Penetration level and impact of ITS applications: the benefit of governmental support in ITS deployment

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Abstract

The impact of ITS applications, especially cooperative driver assistance systems, depends greatly on the percentage of users equipped (i.e. the penetration rate). The application may have little impact if only a few drivers are using the application. A higher penetration level is therefore necessary if maximum impact is desired. This paper argues that government should subsidise ITS developers so that the retail price of ITS applications can be lowered. By doing so more drivers will buy and use the application and a higher impact can be achieved. The improvement in impact, evaluated monetarily, can outweigh the subsidies, whereby a win-win situation arises.

Keywords: penetration level, impact analysis, ITS deployment, subsidy, economic analysis

Introduction

The impact of many ITS applications, especially cooperative driver assistance systems, depends on their penetration levels, i.e. how many road users are equipped with the application. The benefit generated by such an ITS application usually has a non-linear relationship with its penetration level. A simulation-based case study on the impact of CACC (cooperative adaptive cruise control) systems [1] shows that: (a) at a low penetration level of 20%, the average speed just before a lane drop is actually lower than the reference case (0% penetration); (b) at penetration levels higher than 40%, the average speed is higher than the reference case and the increase in speed is a convex function of the penetration level. Therefore it is crucial to consider potential penetration levels during the deployment phases of the ITS application.

Since a higher penetration level is desirable from a traffic point of view, the government (or the traffic management authority) may provide financial subsidies to the ITS developers in order for them to lower the retail price, so that more drivers will purchase and use the ITS application. Alternatively, economic incentives can be given to the driver instead, such as a partial reimbursement of the retail price. This is similar to incentive schemes that reward the driver for safe behaviour [2], where a win-win situation can also be achieved.

This paper starts by formulating the relationship between penetration level and traffic impact. This is followed by the analysis on the market response to retail prices and economic assessment on the system benefit. Then the paper establishes the conditions where a win-win situation exists. Finally the paper concludes with some general remarks.

Formulation: the relationship between penetration level and traffic impact

Denote by E the traffic benefit produced by an ITS application (e.g. reduction of travel time and emission) to an individual driver. Denote by Q the penetration level of the application. E is said to be a function of Q, i.e. $E = f(Q)$. Figure 1 gives an example of such a function (taken from the CACC example in [1]). Lower penetration levels may bring negative impact to the traffic system. In this case there is a *minimum penetration level* (Q^*) in order to achieve positive benefit. At the maximum penetration level of 100%, the achieved benefit is denoted by E_{100}. As long as the function f is monotone for $Q > Q^*$, E_{100} is the maximum achievable benefit.

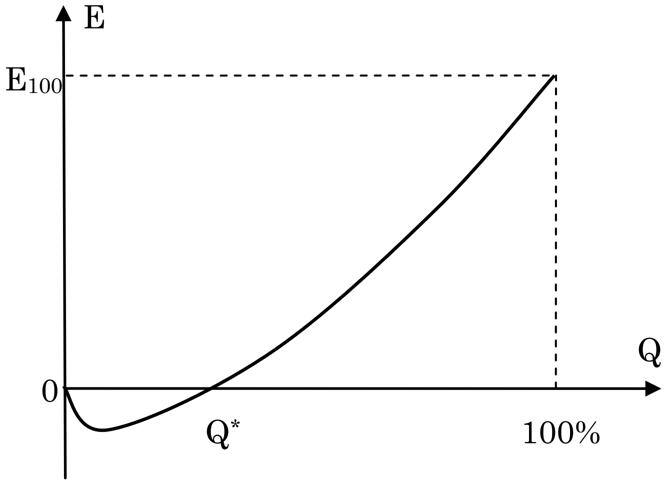

Figure 1 – Traffic benefit (E) of an ITS application vs. its penetration level (Q)

Economics: the relationship between retail price and number of purchase

Drivers' decision of whether to purchase an ITS application mainly depends on its retail price and the potential utility of using it. The price, P, is set by the manufacturer, subject to various objectives and potential constraints. The potential utility of using the application is related to E. If the potential utility is evaluated at $Q = 100\%$ regardless of the actual Q, then the number of purchase, hereby directly linked to Q, is a function of P, i.e. $Q = g(P)$. Figure 2 shows a typical P-Q curve: purchase decreases with higher prices. On the other hand, if utility is evaluated at the actual Q, then an iterative process evolves: $E^{(n)} = f(Q^{(n)})$; $Q^{(n+1)} = g(P, E^{(n)})$, with its equilibrium defined by $Q^{\vartriangle} = g(P, f(Q^{\vartriangle}))$.

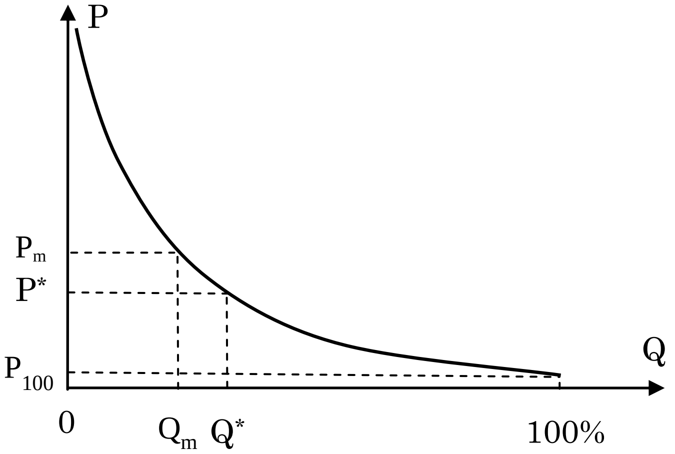

Figure 2 – Penetration level (Q **) vs. retail price (** P **)**

ITS deployment: economic analysis

The revenue generated through the sales of ITS application is $Pg(P)\kappa$, where κ is the population of drivers. Under the objective of revenue maximisation, the optimal price can be derived by solving

$$\begin{aligned} &\min \quad Pg(P)\kappa \\ &\text{s.t.} \quad P \geq 0 \end{aligned}$$

The solution would be equivalent to the solution of $g(P) + P\dot{g}(P) = 0$, represented by P_m in Figure 2.

The existence of Q^* implies that, if the price is set too high, the penetration level will be low and the impact on traffic could be negative. The maximum price in order to achieve a positive impact is given as $P^* = g^{-1}(Q^*)$. For the case illustrated by Figure 2, P_m would be too high and result in negative impact on the traffic system.

A win-win situation: implications for governments

While the manufacturer tries to maximise revenue, $Pg(P)\kappa$, by setting the price at P_m, the traffic operator (or the government) wants to maximise traffic benefit, $f(g(P))\kappa$. When the price is lowered from P_m to $P_m - \Delta P$, the traffic benefit can increase from $f(g(P_m))\kappa$ to $f(g(P_m - \Delta P))\kappa$ but the revenue would drop from $P_m g(P_m)\kappa$ to $(P_m - \Delta P)g(P_m - \Delta P)\kappa$. The increase in benefit is given by

$$\Delta B = f(g(P_m - \Delta P))\kappa - f(g(P_m))\kappa.$$

The decrease in revenue is

$$\Delta R = P_m g(P_m)\kappa - (P_m - \Delta P)g(P_m - \Delta P)\kappa.$$

The following theorem (proof not included here) states that under certain conditions the increase in benefit outweighs the decrease in revenue.

Theorem: If $\dot{g}(P_m) < 0$ and $\dot{f}(g(P_m)) > 0$, then there always exists small enough ΔP's ($\Delta P > 0$) such that $\Delta B - \Delta R > 0$.

The first requirement, $\dot{g}(P_m) < 0$, states that penetration level decreases strictly monotone with retail price at the retail price of P_m. The second requirement, $\dot{f}(g(P_m)) > 0$, states that traffic benefit increases strictly monotone with penetration level at the penetration level of $g(P_m)$. Both conditions are reasonable and easily satisfied (as in Figure 2).

For big ΔP's, consider the ultimate case of lowering the price to P_{100}, revenue would decrease to $P_{100}\kappa$ while benefit increases to $E_{100}\kappa$. The corresponding requirements would be $P_{100} + E_{100} > P_m g(P_m) + f(g(P_m))$, not unlikely to be true judging from Figures 1 and 2.

This implies that a win-win situation can be achieved: the government subsidies the manufacturer for it to lower the price of the ITS application; the reward is in the form of increased traffic benefit (due to higher penetration levels). The amount of subsidy, S, is determined such that

$$\Delta R < S < \Delta B.$$

Compared to the case without subsidies, the gain by the manufacturer is $S - \Delta R$, and the gain by the government is $\Delta B - S$. Therefore a win-win situation arises.

Conclusions

This paper shows that if the traffic impact (or benefit) of an ITS application on an individual driver level has a strictly monotone relationship with the penetration rate, then government subsidies should be provided in order to lower retail price, increase penetration level and increase traffic benefit. Such type of ITS applications are most likely to be cooperative systems, where a high equipment rate is essential.

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