICAL STUDIES

Existence of paradoxes in traveler information provision services in terms of TSTT and vehicular emissions

Scenarios 1 and 2 were set up to evaluate the effectiveness of traveler information provision services on TSTT and vehicular emissions. In these two cases, we simplified our multi-class mixed SUE model into a single class route choice behavior of equipped or unequipped travelers to follow the principle of Stochastic User Equilibrium so as to assess the system performance in terms of TSTT and vehicular emissions before and after providing traveler information services. We only varied travel time perception variation, which implied that before information provision all the unequipped travelers had a higher travel time perception variation, and after information provision, all the equipped travelers had a lower travel time perception variation. The scenario example used here 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 shown in figure 1 below.
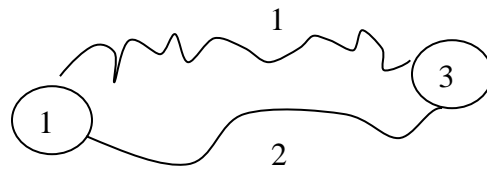

Figure 1. The example network

Scenario 1

In scenario 1, the parameter values adopted are as follows: a) demand parameters: $\tilde{q}^{13} =$ 11000 vph; b) route choice parameters: value of time $B = €$ 15/ hr; travel cost perception variation parameter: unequipped drivers $\theta_1 = 0.05$ €$^{-1}$; equipped drivers $\theta_2 = 15$ €$^{-1}$; c) toll operation parameter: toll $\rho_1 = \rho_2 = 0$ €; d) information service parameter: service charge

C_{ISP} = 0.5 €; e) vehicular emission parameter: link emission factors h_1 =1.3; h_2 =0.8: f) Network parameters: $c_1^0 = 12000$ vph; $c_2^0 = 2000$ vph; $\alpha_0 = 1$; $\alpha_1 = 0.15$, $\alpha_2 = 4$; $t_1^0 = 21$ mins; $t_2^0 = 37$ mins. They are assumed to be fixed and selected for illustrative purposes. In general, they should correspond to network characteristics and a real situation.

In this scenario, TSTT and total vehicular emissions are calculated respectively in two situations, one is where all drivers do not have information provision services equipped in their vehicles (lower θ value) and another is where all drivers are equipped with traveler information provision services (higher θ value). Figures 2 and 3 below show the changes in TSTT and overall vehicular emissions before and after the traveler information provision. It is obvious that TSTT is decreased after all the drivers are equipped with traveler information services, which is shown in figure 2. However, in figure 3, the overall vehicular emissions are increased after the information provision. This means that in this case the traveler information provision service worsens the overall vehicular emissions on the network. These changes are due to the better information provided to all the travelers after they equip the information provision services. This indicates that traveler information provision cannot reduce TSTT and total vehicular emissions simultaneously. In figure 4, we demonstrate the changes in flows on links 1 and 2 before and after information provision. As we can see, before information provision, that is when θ is equal to 0.5, there are more vehicles traveling on link 1 than the ones on link 2. However, after information provision, all drivers are guided to travel link 1. Because link 1 is a high emission factor link with shorter free flow travel time and bigger capacity to accommodate more vehicles, when all drivers are guided onto link 1, overall system travel time can be reduced but there is an increase of overall vehicular emissions. In this case, providing traveler with better information can lower TSTT but raise overall vehicular emissions.
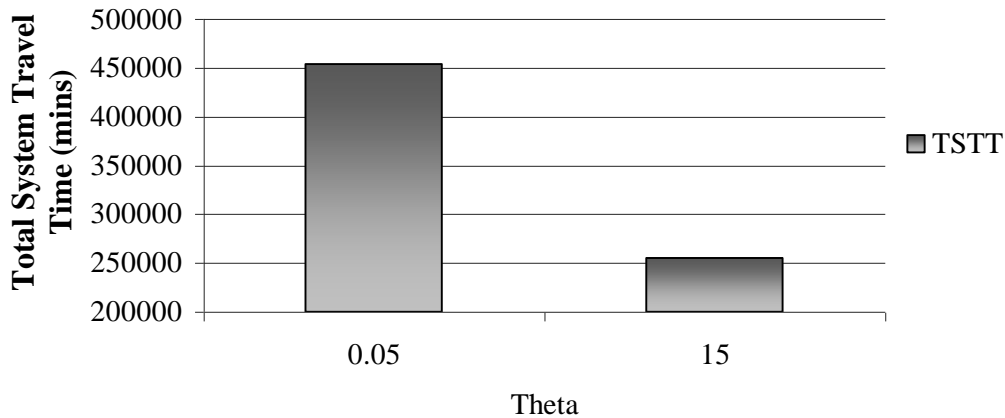

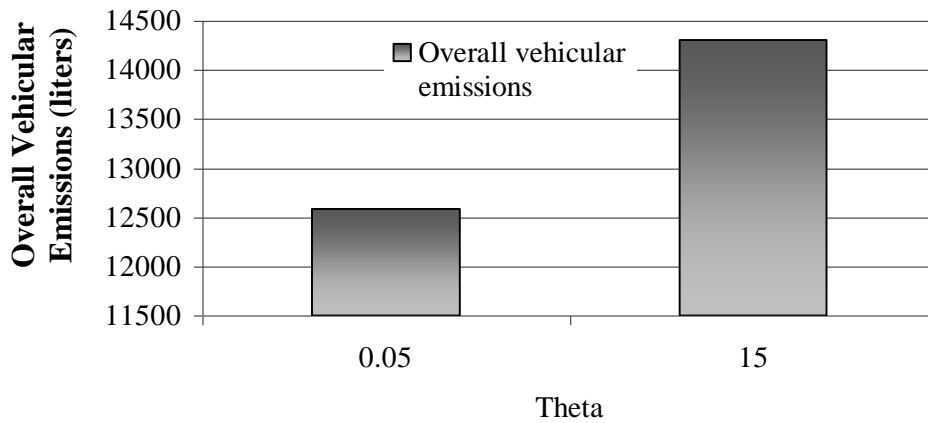Figure 2. TSTT before and after information provision.

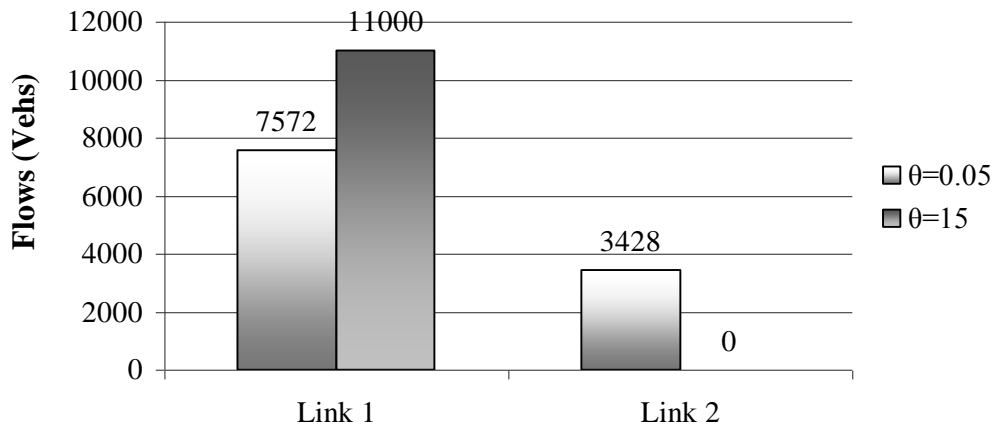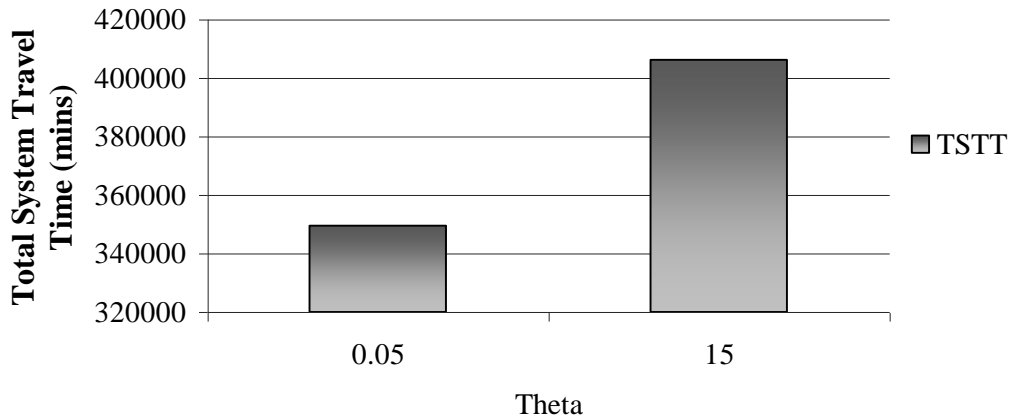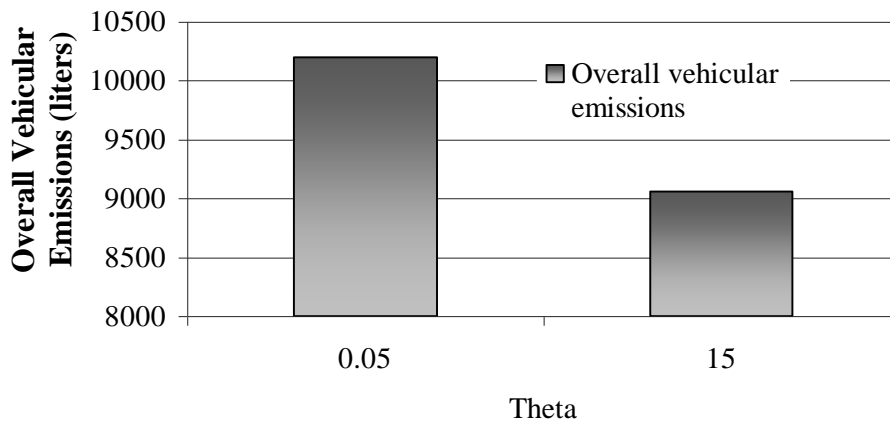Figure 3. Overall vehicular emissions before and after information provision.

Figure 4. Changes in flows on links 1 and 2 before and after information provision.

Scenario 2

In scenario 2, the parameter values adopted are the same as scenario 1 except the followings: e) vehicular emission parameter: link emission factors $h_1 =0.6$; $h_2 =1.3$: f) Network parameters: $c_1^0 = 5000$ vph; $c_2^0 = 12000$vph. Like in scenario 1, these parameters are assumed to be fixed and selected for illustrative purposes. In general, they should correspond to the network characteristics and the real situation.

In this scenario, we found out a paradoxical phenomenon that providing travellers better information cannot always decrease TSTT. Figure 5 illustrates that after information provision, TSTT increases. On the contrary, figure 6 shows that providing traveller information leads to a fall of overall vehicular emissions. This again indicates traveler information provision cannot reduce TSTT and total vehicular emissions simultaneously, even it cannot always lower TSTT as anticipated. Figure 7 further reveals changes in flows on links 1 and 2. It is shown that there are more travellers on link 1 after

information provision. As the total travel demand is fixed, there are fewer travellers on link 2. Compared with link 2, link 1 is a lower emission factor link with shorter free flow travel time but less link capacity. Thus, when more drivers switch their route choice to travel on link 1, TSTT increases because link 1 cannot accommodate more vehicles with a smaller link capacity. Nonetheless, overall vehicular emissions fall because more drivers travel link 1, which is the lower emission factor link.

Figure 5. TSTT before and after information provision.

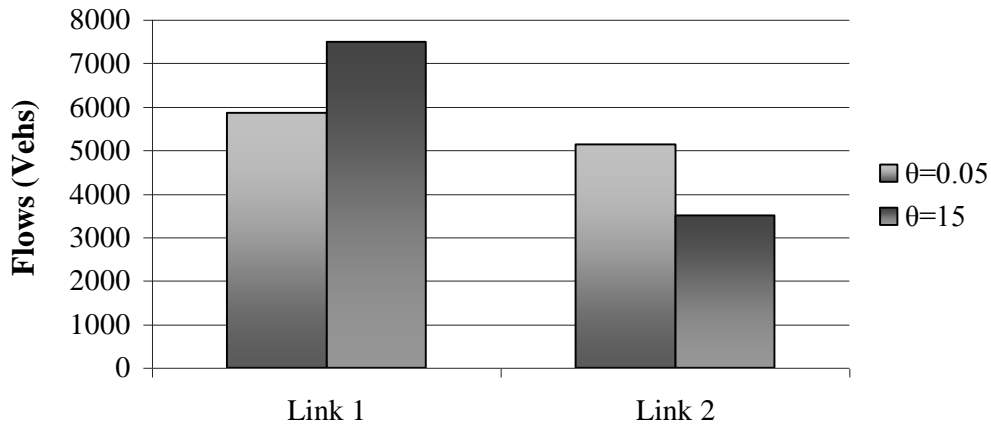Figure 6. Overall vehicular emissions before and after information provision.

Figure 7. Flows on links 1 and 2 before and after information provision.

Evaluating the impacts of information quality and service charges of traveller information provision on TSTT and vehicular emissions

It is demonstrated in last section that there are paradoxical phenomena when implementing traveller information provision services and traveler information provision cannot reduce TSTT and total vehicular emissions simultaneously. With this consideration, we investigate the changes in 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 in figure 1 is employed again and the parameters adopted are the same as in Scenario 1 except the followings: a) demand parameters: $\tilde{q}^{13} = 4500$ vph; b) route choice parameters: travel cost perception variation parameter: unequipped drivers $\theta_1 = 0.15$ €$^{-1}$; equipped drivers $\theta_2 = 2$, 4, 6, 8 €$^{-1}$; convenience of having the device: $\omega = 1.5$ €; e) vehicular emission parameter: link emission factors $h_1 = 1.3$; $h_2 = 0.9$: f) Network parameters: $c_1^0 = 2500$ vph; $c_2^0 = 2000$vph; $t_1^0 = 21$ mins; $t_2^0 = 29$ mins.

Figures 8 and 9 respectively plot changes in TSTT and overall vehicular emissions against service charges of information provision under varied values of travel time perception variation parameter θ. It is observed that when the service charge is smaller than 3 euros, the higher the θ value is, the higher TSTT and overall vehicular emissions are. A higher θ means that drivers have a smaller travel time perception variation implying drivers have better traffic information, and vice versa. Therefore, results depict that providing better information quality to drivers is likely to lead to a rise in both TSTT and overall vehicular emissions. However, when service charge is greater than 3.5 euros,

the level of information quality provided to drivers has minor effect on both TSTT and overall vehicular emissions, as market penetration is low when the service charge is high.
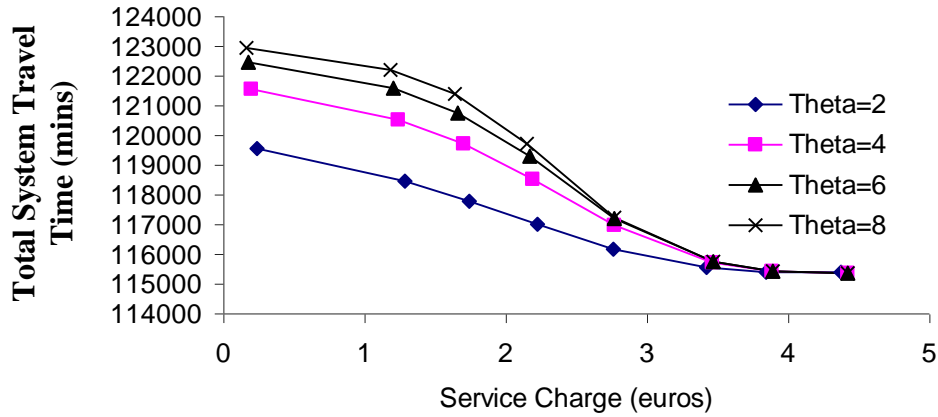

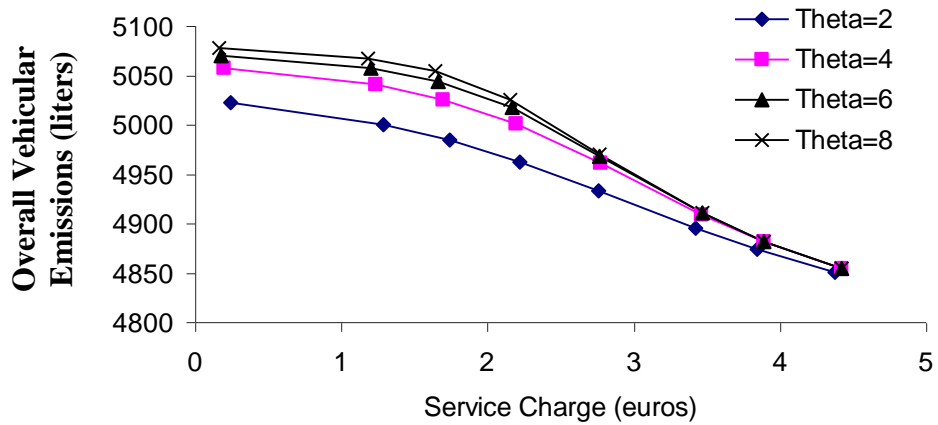Figure 8. The impact of service charges and information quality on TSTT.

Figure 9. The impact of service charges and information quality on overall vehicular emissions.

Figure 10 demonstrates the changes in TSTT against service charges when θ is at value of 2. It is shown that TSTT decreases when the service charge rises, until service charge is around 4 euros, TSTT increases slowly until it goes stable. Figure 11 shows how market penetration changes when the service charge increases. It is obvious that market penetration decreases when the service charge is increased. When the service charge is at around 9.2euros, market penetration is zero. At this level, no driver pays for information provision services due to its high charge. If we consider this situation as the original case where no one buys information provision services, once the service charge starts falling, more travellers are willing to buy the service and market penetration rises. Until service charge is around 3 euros, where market penetration is more than 20%, TSTT is over its original level as represented by the horizontal line in figure 10 where no drivers use the service. In another words, when the service charge is smaller than 3 euros, where market

penetration is higher than 20%, TSTT is worsened off. Nonetheless, when the service charge is ranged from 3 euros to 9.2 euros, TSTT is not greater than its previous level. This implies, under this range of the service charge, the paradoxical phenomenon in terms of TSTT does not occur. However, as shown in figure 12, overall vehicular emissions decline, when the service charge increases. This indicates the utilization of information provision does not play a good role in terms of diminishing the overall vehicular emissions. With the above implications, the government has to control the charges and information quality so as to avoid the increases in both TSTT and total vehicular emissions.
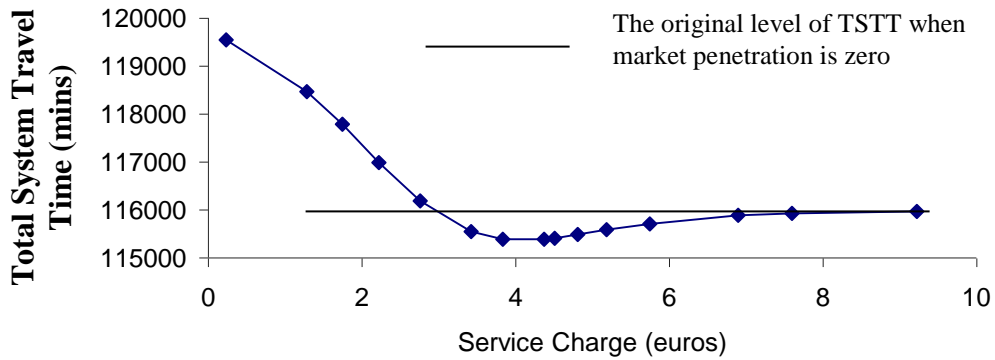
Figure 10. A plot of TSTT against service charges, when θ is 2 $\text{\euro}^{-1}$.
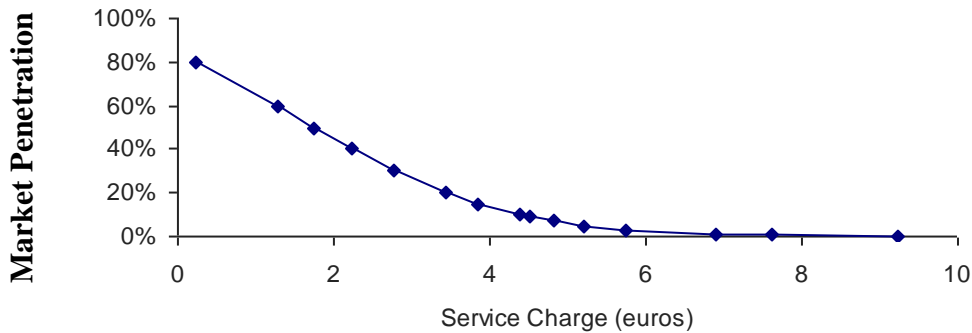
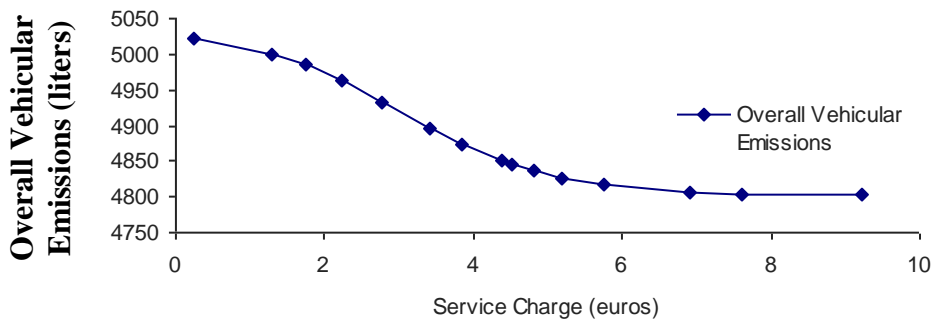Figure 11. A plot of market penetration against service charges, when θ is 2 $\text{\euro}^{-1}$.

Figure 12. A plot of overall vehicular emissions against service charges, when θ is 2 $\text{\euro}^{-1}$.

CONCLUSION

It is normally anticipated that the provision of traveller information services can reduce total system travel time (TSTT), and consequently lower overall vehicular emissions. In this paper, we model the route choice behaviour of the equipped and unequipped travellers as following a mixed-Stochastic User Equilibrium (SUE) so as to study the effects of traveller information provision services on TSTT and overall vehicular emissions. This mixed SUE problem is modelled through the Nonlinear Complementarity Problem (NCP) approach, taking into account the elastic manner of the demand for traveller information provision services. We reveal that there are paradoxical phenomena when implementing traveller information provision services. TSTT and overall vehicular emissions cannot be reduced simultaneously. More importantly, we found out that better information quality does not lead to a better system performance in terms of TSTT and overall vehicular emissions, on the contrary, both TSTT and overall vehicular emissions are worsened off. Results also demonstrate that there is a range of the service charge under which the paradoxical phenomenon regarding TSTT is not likely to occur. This implies that the government has to control the service charges and information quality so as to avoid the increases in both TSTT and total vehicular emissions.

This paper opens up a number of research directions. Firstly, it is assumed that all drivers are homogeneous in terms of value of time. It is meaningful to extend the current model to a multi-class, multi-criterion logit based traffic assignment model to study the impacts of traveller information provision services. The framework in Huang and Li (2007) can be used for this purpose. Secondly, in this study, the total travel demand is fixed. Kanninen (1996) has pointed out ITS may induce potential travel demand. Ignoring latent travel demand may overestimate the benefits of information provision services. It is thus interesting to study the effect of information provision in a network with an elastic travel demand. In addition, extending the existing model to incorporate travel time, cost and network uncertainties would be another challengeable research direction.

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