A Model for Analysis of Impacts of Telecommuting on Network Travel Time

Son The Vu, Upali Vandebona
University of New South Wales, Sydney, NSW, Australia

1 Introduction

Telecommuting is often stated as a potential strategy to reduce several emerging social-economical problems, including transport congestion; environment pollution and production costs. Although more research is needed, in the last three decades many researchers have attempted to analyse and evaluate the impacts of telecommuting on different aspects of the society. In transportation, telecommuting has the ability to reduce travel and pollution (Nilles et al 1974, Nilles 1975; Mokhtarian 1991a, b; Salomon 1985) particularly where the traffic congestion is high, as in many large cities around the World. Understanding the impacts of telecommuting on transport will assist in selecting solutions for the transport demand management, where telecommuting is an important strategy. The analysis and forecast of the travel impacts of telecommuting is particularly essential when the Australian Government has been implementing policies to encourage telecommuting (ATAC, 2006). The travel impacts of telecommuting in this paper are assessed via the savings of network travel time. The network travel time here means the total daily travel time for the work purpose by all workers on both the road network and the rail network. Evaluating the savings of the network travel time is aimed to provide an overview of the benefits of telecommuting on a transport system. However, there are two factors that make this task difficult: (1) Existing analysis models such as the models of Mokhtarian (1998) and Choo *et al* (2005) do not address impacts of telecommuting on the network travel time. (2) Models are specific to the local conditions and particular countries (Ortuzar and Willumsen, 1994; Hensher and Kenneth, 2000) and therefore they need much modification to apply to new conditions. This paper presents a computational method to evaluate the impacts of telecommuting on the network travel time and shows an application using the data from New South Wales.

2 Telecommuting definition

There are a variety of definitions and classifications of telecommuting. The differences of definitions depend on the telecommuting time, location, types of communication and the employment status (salaried or self-employed employees). The time-based classification distinguishes telecommuting into three types according to the amount of time working away from the main work place. If that amount is equal to or greater than 90%, it is referred to as permanent telecommuting. When that amount is 20% to 90%, it is named alternative telecommuting. When the amount of time working away from the main office is less than 20%, it is called supplementary telecommuting (ECaTT, 2000).

Another classification scheme is based on location. There are three main categories of the location-based classification. The home-based and centre-based telecommuting types are well known in the USA and Australia (Nilles, 1988; Shafizadeh *et al*, 2000; ATAC, 2006). The third type, mobile telecommuting (working in mobile offices, on trains, in cars, on flights or in hotels) is reported often in European case studies. Some European authors disagree with the second type (centre-based) mentioned above due to the difficulty in distinguishing centre-based telecommuting from the traditional office. Employment status is another attribute in telecommuting classification. In Europe, the self-employed person with a home-office-small-office is not a telecommuter while the self-employed person having a main office in a contractor premises can be considered a telecommuter (ECaTT, 2000). In terms of the communication, most studies mentioned about the substitution of commuting by information and communication technologies, from the basic means such as telephone to advanced systems like videoconferencing (Hopkinson *et al*, 2002).

For the purposes of this paper, we propose a transport-oriented definition of telecommuting. Telecommuting is the full or part substitution of journeys to work by working from alternative locations. Alternative locations can be home, mobile offices, telecentres, customer sites or a combination of these. Telecommuting covers employed persons, including salaried and self-employed individuals. However, it is necessary to avoid dilution of this pool from freight sector workers such as truck drivers, bus drivers and delivery persons. The time-based classification in this definition categorises full-day and part-day telecommuting instead of full-time and part-time telecommuting as observed in other research. This is because full-day and part-day telecommuting have different quantifiable impacts on transport. Commuting trips and commuting time of the worker are totally eliminated during the day of full-day telecommuting. While on the day of part-day telecommuting, the commuting trips still have to be made and the vehicle-km remains the same. The travel time could be reduced (but not eliminated) in the part-day telecommuting because the commuting trip can be made during off peak.

2.1 Discussion of impacts of telecommuting on travel

There are different impacts on the transport sector from different types of telecommuting.

- Full-day-home-based telecommuting brings the largest saving of travel time and fuel, compared to other types of telecommuting. As mentioned above, journeys to work during telecommuting days are completely eliminated therefore traffic congestion is reduced. In addition, when employees work at home they may use local goods and services and this saves travel. Furthermore, some car and public transport trips can be replaced by relatively shorter walking or bicycle trips. However, this type of telecommuting is also likely to create other trips as the flexible working time may induce other activities. These additional trips will be mainly in the regional transport system. Not all reductions of person-trips lead to a decrease of vehicle-trips. The number of vehicle-trips decrease only when trips of drive alone road users are eliminated. When the telecommuter is a public transport patron or a car passenger, on the day of telecommuting the vehicle-trips may not decrease, although the person-trip of the telecommuter is eliminated.

- Full-day-centre-based telecommuting also reduces travel time and fuel consumption. The telecommuters still have to make journeys to work but the travel time and the travel distance are expected to be shorter. Mokhtarian (1998) has stated that there is no dissimilarity in travel time and travel distance saving between full-time-home-based telecommuting and full-time-centre-based telecommuting. Benefits of this telecommuting type for transportation, environment and economy are similar to the first type. However, full-day-centre-based telecommuting may create more trips for the local transport system. In other words, it shifts the traffic congestion from CBD to suburbs or spreads the traffic congestion from central parts to other areas. Replacement of public transport trips to the CBD by car trips to telecommuting centres could also contribute to this shift. Thus, congestion of local areas should be considered when developing centre-based telecommuting.

- Part-day-home-based telecommuting allows commute trips to occur during off-peak time. This telecommuting type may not save travel distance, but it saves travel time due to off-peak use of the transport network. Possible change of travel modes should be considered for this type. There is a possibility that some commuters may shift from public to private modes in part-day telecommuting as public transport may be less frequent, compared to peak hours. That it is easier to combine work trips with other trips when telecommuters can arrange working time by themselves may also lead to an increase of private mode share.

- Part-day-centre-based telecommuting happens when workers spend part of their working time at telecentres and the rest of the day at their usual work places. Thus, the number of trips, travel time and distance are likely to increase. A reason for part-day-centre-based telecommuting could be unplanned work events or telecommuters trying to avoid peak hours although they cannot work at home.

3 Potential impacts

As presented in Table 1, impacts of telecommuting can be categorised into three groups: transport impacts; environmental impacts and economic impacts.

Table 1: Potential impacts of telecommuting

Positive Impacts	**Negative Impacts**
<u>Transport impacts</u>	

• Reduced commuting trips
• Reduced travel distance
• Reduced VKT
  o Commuting trips
  o Non-commuting trips
• Trips redistributed away from the CBD
• Peak hour traffic spread
• Reduced vehicle ownership
	• Increased non-commuting trips
	• Change in mode share from public to private modes
	• Increased business-related trips
	• Increase in other household member trips

<u>Environmental impacts</u>	
• Reduced traffic accidents • Reduced transport incidents • Improved air quality	• Urban sprawl encouraged • Contribution to local congestion • Increased printed paper
<u>Economic impacts</u>	
• Reduced travel time • Travel cost savings • Increased employee productivity • Increased working hours • Reduced need of medical care by reduction of travel stress and accidents • Reduced required parking spaces • Reduced needed office floor • Reduced office facilities	• Increased household energy usage • Required equipment/facility installation in households

Center-based telecommuting can reduce work trips in the CBD when employees of offices in the CBD go to work at centres in suburbs, near their houses. Similar to flextime work arrangement, part-day telecommuting seems to be useful in spread traffic in peak hours. These transport positive impacts would lead to ease traffic congestion in city centres. Furthermore, telecommuting can lead to a decrease of vehicle ownership when two or three household members are able to share the same car. For a couple, one can telecommute on odd days while the other does even days, for example. Beside positive impacts, Mokhtarian (1998) and Koenig *et al* (1996) also warned possible negative impacts of telecommuting such as increase of non-commuting trips.

4 Analysis methodology

A computation model has been developed to evaluate the savings of network travel time by telecommuting. The network travel time in this paper means the total daily travel time for the work purpose by all workers. Workers who walk to the work place are accounted as private transport travellers. The average travel time of private transport mode is the aggregate average value of travel time of ‘walk only’ trips and all other private transport trips including by bicycles, motorcycles and cars. The average travel time of public transport mode is the aggregate average value of travel time of the road network and the rail network. The public travel time includes walk, wait, transfer and in-vehicle time. The travel time is computed for the round trip.

The impact of telecommuting on a transport performance indicator can be obtained from the amount of trip reduction and the unit impact.

4.1 Number of trip reduction computation

Steps to compute reduction of trips are illustrated in Figure 1. Firstly, the number of telecommuters at a given time is computed from the number of employed persons (*E*) at that time and proportion of telecommuting (*TC*). Then the frequency of telecommuting (*Fi*) is applied to compute the number of telecommuting occasions on a weekday. Next, the transport mode share (*MSj*) is introduced to calculate average reduction of person-trips of a transport mode *j*.

$$TR = E \times TC \times \sum_i F_i \times \sum_j MS_j \tag{1}$$

Where

TR is the number of person commuting trips saved by telecommuting on a weekday
E is the number of employed people
TC is the proportion of telecommuting
F_i is the frequency of telecommuting type *i*
MS_j is the mode share of transport mode *j*

4.2 Travel time reduction computation

The reduction of network travel time by telecommuting can be computed from the reduction of commuting trips and the saving of travel time of commuting trips. The reduction of network travel time by full-day and part-day telecommuting is different thus the frequency of full-day telecommuting (*FDTCF*) and the frequency of part-day telecommuting (*PDTCF*) are applied. In addition, only commuting trips of part-day telecommuters that are shifted from peak hours to non-peak hours can save travel time. To calculate the number of commuting trips of part-day telecommuters that are shifted from peak hours to non-peak hours, parameter α is added to the frequency of part-day telecommuting.

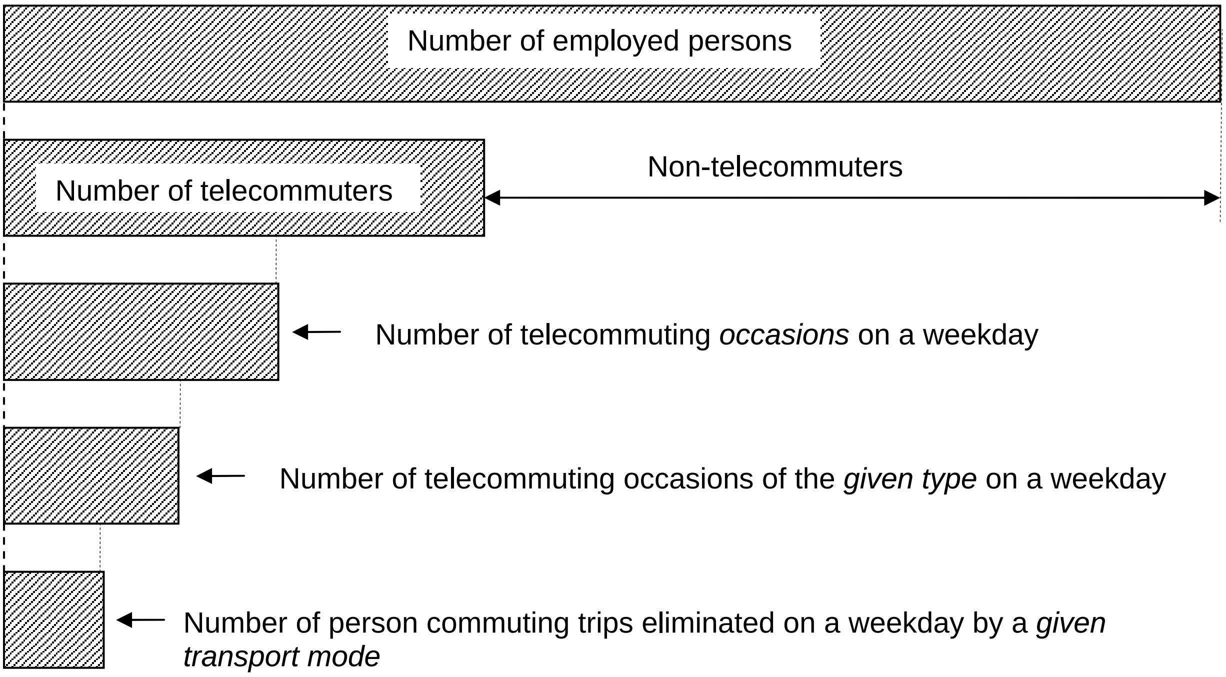

Figure 1: Schematic explanation of computing reduction of number of work trips

$$\sum_i F_i = FDTCF + PDTCF \times \alpha \quad (2)$$

FDTCF is the frequency of full-day telecommuting
PDTCF is the frequency of part-day telecommuting
α is the proportion of commuting trips during peak hours that is shifted to non-peak hours on the days of part-day telecommuting

Because the working time at the main office of telecommuters on the days of part-day telecommuting is shorter than the working time of non-telecommuters, part-day telecommuters can avoid the peak hour travel from at least once during that day. This means the avoiding factor α is greater than 0.5. In addition, the value of α is smaller than 1 because sometimes the commuting trips of telecommuters on the days of part-day telecommuting cannot be shifted from peak hours to non-peak hours due to numerous reasons such as meetings or appointments. The value that α =0.75 is selected in the application for New South Wales. The application is discussed in the Section 5.

The savings of travel times of private and public transport mode are also different. The number of commuting trips of private and public transport modes is therefore computed separately:

$$\sum_j MS_j = PR + PL \quad (3)$$

PR is the mode share of private transport
PL is the mode share of public transport

From equation (1), (2) and (3):

$$TR = E \times TC \times (FDTCF \times (PR + PL) + \alpha \times PDTCF \times (PR + PL)) \quad (4)$$

The travel time savings of each type of commuting trips are now applied to compute travel time savings of network. For example, the average travel time of the commuting trips of private transport mode (*PRT*) is applied to compute the saving from commuting trips of private transport mode on the days of full-day telecommuting. Similarly, the average travel time of the commuting trips of public transport mode (*PLT*) is used to compute the saving from commuting trips of public transport mode on the days of full-day telecommuting. However, for part-day telecommuting, the difference between the travel time of commuting trips of private transport in peak hours and the travel time of commuting trips of private transport in non-peak hours (*PRT-PRNPHT*) is used to compute the saving from commuting trips of private transport mode on the days of such telecommuting. The difference between the travel time of public transport commuting trips in peak hours and the travel time of public transport commuting trips in non-peak hours (*PLT-PLNPHT*) is used to compute the saving from public transport commuting trips on days of part-day telecommuting.

$$T = E \times TC \times (FDTCF \times (PR \times PRT + PL \times PLT) + \alpha \times PDTCF \times (PR \times (PRT - PRNPHT) + PL \times (PLT - PLNPHT))) \quad (5)$$

Where:
T is the travel time saved by telecommuting
PR and *PRT* are the proportion of users of private transport mode and the two-way commuting time of telecommuters by private transport mode at peak hours, respectively
PL and *PLT* are the proportion of users of public transport mode and the two-way commuting time of telecommuters by public transport mode at peak hours, respectively
PRNPHT is the two-way commuting time of telecommuters using private transport mode at non-peak hours
PLNPHT is the two-way commuting time of telecommuters using public transport mode at non-peak hours

The percentage of network travel time savings available from telecommuting can be estimated using:

$$S = 100T / T_0 \quad (6)$$

And

$$T_0 = E \times (PR \times PRT_0 + PL \times PLT_0) \quad (7)$$

Where:
S is the percentage of network travel time savings by telecommuting
T_0 *is* the network travel time of work trips without telecommuting
PRT_0 is the average two-way commuting time of general commuters using private transport mode
PLT_0 is the average two-way commuting time of general commuters using public transport

There are further impacts of telecommuting that could contribute to the reduction of network travel time. From Table 1, these effects on the travel time can be grouped as (1) the change of transport mode of commuting trips of other household members of telecommuters; (2)

change of non-commuting trips of telecommuters and their household members (induced demand); (3) travel mode change of telecommuters; (4) the travel distance increase by residential relocation; and (5) latent demand (e.g. road space that is freed up by telecommuters can stimulate use of private transport).

The impact of the changes of transport mode share on the savings of network travel time will be considered later in scenario analysis. The travel distance increase by residential relocation and the latent demand have been analysed by Mokhtarian (1998). According to this analysis there is no solid evidence to support the increase of the travel by residential relocation and the latent demand. Thus, these impacts are not included in the model. In addition, a lack of studies about changes in travel of other household members of telecommuters has been found. Therefore impacts from these changes on network travel time cannot be quantified in this paper. The increase in non-commuting travel is a potential adverse impact of telecommuting. Former researchers have warned about potential to increase travel when people saved time by telecommuting (Koenig *et al*, 1996; Mokhtarian *et al*, 1995; Mokhtarian and Varma 1998; Hopkinson *et al*, 2002; Henderson *et al*, 1996; and Choo *et al*, 2005). Although the evidence is not strong, previous authors have analysed the potential of using saved commuting time to create non-commuting trips of telecommuters and their family members.

Data about changes of non-commuting trips have been found in some previous projects. In the project of ‘Puget Sound home and centre’, non-commuting trips of telecommuters increased by 0.3 trip and non-commuting vehicle-km traveled of telecommuters increased by 3.2 km (Henderson *et al*, 1996). In three other projects in ‘State of California’, ‘Puget Sound Telecentre’ and ‘Neighborhood Telecentre’, non-commuting trips increased by 0.5, 0.2 and 0.4 trip, respectively. However, the non-commuting vehicle-km traveled decreased by 8, 3.2 and 3.2 km respectively in these projects (Koenig *et al*, 1996; Henderson and Mokhtarian, 1996; and Mokhtarian *et al*, 1997). Only in the project of ‘Puget Sound home and centre’, there was an increase on both the non-commuting trips and the vehicle-km traveled. In three other projects, the non-commuting trips increased but the vehicle-km decreased.

From these data, we are able to compute a possible range of influence of non-commuting travel on network travel time. The range of influence is computed by the proportion of the change of non-commuting vehicle-km traveled and the saving of commuting vehicle-km traveled by telecommuting. The limits of range of influence is computed from the largest increase and decrease of non-commuting vehicle-km traveled. The increase of vehicle-km traveled of non-commuting trips is 3.2 km over 56.3 km of the commuting distance saving in the project of ‘Puget Sound home and centre’. This means that 0.057 of commuting travel saved by telecommuting may be counteracted by an increase of non-commuting travel. Similarly, a decrease of 8.1 km of non-commuting travel was observed against 48.3 km of commuting travel saved in the project of ‘State of California’. The corresponding fraction of these values is 0.17. Thus, savings of network travel time may increase 17% from the decrease of non-telecommuting travel. To account for the influence of non-commuting travel changes on network travel time we introduce the variable *NCT* to the model.

5 Scenarios analysis

In this section, the proposed model has been applied to seven scenarios in New South Wales. Inputs for scenarios have been determined as follows:

Telecommuting proportion: There are four reports that give specific data of telecommuting proportions in Australia and New South Wales. According to ABS (2000), one million employed Australians (11%), worked all or most of their working hours at home, or had an arrangement to do so. However, New South Wales is one of three states with a high rate of telecommuting in Australia (Sensis, 2005 and ATAC, 2006), the total proportion of home-based telecommuting (during normal business hours for a full or part day) in New South Wales was 8% (244,700) of over 3 million total employed persons in 2001, according to ABS (2002). Similarly, RTA (2000) stated telecommuting of New South Wales was 10 to 15 % of the workforce. A much larger telecommuting proportion has been reported by Vidal (2004) and Sensis (2005) that around 30% Australian were teleworkers in 2004 and 2005.

In a broader picture, most studies from developed countries confirmed a positive trend with rapid increase of telecommuting proportion. Braus (1993) showed telecommuting in US increased by 20% and reached 7.9 million between 1990 and 1992. ITAC (2004) forecasted that an estimated 100 million US workers (approximately 70%) will telework by 2010. Most European surveys indicate that there is a far greater proportion of the workforce who would like to telework than those who are actually teleworking (Sensis, 2005). An estimated 73% of US workers were interested in teleworking in 2002 while only 37% of these stated that it would be feasible. A similar gap between telework interest and feasibility was reported for Europe where these rates were 66 and 32%, respectively.

A positive trend is observed in Australia as well. In the mid 1990s, Australian Bureau of Statistics estimated only one in twenty-five employees worked from home. In 2000 this figure was at least one in five working Australians. This amounted to 1.68 million workers who worked from home, where 980,000 of them worked mainly from home (ABS, 2000). According to ABS (2002), about 47% teleworkers would like to telework more often, whilst 38% of those who work at home only after normal business hours would also like to telework. And of those employed who have never teleworked at home, 27% (566,700) reported that they would like to telework. The above data points toward a tendency for an increase in both telecommuting frequency and popularity in the future in NSW. Additionally, according to Sensis (2005), 87% teleworkers reported informal arrangements and 4% were unsure. This shows the demand for telecommuting when more employers have policies to encourage telecommuting. And Vidal (2004) also estimated that Australian mobile teleworkers will increase from 2.8 million (~30%) in 2004 to 3.4 million (~37%) by 2008. Furthermore, employees and employers will find it easier to implement teleworking arrangements in the future due to the decreasing equipment and communications costs and the increasing availability of advanced telecommunication solutions and communications packages designed for teleworkers. The Virtual Private Network, its integration to VoIP and Google Apps Premier Edition are examples of promising telecommunication services for telecommuting.

A telecommuting proportion of 8% has been adopted in keeping with 2001 data from ABS (2002) in the application designed for New South Wales in this paper. For the maximum level of telecommuting, Nilles (1988) hypothesized that 80% of information workers were potential telecommuters and 50% of workforce was composed of information workers. Thus, Nilles proposed that 40% of all workers were potential telecommuters. Later, other studies and surveys have shown that the telecommuters included workers other than just information workers (ECaTT 2000; ABS 2000). From these reasons the upper limit of telecommuting can be expected to be greater than 40% of workforce. In seven scenarios of this paper, the telecommuting proportion is expected to increase and the range from 20% to 40% in 2021 has been selected. We utilised two types of expressions to describe telecommuting increment. The first method used a linear function. The second method used a logistic function (Kingsland, 1995) as follows:

$$P(t) = \frac{KP_0 e^{rt}}{K + P_0 (e^{rt} - 1)} \qquad (8)$$

Where *P(t)* is the proportion of telecommuting at time *t*, *K* is the carrying capacity, P_0 is the initial proportion of telecommuting, and *r* is the growth rate of telecommuting.

Telecommuting frequency: In this paper, the fraction form of telecommuting frequency is used. In this form, telecommuting frequency is the ratio between the number of telecommuting days and the number of working days. Five working days per week was used to convert the values of telecommuting frequency to fraction form. By this way, telecommuting once per fortnight corresponds to the telecommuting frequency of 0.1 and telecommuting once per four weeks corresponds to the telecommuting frequency of 0.05. Lake and Cherrett (2002) stated that predominant teleworking practice was part-time telecommuting, and the average telecommuting frequency was 0.3 away from the normal workplace. Telecommuting frequency was 0.2 in RTA (1995) and 0.24 in Mokhtarian (1998). In Sensis (2005), over 80% teleworkers teleworked up to frequency of 0.25. Telecommuting frequency of 0.3 was observed by Hamilton (2006) as well. ABS (2002) reported that nearly half of existing teleworkers would like to telework more. This can lead to an increase of telecommuting frequency in the future.

Accounting for an increasing trend of telecommuting frequency in above references, and the value of 0.2 from RTA (1995), we utilised 0.24 as the average telecommuting frequency of New South Wales in 2001. This is assumed to consist of 0.18 of frequency of full-day telecommuting and 0.06 of frequency of part-day telecommuting. The values of 0.18 and 0.06 are the average telecommuting frequency of all telecommuters. Four telecommuters with telecommuting frequency of 0.2 and one telecommuter with telecommuting frequency of 0.1 will lead to an average frequency of 0.18, for example.

Employment: According to ABS (2002), employment of New South Wales in 2001 was 3,044,800. And according to Hudson (2004) the working population in Australia will increase by 170000 per year to 2020 with 50000 employment per year in NSW (NSW Government, 2006). These data have been used as inputs (see Table 2) in scenarios presented in this paper.

Transport mode share: ABS (2002) estimated that 87% (213,000) of all teleworkers in New South Wales used a car for at least part of the trip to work when they were not teleworking. Other types of transport used by teleworkers included train (12%), walking (9%) and bus (8%). These data were not clear about the share of private transport mode. TPDC (2005) showed that private mode share in 2001 was 70% of total trips on weekdays; walk only was 17.4% and public transport was 10%. Data from TPDC (2005) was for total trips, and inapplicable for the present analysis. According to UTFB (2001), work trips by private transport modes in Sydney were 71.2% and by public transport were 18.7%. These values were applied in scenario analysis presented in this paper for the base year.

Proportion of avoiding peak-hour commuting: This measure applies in relation to part-day telecommuting. Network travel time reduction by part-day telecommuting is mainly due to the transfer of commuting trips from peak period to non-peak period. The difference between travel time in peak-hours and non-peak-hours contributes to travel time savings. The ideal scenario for both part-day telecommuters and transport system is that telecommuters work for a period of time at home to avoid both morning peak-hours and afternoon peak-hours on telecommuting days. This is not always feasible because of task requirements and appointments. However, as part-day telecommuters work for a period of time at home, at least they can avoid one direction of their trip during peak hours on one telecommuting day and thus the percentage of avoiding peak-hour commuting is between 50% and 100 %. In the application presented in this paper, this proportion was considered to be 0.75.

Travel time: According to TPDC (2005), the average work trip duration in Sydney in 2001 was 31 minutes and thus the average travel time of round work trips was 62 minutes. The average travel time for the whole of New South Wales is expected to be greater. According to RTA (2000), teleworkers spent an average of 3.25 hours commuting to and from work each day to their usual office. In our application, average travel time of telecommuters was selected as 1 and 1.5 hours for private and public transport modes, respectively in peak hours and 0.5 and 1 hour in non-peak hours for a total two way commuting time per day. With the assumption that commuters of long journeys are more inclined to telecommute, the average travel time of general commuters was selected as 0.7 and 1.2 hours for private and public transport modes.

Seven scenarios were proposed to cover possible changes of socioeconomic characteristics for New South Wales. In the first scenario (see Table 2), full-day telecommuting frequency, part-day telecommuting frequency, public and private transport mode share are kept unchanged throughout the 20 years period, at the level of 2001 (base year), at 0.18, 0.06, 0.71 and 0.19 respectively. In this scenario, telecommuting proportion is assumed to increase linearly from 0.08 % to 0.2 % between 2001 and 2021. Travel time was also kept unchanged at values previously mentioned.

In the second scenario, telecommuting frequency is assumed to increase linearly. The frequency of full-day telecommuting increases from 0.18 in 2001 to 0.27 in 2021 while the frequency of part-day telecommuting increases from 0.06 to 0.08 in the same period of time. Other variables are as in scenario 1. This scenario is selected to investigate the sensitivity of telecommuting frequency on travel time saving.

Table 2: Computation process for scenario 1

Variables	Definitions	Assumptions or estimated values		Units
		2001	2021	
E	Number of employed persons	3,044,800	4,044,800	
TC	Telecommuting proportion	0.08	0.2	
FDTCF	Frequency of full-day telecommuting	0.18	0.18	
PDTCF	Frequency of part-day telecommuting	0.06	0.06	
α	Proportion of part-day telecommuters avoiding peak-hour commuting	0.75	0.75	
PR	Private mode share	0.71	0.71	
PL	Public mode share	0.19	0.19	
PRT	Travel time by cars in peak hours of telecommuters	1	1	hours/round trip
PLT	Travel time by public transport in peak hours of telecommuters	1.5	1.5	hours/round trip
PRNPHT	Travel time by cars in non-peak hours of telecommuters	0.5	0.5	hours/round trip
PLNPHT	Travel time by public transport in non-peak hours of telecommuters	1	1	hours/round trip
NCT^{+}	The positive effects from non-commuting travel	1.17	1.17	
NCT^{-}	The negative effects from non-commuting travel	0.943	0.943	
T	**Travel time saved**	**48558**	**161266**	**hours/day**

In the third scenario, both the telecommuting proportion (see Figure 4) and telecommuting frequency increase. The telecommuting frequency increases as in the base scenario while the telecommuting frequency increases as in the second scenario.

To investigate the sensitivity of transport mode share we designed the fourth scenario with the private mode share increasing linearly by 9%, from 71% in 2001 to 80% in 2021, whilst public transport mode share decreases linearly by the same value to 10% in 2021. Other inputs were kept the same as in the first scenario.

The fifth scenario is based on the fourth scenario with the travel time of private transport increasing from 1 hour in 2001 to 1.4 hour in 2021. It is reasonable to anticipate that an increase of private mode share leads to an increase of traffic congestion and thus also an increase of private transport travel time.

In the sixth and seventh scenarios we applied the logistic function (see Equation (8)) for the increase of telecommuting proportion from 2001 to 2021. In the sixth scenario, K = 0.4 and r = 0.3 were applied. This means that the telecommuting proportion will increase according to the S-curve and almost reach the maximum level in 2021 (0.4). In the seventh scenario, constants K and r are chosen at 0.7 and 0.09 respectively. This means that the telecommuting proportion will increase gradually and reach 0.31 in 2021. For the purpose of comparison Figure 4 provides the graphical form of the telecommuting proportion of the seven scenarios. Other inputs are as in scenario 1.

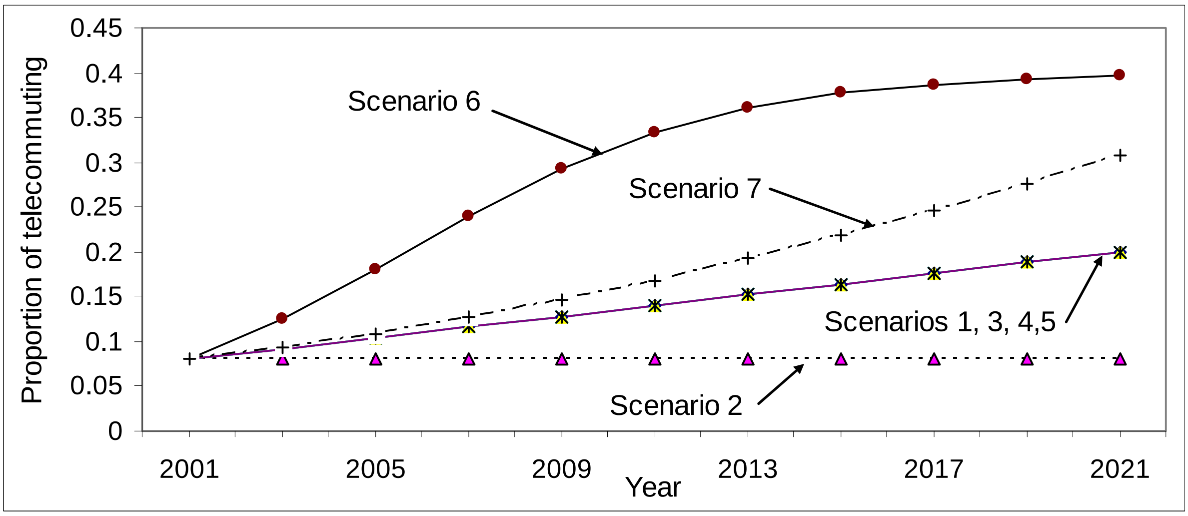

Figure 4: Full-day telecommuting proportion for the seven scenarios from 2001 to 2021

The saving of network travel time in 2001 is 2.2% (see Figure 5). The telecommuting proportion and telecommuting frequency strongly affect the network travel time savings. In the linear form, an increase of 12% of telecommuting, from 8% in 2001 to 20% in 2021, brings an increase of 3.3% in the saving of network travel time (scenario 1). In the Logistic function form, an increase of 23 % of the telecommuting proportion leads to an increase of 6.2% of the saving of network travel time, from 2.2% in 2001 to 8.4% in 2021 (scenario 7).

The network travel time saving of the sixth scenario is the greatest at 11% with an estimation range from -20,000 to +60,000 hour/day in 2021. This saving is equivalent to over 3 million dollar per day (value of time is assumed to be $10/hour). As mentioned before, amount of estimation range is computed from non-commuting travel observed in previous studies. The sixth scenario is followed by the seventh scenario with 8.4% of network travel time reduction in 2021. However, the increment rates of telecommuting proportion of the sixth and the seventh scenario are different. The graph of telecommuting proportion of the sixth scenario has an S-shape with a sharp increase during the middle period, and lower rates at the two edges. In this scenario, the diffusion of telecommuting will be saturated in 2021. This means that if the diffusion process of telecommuting occurs according to the sixth scenario then the maximum saving of network travel time would be 11%. The telecommuting proportion graph of the seventh scenario has a concave shape. This is equivalent to the first period of diffusion process of telecommuting and promises a long-term increase of telecommuting.

The first, third, fourth and fifth scenarios have the same rate of telecommuting diffusion but different results for the reduction of network travel time. The third scenario has the highest network travel time saving in this group. The graph of the third scenario shows a strong influence of telecommuting frequency on network travel time savings. This saving is 8.1%, compared to 5.5% of the first scenario, in 2021. The network travel time savings of the two remaining scenarios in this group is 7.7% and 5.6% for the fifth and fourth scenarios respectively (Figure 5). These values also reflect a considerable influence of average individual travel time on network travel time saving. The saving of network travel time in the fifth scenario in 2021 is 1.1% greater that that of the fourth scenario when the average private transport travel time increases by 40%. The influence of transport mode share is also significant as seen by a comparison of the savings in the first and fifth scenarios.

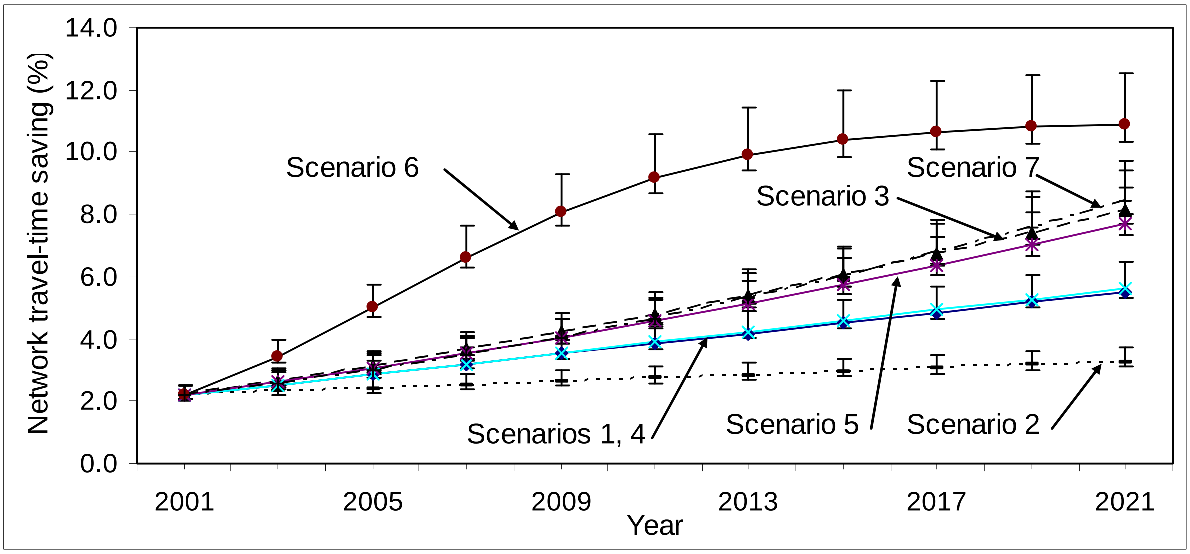

Figure 5: Network travel time savings

6 Conclusions

The paper presents a computation model to evaluate the impacts of telecommuting on network travel time. The meaning of network travel time in this paper is the total daily travel time for the work purpose by all workers on both the road network and the rail network. A framework with the time-based classification of telecommuting is proposed. The classification identifies full-day and part-day telecommuting as two categories with different impacts on the transport system and travel time. The framework is also useful in extending the model to evaluate impacts of telecommuting on vehicle-km traveled, traffic congestion and environment. These areas would be the further development of the model.

The main focus of this research has been to develop a forecasting methodology that enables the estimation of savings of network travel time using the data available from published sources. The reduction of network travel time here consists of two parts: the travel time saved by eliminated commuting trips and the travel time saved by commuting trips shifted from peak to off-peak hours. The savings of network travel time by private and public transport modes are computed separately to account for the differences of travel time. The model development has been explained in this paper using a diagram and mathematical expressions. The model examines the savings of network travel time directly, not through the difference of network travel time with and without telecommuting. The network travel time savings can be converted to a percentage form by comparing with the total network travel time of journeys to work. The impacts of telecommuting on network travel time are computed based on the proportion of telecommuting, frequency of telecommuting, and transport network performance measures.

The model has been applied to seven scenarios for New South Wales. The plausible input values have been selected from other sources. It is observed from the literature that the telecommuting proportion and telecommuting frequency have real world potential to increase with time. The telecommuting frequency has been selected at 0.24 in the base year and increased to 0.35 in 2021 in two scenarios. The growth of telecommuting proportion has been simulated by two patterns (a) linear and (b) Logistic function with different bounds. The telecommuting proportion has taken values from 20% to 49% in 2021 for the scenario applications. This wide range of telecommuting proportion has been selected to cover the spread of values reported in the literature. The adverse impacts that may increase travel have been also taken into consideration.

Telecommuting proportion and telecommuting frequency have strong influences on network travel time. A scenario has also been designed to examine the effect of the transport mode shift (increased private and reduced public transport mode share) of telecommuters on the savings of network travel time. The influence of the individual commuting trip travel time and the transport mode share on savings of network travel time is also considerable. The application has shown the potential economic benefit through the savings of network travel time. Furthermore, the benefit increases rapidly when the telecommuting proportion and telecommuting frequency are encouraged to increase.

References

Australian Bureau of Statistics (2000) *Locations of Work* Canberra: ABS http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/9A2BC8F6F641BDC4CA256A5A0001EB68/$File/62750_jun%202000.pdf

Australian Bureau of Statistics (2002) *Teleworking NSW 2001 Report* 1373.1 Canberra: ABS http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/E114E1CF19F28FEDCA256B97007D589A/$File/13731_oct%202001.pdf

Australian Telework Advisory Committee (2006) Telework for Australian Employees and Businesses: Maximising the Economic and Social Benefits of Flexible Working Practices. *Report of the Australian Telework Advisory Committee to the Australian Government* ISBN 0 642 75339 3 Commonwealth of Australia Canberra: ATAC http://www.dcita.gov.au/__data/assets/pdf_file/37022/ATAC_REPORT.pdf

Braus, P. (1993) Homework for Grownups *American Demographics,* pp. 38-42

Choo, S., Mokhtarian, P. L. and Salomon, I. (2005) Does telecommuting reduce vehicle-miles traveled? An aggregate time series analysis for the U.S., *Transportation*, 37-64

ECaTT (2000) *Benchmarking Progress on New Ways of Working and New Forms of Business across Europe* Bonn: empirica

Hamilton, B. A. (2006) International Approaches to Tackling Transport Congestion, *Paper 6 (Final): Information & Communications Technologies* A5022/WP/WP6 Melbourne Victorian Competition and Efficiency Commission

Hensher, A. D. B., J. Kenneth (2000) *Handbook of Transport Modelling* New York: Pergamon Press

Henderson, D. K., Koenig, B. E. and Mokhtarian, P. L. (1996) Using travel diary data to estimate the emissions impacts of transportation strategies: The Puget Sound Telecommuting Demonstration Project: *Journal of the Air and Waste Management Association*, 46(1), PP 47-57

Henderson, D. K. and Mokhtarian, P. L. (1996) Impacts of the center-based telecommuting on travel and emissions: analysis of the Puget Sound demonstration project, *Transportation Research Part D*, 1**,** 29-45

Hopkinson, P., James, P. and Maruyama, T. (2002) Sustainable teleworking-Identifying and Evaluating the Economic, Environmental and Social Impacts of Teleworking, *Report 3*

Hudson (2004) The ageing population: implications for The Australian Workforce *Whitepape* The 20:20 Hudson Australia Series: Global resources and human capital solutions www.jobs.au.hudson.com/documents/jobs_au_Ageing_Whitepaper.pdf

International Telework Association and Council (2004) *Work at home grows in past year by 7.5% in U.S. use of broadband for work at home grows by 84%* Scottsdale: ITAC

Kingsland, S. E. (1995) *Modeling Nature* (2nd ed) Chicago and London: The University of Chicago Press

Koenig, B. E., Henderson, D. K. and Mokhtarian, P. L. (1996) The travel and emission impacts of telecommuting for the state of California Telecommuting Pilot Project, *Transportation Research Part C*, 4**,** 13-32

Lake, A.S. and Cherrett, T.J. (2002) *The Impact of ICT on Travel and Freight Distribution Patterns* London: UK Department for Transport

Mokhtarian, P. L. (1991a) Defining telecommuting, *Transportation Research Record*, 1305, 273-281

Mokhtarian, P. L. (1991b) Telecommuting and travel: state of the pracitce; state of the art, *Transportation*, 18(4), 319-342

Mokhtarian, P. L. and Varma, K. V. (1998) The trade-off between trips and distance traveled in analyzing the emission impacts of center-based telecommuting *Transportation Research Part D*, 3**,** 419-428

Mokhtarian, P. L. (1998) A synthetic approach to estimating the impacts of telecommuting on travel *Urban Studies*, 35**,** 215

Mokhtarian, P. L., Handy, S. L. and Salomon, I. (1995) Methodological issues in the estimation of the travel, energy, and air quality impacts of tekecommuting *Transportation Research Part A,* 29A**,** 283-302

Mokhtarian, P. L., Ho, C. I., and Hung, S. (1997) Residential Area-based Office Project: Final report on evaluation of impacts. Prepared for Federal Highway Administration and the California Department of Transportation Office of Traffic Improvement. *Research Report* UCD-ITS-RR-97-xx, Institute of Transportation Studies, University of California, California

New South Wales Government (2006) *Employment report* Department of State and Regional Development Sydney

Nilles J. M., Carlson F. R. Jr., Gray P. and Hanneman G. J. (1974) Development of Policy on the Telecommunications-Transportation Tradeoff *Report NSF-RA-5-74-020* California: University of Southern California and the National Science Foundation, California

Nilles J. M. (1975) Telecommunications and organizational decentralization. *IEEE Transactions on Communications*, 10, 1142-l 147

Nilles, J. M. (1988) Traffic reduction by telecommuting: A status review and selected bibliography. *Transportation Research*, 22A, 301-317

Ortuzar, J. d. D. and Willumsen, L. G. (1994) *Modelling Transport* (2nd ed) New York: John Wiley & Son

Road and Traffic Authority NSW (1995) *Report of travel impacts:* RTA Teleworking Pilot Project. Network Development Branch, Surry Hills, New South Wales: RTA

Road and Traffic Authority NSW (2000) *Summary Report*: RTA West Gosford Telecenter Project. Network Development Branch, Surry Hills, New South Wales: RTA

Salomon, I. (1985) Telecommunications and travel: substitution or modified mobility?, *Jounal of Transport Economics and Policy*, 19(3), 219-235

Sensis (2005) Teleworking *Sensis Insights Report* Melbourne: Telstra Corporation Limited
http://www.dcita.gov.au/__data/assets/pdf_file/31984/Sensis_Insights_Teleworking_Report_June_2005.pdf

Shafizadeh, K. R., Mokhtarian, P. L., Niemeier, D. A. and Salomon, I. (2000) The Costs and Benefit of Home-Based Telecommuting, *California PATH Research Report* UCB-ITS-PRR-2000-20 ISSN 1055-1425 California PATH Program, Institute of Transportation Studies, University of California, Berkeley

Transport and Population Data Centre (2005) 2003 Household Travel Survey *summary Report* ISBN 0 7313 2833 7 NSW Department of Planning Sydney*:* TPDC

Urban Transport Fact Book (2001) *Australia Metropolitan Areas Work Trip Market Share*: UTFB
http://www.publicpurpose.com/ut-ausjtw.htm

Vidal, S. (2004), Australia Telecommuting Services and Equipment 2004-2008 Forecast & Analysis: IDC Australia
http://www.idc.com.au/solutionscentre/telco/press_detail.asp?releaseid=130