The Value of Wireless Internet Connection on Trains: Implications for Mode-Choice Models

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Abstract

Deployment of advanced technologies has enabled wireless internet access for commuters on various transportation modes. Such networked environments have enabled riders to engage in productive activities in transit. The ability to perform activities while traveling, especially paid work, may significantly affect the value of travel time (VOTT), with potential impacts on mode choice and commute patterns. In this study, we develop a model of the VOTT grounded in utility theory and activity choice analysis.

We use an efficiency factor which represents the ratio of the efficiency of working on transit to the efficiency of working at the workplace. This efficiency factor is used extensively in our models. Internet connection is expected to increase factor efficiency by providing access to real time information and enhanced communication. The model developed is used to explore the effects on VOTT of working in an enhanced networked environment while commuting. The results show that utility increases and VOTT decreases with increase in the efficiency of work while in transit, as is intuitive.

An indirect utility function has been derived to represent travel on modes with internet access. The derivation permits an elegant introduction of internet access as an attribute in utility based choice models.

Finally, the proposition that internet access may influence mode choice is corroborated by a survey conducted in June 2005 on Capitol Corridor trains.

Keywords: value of travel time, activity choice model, wireless internet connection, indirect utility function, transit

1. Introduction

Advances in the technology of wireless communications, such as wireless fidelity (WiFi) connections on transportation modes have increased the opportunity for riders to engage in productive activities while in transit. Wireless internet connections have allowed riders to conduct business or connect to websites for personal, leisure, and entertainment purposes. The benefits of wireless internet access can also be extended to the operators. The infrastructure and internet access could be used to improve ticket collection, bundle value-added services, and implement services for improving operational efficiencies. The service could also be used for improving public safety and security.

Due to its immense use to the riders, wireless internet service is poised to be introduced to many rail systems in the near future. According to some industry estimates, most rail system riders in North America and Europe are expected to have onboard wireless internet access in the next five to ten years. Some services are also offered on a commercial basis as between Paris and Brussels on the Thalys high speed trains (Kanafani, 2005). While mostly applicable to trains, some buses are equipped with this service too, as are the Western Contra Costa Transit Authority buses.

The opportunity of working while commuting could have far-reaching consequences on the choice of mode. The ability to use travel time to perform a productive activity such as paid work will affect the value of time of riders. If the benefits are found to be substantial, this could shift the focus away from decreasing the door-to-door journey time to improving the ride, such that the possibility of work or leisure is enhanced. This may include better seats, provision of table supplies and electrical outlets for laptop computers.

For transport professionals, its most important effect could be a possible change in the relative advantage of public transportation. An important determinant of mode choice, the value of travel time (VOTT) has the widely accepted definition as the amount of money a rider is willing to pay for a saving of time in travel (Vilain and Bhandari, 2002, Jara-Diaz and Guevara, 2003) while remaining equally well off. In contrast to this definition based on time saved, the value of time for activities other than travel is usually measured by the time spent on those activities. That is, notwithstanding the field of work in the positive utility of travel, (Richardson, 2003, Mokhtarian, 2005), time in transit has a negative utility for many, whereas time spent on most other activities has a positive utility. The ability to engage in a productive activity while in transit will therefore lower VOTT.

In this paper we study the effect of adding wireless internet access to transit modes on VOTT. The core issue being goods-time substitution, we model the effect of work in transit using activity choice models along the lines of Becker and DeSerpa among many others (Becker, 1965, DeSerpa, 1971). While this effect may be studied by including internet access as a dummy variable in a mode choice model, the use of activity choice models permit greater understanding of the relation of in-transit work time with other activity times. The study provides a basis for exploring the effect of internet access, on a broader set of activities and choices including leisure and e-shopping, in addition to the effect on work that is the subject of this study. The indirect utility function for mode choice is derived from the activity choice model framework following an approach proposed by Train and McFadden, 1978.

The paper is organized as follows. The relevant background literature is discussed in Section 2. In Section 3, several activity choice models are formulated. These models and the VOTT derived from them, represent the effect of work in transit parametrically. Subsequently, we illustrate some numerical examples. In Section 4, the results of a survey conducted on CCJPA trains are summarized to assess users' willingness to pay. In Section 5, the extension of the activity choice model and the implication of internet access on mode choice are explored. Section 6 concludes the paper with a general discussion and identification of further work.

2. Background

Much of the literature on activity choice analysis builds on Becker's seminal work (Becker, 1965) and its further development by DeSerpa, 1971. The basic model is one of utility maximization subject to constraints on money and time budgets. In the original form Becker considered utility as a function of final activity bundles that are combinations of market goods and time spent in their consumption. DeSerpa introduced an additional technological constraint intended to reflect the relation between the minimum time needed and the amount of an activity that is consumed. Activities for which this constraint is not binding are leisure activities (DeSerpa, 1971). DeSerpa's approach is formulated as follows:

$$Max U(X,T) \tag{1}$$

$$Y - PX >= 0 \rightarrow \lambda \tag{2}$$

$$T^o - \sum_{i=1}^{n} T_i = 0 \rightarrow \psi \tag{3}$$

$$T_i \geq a_i X_i \rightarrow \kappa_i \tag{4}$$

In this form U is the utility function, X, the vector of goods consumed, and T the vector of time spent in consumption. P is the price vector and Y is the total income. T^o is the total time available and T_i is the time spent consuming the i-th good of the n good (activity) bundles. The technologically or institutionally determined minimum amount of time required to consume one unit of X_i is represented as a_i. λ, ψ, and κ_i are Lagrange multipliers so that λ is the marginal utility of income, ψ the marginal utility of time, κ_i the marginal utility of saving time in the i-th activity, and the ratio κ_i / λ is the value of saving time in i-th activity.

Eq. (1) represents the objective function for maximization of utility as a function of goods and time. Eq. (2) represents the income constraint and Eq. (3), the time budget constraint. The technological constraint is represented by Eq. (4).

To use this model for the evaluation of VOTT, Jara-Diaz and Guevara, 2003, proposed a Cobb-Douglas utility function and denoted travel time and travel cost as distinct variables. The model follows:

$$Max U = \Omega T_W^{\theta_w} T_t^{\theta_t} \prod_{i \in I} T_i^{\theta_i} \prod_{k \in K} X_k^{\eta_k} \tag{5}$$

$$wT_W - \sum_{k\in K} P_k X_k - c_t \ge 0 \rightarrow \lambda \tag{6}$$

$$\tau - T_W - T_t - \sum_{i\in I} T_i = 0 \rightarrow \psi \tag{7}$$

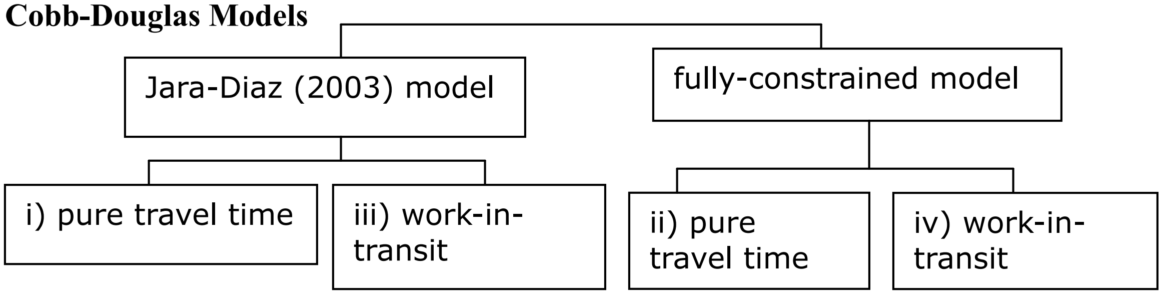
$$T_t - T_t^{\min} \ge 0 \rightarrow \kappa_t \tag{8}$$

Ω is a utility constant, T_W, T_t, T_i are the time bundles spent on work, travel, and other activities respectively. X_k is the k-th commodity, P_k, the price of the k-th commodity, w, the wage rate, and c_t the travel cost. τ is the time budget and T_t^{min} is the minimum time required for travel. I is the set of all activities except work and travel and K is the set of all goods. $\theta_w, \theta_t, \theta_i$ and η_k are parameters corresponding to work, travel, other activities and goods respectively. The Lagrange multipliers are the same as DeSerpa's model, with κ_t representing marginal utility of saving time in travel. As in the previous model, Eq. (1) represents the objective function, Eq. (2) represents the income constraint, Eq. (3) the time constraint, and Eq. (4) the technological constraint. It is to be noted that in this form, T_t represents pure travel time with no activity being performed during travel. Also, travel time is the only time bundle for which a technological constraint has been considered. In travel, the technological constraint represents existing technologies and boundaries, as a result of which a minimum travel time between two places is stipulated. When travel has a positive utility, i.e. for leisure trips, the constraint is not binding.

3. Modeling the Value of Working in Transit

To model the effect of working while in transit we modify the Jara-Diaz and Guevara, 2003 model by introducing the activity 'work in transit' (*wt*) and adding the time spent working in transit T_{wt} into the relevant elements of the utility maximization problem. In the following subsections, we develop some alternative models of both pure travel time and hybrid work-travel time and explore the form of the VOTT calculated from these models. The complete set of models is represented diagrammatically in Figure 1.

Cobb-Douglas Models



Linear Models
v) Pure travel time model
vi) Work-in-transit model

FIGURE 1 Representation of the models

3.1 Pure Travel Time Models

The first pure travel time model is a re-statement of the Jara-Diaz and Guevara, 2003 model. It is referred to subsequently as model (i).

$$MaxU = T_w^{\alpha} T_t^{\beta} T_l^{\gamma} X_k^{\eta} \tag{9}$$

$$rT_w - pX - c_t \geq 0 \rightarrow \lambda \tag{10}$$

$$\tau - T_w - T_t - T_l = 0 \rightarrow \psi \tag{11}$$

$$T_t - T_t^{\min} \geq 0 \rightarrow \kappa_t \tag{12}$$

For this and all subsequent models in this paper, T_w, T_t, T_l are the time bundles spent on work, travel, and other activities respectively. X is the commodity bundle, p, the price of the commodity bundle, r the wage rate, and c_t the travel cost. τ is the time budget and $T_t^{\min}$ is the minimum time required for travel. α, β, γ and η are the utility elasticities of work, travel, other activities and goods respectively, and the Lagrange multipliers are the same as in the previous model. If $m = T_t^{\min} / T_l$, the VOTT obtained from this model for compulsory, non-leisure travel such as work trips for binding technological constraint is:

$$\frac{\kappa_t}{\lambda} = \frac{pX[(\gamma / T_l) - (\beta / T_t^{\min})]}{\eta} = \frac{pX}{\eta T_l}[\gamma - \beta / m] = \frac{pX}{\eta T_t^{\min}}[m\gamma - \beta] \tag{13}$$

It is evident that VOTT is directly proportional to pX, the total spending, and inversely proportional to η and T_t^{min}, the minimum stipulated travel time and the contribution of the goods bundle to the utility. It is also inversely proportional to η and T_l, i.e. the product of leisure time and the contribution of the goods bundle to utility. This is consistent with other studies of the value of travel time such as Richardson, 2003, which finds that high income riders with a greater value of consumption bundle value their time more and are willing to pay more to decrease travel time, as compared to the 'income poor'. Also, for the 'time rich', as total leisure time increases, it becomes increasingly less important to pay a high amount to reduce travel time. With an increase in total travel time, a rider would want to pay increasingly less for a marginal decrease in travel time. The fact that it is inversely proportional to the coefficient of the market good in the utility function is intuitive. When the market good contributes a large share of a rider's utility, time contributes a relatively smaller share and as such, VOTT is not very high.

The above result of VOTT can be re-stated in this alternative form:

$$\frac{\kappa_t}{\lambda} = \frac{rT_w(\beta T_l - \gamma T_t^{\min})}{T_t^{\min}(T_l - \gamma T_w)} \tag{14}$$

This illustrates the manner in which VOTT varies directly with income, rT_w. Another simplification can be obtained by letting the ratios T_w/T_l =n and T_t^{min}/T_l= m, which yields the following expression for VOTT.

$$\frac{\kappa_t}{\lambda} = \frac{rn(\beta - \gamma m)}{m(1 - \gamma n)} \tag{15}$$

Contrary to expectation, VOTT decreases with the increase in the ratios of travel time to leisure time. A likely explanation for this result is that, the population with a high ratio of commute time to leisure time represents the lower income group with the longer commute time. However, the model also shows that, the higher the ratios of work time to leisure time, the greater the VOTT, since such characteristics are possible indicators of the higher income working population.

For the case of leisure trips, since the technological constraint is not binding, VOTT is zero for $T_t > T_t^{\min}$ at optimality because κ_t is zero.

Model (ii) is obtained from model (i) by adding three technological constraints. The first, Eq. (16) places a lower bound ($T_w^{\min}$) on work time, Eq. (17) relates leisure time to consumption of a goods bundle and Eq. (18) places a lower bound (X^{min}) on bundles of goods consumption. Model (ii) with the additional technological constraints is as follows.

$$MaxU = T_w^{\alpha} T_t^{\beta} T_l^{\gamma} X_k^{\eta}$$
$$rT_w - pX - c_t \geq 0 \rightarrow \lambda$$
$$\tau - T_w - T_t - T_l = 0 \rightarrow \psi$$
$$T_t - T_t^{\min} \geq 0 \rightarrow \kappa_t$$
$$T_w - T_w^{\min} \geq 0 \rightarrow \kappa_w \tag{16}$$
$$T_l - bX \geq 0 \rightarrow \kappa_l \tag{17}$$
$$X \geq X^{\min} \rightarrow \kappa_x \tag{18}$$

Interpretation of the technological constraint relating to time at work is that, at the margin, a minimum amount of institutionally determined time needs to be spent for work. For those with a positive utility of work, the constraint is not binding. Similarly the constraint relating time and consumption states that a minimum amount of time must be spent for consumption of a certain goods bundle, and this time can be exceeded for leisure activities. The technological constraint relating to consumption states that consumption may be greater than or equal to the minimum necessary consumption. For instance, a person may indulge in buying four shirts where one was necessary. It is assumed that at optimality, $T_w = T_w^{\min}$, $T_l > bX$ and $X > X^{min}$, that is, the technological constraint relating to work time is binding at optimality whereas the other two constraints are not binding. Also, the minimum constraint on consumption is not binding. VOTT obtained from model (ii) is the same as that obtained from model (i), Eq. (13). However, due to presence of additional constraints, the direct proportionality to income, i.e. Eq. (14) cannot be verified.

The next discussion involves the effect of combining paid work during travel in the Cobb-Douglas model.

3.2 Travel Time Models with Work in Transit

Model (i) and model (ii), developed in the previous section, are modified in this section to include T_{wt}, the time spent working in transit. Modifying model (i) results in the following restatement of the utility maximization problem referred to subsequently as model (iii):

$$MaxU = (T_w - fT_{wt})^{\alpha} (T_t - T_{wt})^{\beta} T_{wt}^{\delta} T_l^{\gamma} X_k^{\eta} \tag{19}$$
$$rT_w - pX - c_t \geq 0 \rightarrow \lambda$$

$$\tau - (T_w - fT_{wt}) - T_t - T_l = 0 \rightarrow \psi \tag{20}$$
$$T_t - T_t^{\min} \geq 0 \rightarrow \kappa_t$$

in which f is an efficiency factor. Hensher, 1977, introduced the concept of 'productivity of work done while traveling relative to that at the workplace'. We postulate that working while traveling has an efficiency factor f $(0 \leq f)$ such that the work done in time T_{wt} while traveling, is equivalent to work done in time fT_{wt} at the fixed workplace. The value of f depends on the nature of work, i.e. the extent to which the work can be performed in transit and away from the fixed office location. Allowing f>1 captures the possibility that transit provides a preferred venue for working since there is no interruption from colleagues. Model (iii) is valid under the condition that $f>0$.

From the first order conditions, the following expression is obtained for the VOTT:

$$\frac{\kappa_t}{\lambda} = \frac{\gamma / T_l - \beta / (T_t^{\min} - T_{wt})}{\eta / pX} \tag{21}$$

The expression yields that VOTT is independent of the coefficient of work time, α , the coefficient of travel time, β , and the coefficient of time of work in transit, δ . Hence VOTT will be the same, whether or not time of work in transit is weighted the same as work time, travel time or differently in the utility function. Model (i) Eq. (13) may be modified to obtain the following form of the VOTT:

$$\frac{\kappa_t}{\lambda} = \frac{\gamma / T_l - \beta / T_t^{\min}}{\eta / pX} \tag{22}$$

On comparing Eq. (21) and Eq. (22), it is evident that for a positive value of T_{wt}, the model shows a reduction in VOTT as compared to the pure travel time model, as a result of the ability to work while in transit. The result obtained from model (iii) shows that the VOTT is independent of f.

Model (iv)

The technological constraints represented by Eq. (16), Eq. (17), and Eq. (18) in model (ii) also apply to model (iv). Model (iv) with the additional constraints is as follows.

$$MaxU = (T_w - fT_{wt})^{\alpha} (T_t - T_{wt})^{\beta} T_{wt}^{\delta} T_l^{\gamma} X_k^{\eta}$$
$$rT_w - pX - c_t \geq 0 \rightarrow \lambda$$
$$\tau - (T_w - fT_{wt}) - T_t - T_l = 0 \rightarrow \psi$$
$$T_t - T_t^{\min} \geq 0 \rightarrow \kappa_t$$
$$T_w - T_w^{\min} \geq 0 \rightarrow \kappa_w$$
$$T_l - bX \geq 0 \rightarrow \kappa_l$$
$$X \geq X^{\min} \rightarrow \kappa_x$$

This model would include a further constraint, Eq. (23), which represents the non-work component of travel time, such as waiting time, out of vehicle travel time etc.

$$T_t - T_{wt} \geq a \rightarrow \kappa_{wt} \tag{23}$$

In addition, there is a non-negativity constraint on time for work in transit.

$$T_{wt} \geq 0 \rightarrow \kappa_1 \tag{24}$$

Some assumptions are made on the complementary slackness conditions at optimality. At optimality, it is assumed that a rider spends the minimum required time on travel, $T_t = T_t^{\min}, \kappa_t > 0,$ and on work at the workplace, $T_w = T_w^{\min}, \kappa_w > 0$. During the commute, the rider effectively utilizes all possible time on work, i.e. all time except waiting time, out of vehicle travel time etc, $T_t - T_{wt} = a, \kappa_{wt} > 0$. The rider spends more than the absolute minimum time on consumption, $T_l > bX, \kappa_l = 0,$ and the number of units of consumption is also not bound to be the minimum $X > X^{\min}, \kappa_x = 0$. Further, time of work in transit is positive, $T_{wt} > 0, \kappa_1 = 0$.

The VOTT is obtained as follows:

$$\frac{\kappa_t}{\lambda} = \frac{pX}{\eta}\left(\frac{\gamma(1-f)}{T_l} - \frac{\delta}{T_{wt}} + \frac{f\alpha}{T_w - fT_{wt}}\right) \tag{25}$$

In the form of VOTT obtained in Eq. (25), VOTT decreases with an increase in the value of *f,* if γ is large as compared to α. This is equivalent to the decrease in VOTT due to an increase in the efficiency of work during travel for those riders, for whom time spent in other (leisure) activities; contribute a greater proportion of positive utility than that spent at work. The VOTT calculated in this case is less than that calculated for the model without T_{wt} if $\frac{f\gamma}{T_l} + \frac{\delta}{T_{wt}} - \frac{f\alpha}{T_w - fT_{wt}} < \frac{\beta}{T_t^{\min}}$

It is clear that, as compared to model (iii), model (iv) better represents the manner in which VOTT may be affected by the introduction of technologies that enable work in transit.

3.3 Numerical Illustration with a Linear Utility Function

To develop a numerical example we adopt the linear utility function along with the constraint for model (ii) and model (iv) to find the change in VOTT.

3.3.1 Pure Travel Time Model

A greater number of constraints are required for the linear form than for the Cobb-Douglas form to ensure that none of the goods and time bundles is zero at optimality. The linear form of the activity choice model representing pure travel time referred to as model (v) follows:

$$MaxU = \nu + \alpha T_w + \beta T_t + \gamma T_l + \eta X \tag{26}$$

$$rT_w - pX - c_t \geq 0 \rightarrow \lambda$$

$$\tau - T_w - T_t - T_l = 0 \rightarrow \psi$$

$$T_t - T_t^{\min} \geq 0 \rightarrow \kappa_t$$

$$T_w - T_w^{\min} \geq 0 \rightarrow \kappa_w$$

$$T_l - bX \geq 0 \rightarrow \kappa_l$$

$$X \geq X^{\min} \rightarrow \kappa_x$$

On making the same assumptions on the complementary slackness conditions at optimality as in model (ii) VOTT is obtained as:

$$\frac{\kappa_t}{\lambda} = \frac{p(\gamma - \beta)}{\eta} \quad (27)$$

This is directly proportional to price of the market good and inversely to its coefficient in the utility function as in the case of the Cobb-Douglas utility function. VOTT also increases with increase in the coefficient of time for other activities in the utility function and decreases with increase in the coefficient of travel in the utility function, as is intuitive.

3.3.2 Travel Time Model with Work in Transit

The linear model representing effect of work in transit is formulated as:

$$MaxU = \nu + \alpha(T_w - fT_{wt}) + \delta T_{wt} + \beta(T_t - T_{wt}) + \gamma T_l + \eta X \quad (28)$$

$$rT_w - pX - c_t \geq 0 \rightarrow \lambda$$

$$\tau - (T_w - fT_{wt}) - T_t - T_l = 0 \rightarrow \psi$$

$$T_t - T_t^{\min} \geq 0 \rightarrow \kappa_t$$

$$T_t - T_{wt} \geq a \rightarrow \kappa_{wt}$$

$$T_w - T_w^{\min} \geq 0 \rightarrow \kappa_w$$

$$T_l - bX \geq 0 \rightarrow \kappa_l$$

$$X \geq X^{\min} \rightarrow \kappa_x$$

$$T_{wt} \geq 0 \rightarrow \kappa_1$$

As in case of the Cobb-Douglas model, this model is valid only for values of f>0. The assumptions on the complementary slackness conditions at optimality are same as that in model (iv). The VOTT obtained from this equation is:

$$\frac{\kappa_t}{\lambda} = \frac{p[\gamma + \delta - 2\beta - f(\gamma - \alpha)]}{\eta} \quad (29)$$

In this form, the VOTT decreases with an increase in the value of f. It also decreases with an increase in the value of β, the coefficient of travel time. It increases with increase in p, the price of the goods bundle, α, the coefficient of work time and δ, the coefficient of time of work in transit. It also increases with an increase in the value of γ, the coefficient of time for other activities except for the case f=1 when the VOTT becomes independent of γ.

Since all the coefficients of the different time and goods bundles are included in the VOTT it is important that T_{wt} have a coefficient different from that of travel time or work time. The VOTT obtained is less than that obtained from model (v) if:

$\delta < \beta + f(\gamma - \alpha)$

For both expressions of VOTT calculated in the linear utility model, it is observed that VOTT is directly proportional to the price of the market good and inversely to the coefficient of the market good in the utility function. Recall that this is similar to the Cobb-Douglas form of model (iv).

In the next section *f* is varied parametrically for the model with linear utility function to evaluate the effect of internet access on the value of time.

3.3.3 Numerical Example

A numerical example, assuming hypothetical coefficients, hypothetical values, and a linear utility function, is used to illustrate the effect of work in transit. With no work in transit, the utility maximization problem is as follows.

Numerical Example (1)

$$MaxU = 5T_w + 3T_t + 3T_l + 3X \tag{30}$$

$$20T_w - 5X - 6 \geq 0 \tag{31}$$

$$24 - T_w - T_t - T_l = 0 \tag{32}$$

$$T_t - 1 \geq 0 \tag{33}$$

$$X - 3T_l \leq 0 \tag{34}$$

Eq. (30) represents the objective function with utility as a linear function of time allocated to work, travel, leisure and the goods bundle. Eq. (31) represents the income constraint in which the person's wage rate is 20 money-units/unit time. The price of goods is 5 money-units, and that of transportation if 6 money-units. Eq. (32) represents the time constraint with a cap at 24 time-units. Eq. (33) represents a technological constraint in which the person's travel time is exogenously constrained to be a minimum of 1 time unit. It may be longer if travel is perceived as a leisure activity. Eq. (34) represents the other technological constraint in which consumption of the goods bundle is endogenously constrained to take a maximum of three times the leisure time, or alternatively, leisure time is at least the time required to consume one-third of the goods bundle.

The solution to this is as follows:

$$U^* = 208.8$$

$$T_t = 1, T_l = 12.97, T_w = 10.03, X = 38.91$$

$$VOTT = K_t / \lambda = -6 / -0.2 = 30\, money - units / unit - time$$

Now assuming presence of internet access, permitting work during travel, with *f* = 0.8, the utility maximization problem is as follows.

Numerical Example (2)

$$MaxU = 5(T_w - 0.8T_{wt} + T_{wt}) + 3(T_t - T_{wt}) + 3T_l + 3X \tag{35}$$

$$20T_w - 5X - 6 \geq 0 \tag{36}$$

$$24 - (T_w - 0.8T_{wt}) - T_t - T_l = 0 \tag{37}$$

$$T_t - 1 \geq 0 \tag{38}$$

$$X - 3T_l \leq 0 \tag{39}$$

In Eq. (35), the utility function is a linear function of the work time, work in transit time, leisure time, travel time, and the goods bundle. The ratio of efficiency of work during transit compared to work at the workplace is 0.8 (Eq.(36).

The solution to this example is:

$$U^* = 214$$

$$T_t = 1, T_l = 13.43, T_w = 10.37, X = 40.29, T_{wt} = 1$$

$$VOTT = K_t / \lambda = -0.8 / -0.2 = 4 units / unit - time$$

The results obtain that with the presence of internet allowing the overlapping of work with travel, the value of utility increased from 208.8 units to 214 units. The VOTT dropped from 30 money-units per unit time to 4 money-units per unit time. For riders who can work at an efficiency of 0.8 during commute as that compared to the workplace, the value of internet access will be equal to the difference between the two VOTT, i.e. 26 units. If internet service is priced at 26 units, the pricing would extract all the rent from the provision of internet connection. Alternatively, if it is priced at less than 26 units, then there would be a modal shift in favor of the mode with the internet connection.

While the focus of this study is on work in a networked environment, many activities are already carried out in transit in absence of the wireless internet connection. These activities, such as reading, writing, knitting etc. are already carried out constitute work in transit. As such, for all practical purposes, there is no pure work situation, and the difference in VOTT will be for two situations of work in transit, one in a networked environment and the other without. The difference, as such, will be less steep.

For various values of f in numerical example (2), the values of VOTT and utility are shown in Table 1. It is observed that with increase in the value of f, the VOTT decreases and the utility increases. The decrease in VOTT is linear as is also evident from the parametric form of VOTT. At f=1, i.e. at efficiency equal to that of the workplace, the model accurately yields VOTT to be zero.

TABLE 1 Values of VOTT and objective function for different values of f

f	VOTT ($/hr)	VOTT (% of hourly wage rate)	Utility
0 (no work in transit)	-6/-0.2 = 30	150	208.8
0.5	-2/-0.2 = 10	50	212.8
0.8	-0.8/-0.2 = 4	20	214
1	0/-0.2 =0	0	214.8

4. Findings from Historical Data and a Survey Conducted aboard San Jose-Sacramento Train

Historical ridership data obtained from Capitol Corridor Joint Projects Authority (CCJPA) for the period September 2004 to March 2005 reveals some trends in ridership. Weekday ridership ranged from 3000 to 5000 trips per day, and weekend ridership ranged from 1500 to 2500 trips per day. Regarding travel frequency, it was observed that just over 50% of riders who travel over 20 times a year are on their daily commute to and from work. It is likely that is wireless internet connection is provided; this 50% will be the primary market of the service (Kanafani, 2005).

A survey was conducted on the CCJPA San Jose to Sacramento train to assess the possible market for wireless internet connection on trains for over one week in July 2005. The average travel time is 99 minutes (minimum 15minutes, maximum 256, standard deviation 37 minutes), the average number of trips per year is 150 (minimum 1, maximum 720, s.d 178). Of the 1092 responses received, 50 % of the population travels more than 94 times a year and 50 % of the population travels more than 50 minutes per trip. 65% of the riders expressed willingness to use the service if free and 26% would pay for it. 27% expressed interest in increasing the number of trips if the service is introduced. 67% were business riders and 33% were non-business riders. Of the business riders 44% expressed willingness to pay for the service and 56% would use the service if it were free. Of the non-business riders, only 20% expressed interest to pay for the service (Kanafani, 2005).

The survey revealed further information on the willingness to pay based on the duration and frequency of the ride. The information based on the duration of the ride is shown in Table 2 and that on the frequency of the ride is shown in Table 2.

TABLE 2 Potential users' willingness to pay based on duration of ride (business users only)

	<80 minutes	**80-185 minutes**	**>185 minutes**
Percent business riders willing to pay for service	26	51	54
Percent business riders willing to use service only if free	74	49	46
Total	100	100	100

It is evident that the commuters with longer trip lengths are willing to pay to use internet on trains so that they could convert their travel time to useful work time. Commuters with shorter trip lengths whereas, do not feel compelled to pay for using internet on trains.

The survey also revealed information on the preferred strategy of payment, hourly, daily, monthly or per trip, as well as the amount that the users would pay under each category of payment. This information has been segregated as the mean flat rate for the occasional, average and frequent commuters. For the hourly rate, the occasional riders are those who travel for less than 60 minutes one way and the frequent riders are those traveling for more than 312 minutes one way. Those traveling between 60 and 312 minutes one way constitute the 'average' rider. For charge by day, those traveling between 20 and 80 times a year constitute the average rider, those traveling less than 20 times, the occasional rider and more than 80 times, the frequent rider. For charge by trip, those who travel less than 99 times a year constitute the occasional user and those traveling more than that are the frequent user. The monthly charge has been determined on the basis of data for time connected. The occasional users are those who propose to connect for less than or equal to 80 minutes and the frequent user are those who propose to connect for more than 80 minutes. The average user has been calculated by finding the mean of all passengers who preferred to pay using the monthly mode of payment.

TABLE 3 Potential users' willingness to pay based on frequency of travel

	Occasional rider/user	Frequent rider/user	'Average' rider/user
Maximum price per hour ($)	3.42	1.92	2.84
Maximum price per day ($)	7.2	5.02	6.41
Maximum price per trip ($)	5.42	3.18	4.44
Maximum price per month ($)	18.33	26.34	20.32

Except for the case of monthly payment, in all cases the occasional rider agreed to a higher rate than the frequent rider. Since, for the monthly payment, the willingness to pay is calculated on the basis of number of hours connected, the frequent user averages a higher sum than the occasional user.

Different types of commuters would have different preferred modes of payment. The frequent rider would find it economical to buy a monthly pass, whereas the infrequent one-way commuter traveling for one hour or less would prefer the hourly rate. The infrequent commuter with duration of trip longer than two hours will prefer the per trip charge. Of the previous category, those who will make more than one trip on the same day, for instance a return trip, will prefer the daily pass. Table 3 shows the willingness to pay of potential users. Except in the case of charge by month, in all cases the frequent rider agreed to a lower flat rate than the occasional rider, so as to reduce overall costs.

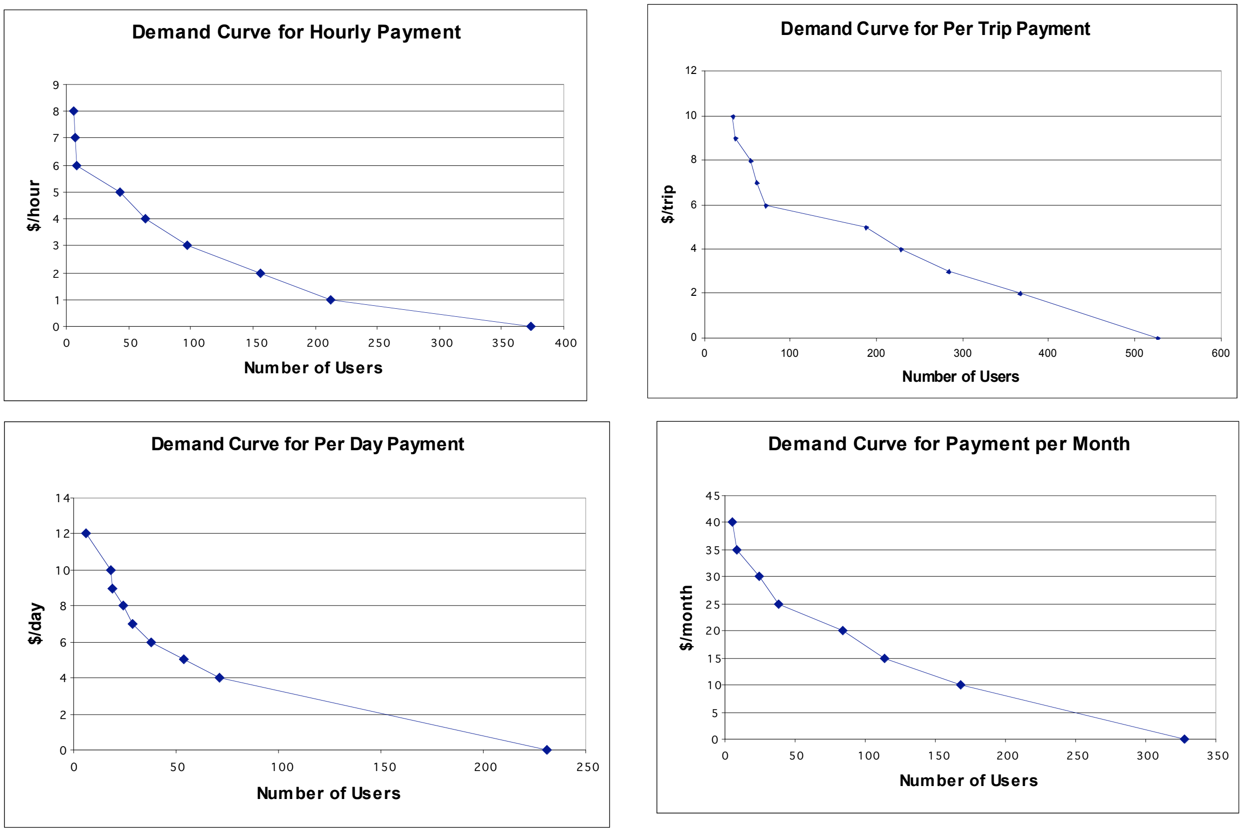


FIGURE 2 Demand curves for the different payment strategies

Figure 2 shows the plots of the demand curves for the different payment strategies. All plots exhibit a gradual slope in the lower price ranges but a steeper one in the higher price ranges. Since marginal cost is zero in these cases, we can assume that the price at which revenue is maximized will be the information obtained from the demand curve.

77% of the riders possess high speed internet connections at home. As such, to accelerate user's adoption of the internet connectivity service on train, the service needs to be offered based on an infrastructure with higher bandwidth and a secure operational environment. However, existing wireless technologies can only offer low-bandwidth infrastructure as a viable communication option. .

5. The Indirect Utility Function and the Mode Choice Model

Train and McFadden, 1978, illustrate two alternative methods of estimating the indirect utility function for a mode choice model from a Becker type activity choice model. In the first method, the optimal value of T_w is obtained and substituted in the utility function. In the second method the expenditure function is first estimated. We used the second method to derive the indirect utility function for the Cobb-Douglas models, (ii) and (iv). However, the indirect utility function for the linear utility function could not be derived, since the process of differentiation rids the expression of the variables.

For Eq. (9), the Cobb-Douglas utility function representing pure travel time, the form is first modified to include the inequality constraints in model (ii) that are assumed to be binding at optimality. This leads to the following form of the utility function:

$$U = T_W^{\min\,\alpha} T_t^{\min\,\beta} T_l^{\gamma} X^{\eta}$$

The indirect utility function, as calculated by first finding the expenditure function is:

$$Y_1 = A[r(\tau - T_t^{\min}) - c_t]^{(\gamma+\eta)}$$

where $A = T_W^{\min\,\alpha} T_t^{\min\,\beta} [\frac{\gamma}{r(\eta+\gamma)}]^{\gamma} [\frac{\eta}{p(\eta+\gamma)}]^{\eta}$

The Cobb-Douglas utility form representing work in transit, Eq. (19), is modified to include the inequality constraints of model (iv) assumed to be binding at optimality, is as follows:

$$U = [T_W^{\min} - f(T_t^{\min} - a)]^{\alpha} a^{\beta} (T_t^{\min} - a)^{\delta} T_l^{\gamma} X^{\eta}$$

The indirect utility function in this case, also calculated by the expenditure function method as explained in Train and McFadden (*6*) is:

$$Y_2 = B[r(\tau - T_t) - c_t]^{(\gamma+\eta)}$$

where $B = [T_w^{\min} - f(T_t^{\min} - a)]^{\alpha} (T_t^{\min} - a)^{\delta} a^{\beta} [\frac{\gamma}{r(\eta+\gamma)}]^{\gamma} [\frac{\eta}{p(\eta+\gamma)}]^{\eta}]$

The indirect utility function derived from the activity choice models lends itself to an elegant representation of work in transit.

The probability of choosing the mode with internet connection (mode 2) assuming a logit model is:

$$P(Y_2) = \frac{e^{Y_2}}{e^{Y_1} + e^{Y_2}}$$

$$= \frac{e^{B[r(\tau - T_t^{\min}) - c_t]^{(\gamma+\eta)}}}{e^{A[r(\tau - T_t^{\min}) - c_t]^{(\gamma+\eta)}} + e^{B[r(\tau - T_t^{\min}) - c_t]^{(\gamma+\eta)}}}$$

6. Conclusion & Discussion

Using activity choice models, this study shows that combining work with travel increases the utility of the rider and reduces VOTT. The extent of this effect depends on the form of the utility function. For Cobb-Douglas utilities, VOTT depends on the various activity times, consumption patterns, efficiency factors and the coefficients in the utility function. In the linear utility models VOTT depends on the efficiency factor and coefficients only.

The difference in VOTT obtained, between work in transit and no work in transit situations, may be used to guide the development of a pricing scheme for a service, like wireless internet connection that aids the possibility of work in transit.

This study also explores a methodology of estimating the indirect utility function from the activity choice model so as to formulate a mode-choice model.

This study and others (Kirby, et.al.2007, Zhang, et.al. 2006) have shown that adding possibilities of useful activities to travel is beneficial. With wireless internet connection becoming ubiquitous in every sphere, adding to the scope of work in transit, this study is an introduction of a new research agenda. There are many possible benefits and disbenefits to the phenomenon of deployment of internet connection on trains and transit. The concept of the mobile office could change our perception of travel, and shift the focus from the speed of travel to the comfort and convenience of travel.

However, introduction of internet service will not necessarily affect every rider. Those with short commutes, with commutes in crowded buses or trains, or with many transfers will not gain much. Many work types for instance that of assembly line workers have little benefit from an internet connection. Finally, internet users tend to have higher incomes and more education than the average person (GAO, 2001). As such, only those systems that serve a majority of such riders could use it.

While recognizing that there are many riders who will not use the service, there is a possibility that the mobile office environment may affect the enjoyment of their travel time adversely (Zhang, et.al. 2006). For those who will use the service, the shift of focus away from the duration of commute time, may cause riders to reside at long distances from their place of work causing urban sprawl and its associated disbenefits.

Future work on this study will focus on validating the models with data and exploring the effect of an in transit internet connection on travel choices that go beyond mode choice. This includes valuing the benefits of in transit internet access and exploring the effects on home-workplace vocational dynamics.

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