Contemporary Engineering Sciences, Vol. 9, 2016, no. 30, 1491 - 1501
HIKARI Ltd, www.m-hikari.com
https://doi.org/10.12988/ces.2016.68147

Airport Ground Access and Urban Congestion: A Paradox of Bi-Modal Networks

Luca Mantecchini

DICAM, School of Engineering and Architecture, University of Bologna
viale del Risorgimento 2, 40136 Bologna - Italy

Filippo Paganelli

DICAM, School of Engineering and Architecture, University of Bologna
viale del Risorgimento 2, 40136 Bologna - Italy

Abstract

Public transport systems with separated way, such as automated people movers or mass transit systems, play a fundamental role as far as airport ground access is concerned, due to high potential capacity and reliability of service time. It is widely recognized that those transport systems, introduced in cities already congested by car traffic, are able to attract only a little share of the urban transport demand due to the fact that they can take competitive advantage and tangible effects on urban mobility only under high congestion levels on the road network. These conditions are proper of congested urban networks, in particular when airports are located close to urban areas so as passengers can travel from/to airports using either the urban road network or the transit systems. This paper shows that, as far as regional and urban airports are concerned, when a new transit system with exclusive rights of way is introduced to enhance airport ground accessibility, a substantial modification of the road network is necessary both in terms of infrastructure and signal policies, to reduce the capacity of the streets in the parts of the town served by transit system in order to establish an efficient bimodal transport system.

Keywords: airport ground access; public transit systems; capacity

1 Introduction

In the last two decades, mainly due to the development of low-cost carriers (LCCs), regional and secondary airports experienced a rapid growth of transportation demand. This led to increasing airport ground access related issues, in particular congestion and its related impacts (Francis et al., 2004; de Neufville, 2006, Reynolds-Feighan, 2006, Budd et al., 2011). The main characteristics of LCCs have strongly changed structure, procedures, and business models of different stakeholders in both the supply (airport-airlines) and the demand point of view. As Kouwenhoven (2008) points out, in North-Western European countries growth rates are creeping up especially at smaller airports as a result of low-cost airlines' policies to strengthen their business at those airports. In addition, airports are increasingly developing commercial and recreational activities, attracting even more customers. The accessibility itself is furthermore an important issue from a planning and political point of view. Most regional airports are located close to cities or metropolitan areas. As a result, urban road networks have been experiencing dramatic traffic growth: congestion and other related impacts, as well as accessibility and airport positioning, have become a relevant issue in the highly competitive air transport market (Postorino and Mantecchini, 2014, 2016; Mantecchini, 2015). Improving accessibility at airports (by enhancing current infrastructures or by introducing new access modes such as light rail transit or automated people mover connections) could be an option for policy makers and airport operators. Cervero (1997) pointed out the paradigm shift from "auto-mobility planning" to "accessibility planning" as an appropriate strategy to increase accessibility and to decrease the negative impacts of transportation on the environment (Yigitcanlar et al., 2007). Many definition of the topic "congestion" are present in scientific literature: from the point of view of transportation engineering, congestion is defined as any measure of the surplus of car travel time with respect to free flow conditions. Thus, we may define the congestion level of a road link, or of an urban road network, as the ratio between the average time spent to travel under given traffic conditions and the average time to travel in free flow conditions. According to a different, widely adopted vision, congestion could be defined as the ratio between the actual traffic flow on a road link and the capacity of the same link. In addition, the term "congestion" is frequently used to indicate the traffic conditions that generate negative externalities: consumption of urban space, safety reduction, noise and pollution emissions.

During the last decades many Public Administrations in both EU and the US have improved public transport systems as effective way to reduce the negative effects of vehicular congestion in urban areas. However many authors (e.g. Bouf and Hensher, 2007; Taylor, 2004), on the basis of theoretical considerations and experimental data, have observed, that rail transit has in general limited effects on traffic congestion and attracts only a small share of urban transport demand. Foote et al. (2007), following an analysis of airport passengers' access mode at Chicago airport, highlight that cost, time and closeness are the most important factors affecting actual rail users, while remoteness is cited as the most important deterrent.

Hence, mass rapid transit systems would increase their market share in airport ground access only if a convenient access to trip origins and destinations is provided. Tam et al. (2011) studied the effects of travel time reliability on air passengers' ground access mode choice, finding that the improvement of travel time reliability is crucial in order to increase the transit systems' market share.

The difficulties of rail system to efficiently reduce road congestion, also in airport ground access issues, can be explained by considering that the point-to-point travel time on a transit system (considering both waiting time and running time) is in general greater than the time needed by car under free flow conditions. Then, in order to make the transport cost by car closer to the cost needed by transit system, so that the latter can attract larger shares of passenger demand, paradoxically a high level of congestion on the road network is necessary, as a reduced difference of the generalized transport costs (disutility) associated to the two access modes would induce a shift from cars to public transit system. Nevertheless, since the marginal road transport cost in congestion conditions is usually high, even a little reduction in car traffic flow rate is sufficient to determine a substantial reduction of its corresponding generalized transport cost, thus harming future passenger modal shifts.

Even if a new mass transit system has limited effect in reducing road networks' congestion, it can nevertheless noticeably reduce environmental impacts due to road traffic. Following this assumption, it is necessary that the point-to-point airport access costs by car and by transit system remain almost the same even following a demand shift from the former to the latter system. As a direct consequence of the cost function associated to car users, the cost decreases sharply when the traffic decreases; it is then necessary to artificially increase the transport cost for road transport. This – apparently paradoxical – result could be reached by imposing an additional monetary cost, i.e. a road surcharge or congestion fee, to car users. Although, this measure would be ineffective, as it was previously discussed, because it would keep the congestion level low and would generate an undesired increase in the number of car trips by users with high willingness to spend. Otherwise, the capacity of the alternative road routes has to be "driven" towards reduction when the transit system is introduced, thus enhancing the "natural" diversion of users from cars to transit system with an "artificial" limitation of the inverse phenomenon (congestion reduction and rebalancing of car users), which results in a reduction of the externalities associated with road traffic and in making the airport ground access system more environmental friendly. As a prerequisite, the transit system ought to provide enough capacity and good level of service.

The use of induced congestion as a strategy to control the urban transport network in presence of high flow rates due to relevant attractive points (as airports), makes it possible to keep almost constant the airport access cost by car after the introduction of a new public transit system. Under a practical point of view, the reduction in the capacity of an urban road network can be realized by various means, depending on the characteristics of the network: by reducing the road section in some selected links; by setting traffic signals imposing additional waiting time to selected flows; by modifying the itinerary through the introduction/ modification of one-ways.

From these considerations, we deduce that the introduction of a transit system to connect an airport to the city center in an urban area gives rise to important changes in the transport system, which requires a modification of the road network both in terms of infrastructure and regulation. The new urban transport system so generated (modified road network + transit system) can not only decrease substantially the environmental damages due to traffic to/from an airport, but it can also reduce the generalized transport costs when the congestion is high.

In the followings a theoretical model of bimodal urban transport system serving an airport is presented, with the aim of evaluating the effects on the generalized transport access costs and on the environmental impacts caused by a network modification (both in terms of infrastructure and traffic regulation) consequent to the introduction of a new airport-city transit system.

2 A model of bimodal airport ground access system

Consider a pair of nodes, *O* is the city centre and *A* is the airport, connected by two modes of transport: a private car system, travelling on a road network, and a transit system on its own infrastructure. Let *d* be the hourly passenger demand from *O* to *A*, obtained by airport flight timetable. A passenger, considered as a “rational” and informed user, chooses the alternative “car” to travel from *O* to *A* only if the generalized travel cost C^c by car is less than the generalized travel cost C^p by public transit system, and the opposite if $C^c > C^p$. Let:

- f^c, f^p = passenger hourly flows, by car and by transit respectively, from *O* to *A*, where $f^c + f^p = d$. We suppose that only a passenger (driver or accompanied) occupies a car.
- *l* = length of the route from *O* to *A*, considered equal for both the transport systems.
- t_f = unitary travel time on the road system in free-flow conditions.
- *VOT* = Value of Time spent travelling.
- *K* = capacity of the road network from *O* to *A*, considered as the maximum hourly flow rate that is realized in correspondence of an unitary travel time equal to $2t_f$.
- t^c = off-board time for a car user, mainly due to the time wasted searching for the airport terminal parking.
- t^p = off-board time spent by a transit system user, mainly due to both the path between the origin and the transit system stop/station and the transit system stop to the airport.

CC = unitary transport cost by car.

- v^p = commercial speed of the transit system.
- $w = 1/(2f)$ = average waiting time at a transit stop/station, in the hypothesis that transit vehicles follow a regular process (typical for rail system or for transport

systems with separate track), while passengers follow a randomly distributed arrival path (usually a Poisson process), where *f* is the scheduled frequency of the transit system.
- *FP* = the fare of the transit system from *O* to *A*.

Many types of volume-delay function have been proposed and applied in literature, by far the most used is the BPR function (BPR, 1964), defined as:

$$t = t_f \left[1 + (f^c / K)^{\beta}\right] \tag{1}$$

where β is a scale parameter depending on geometry and infrastructure characteristics of the road. Following the previous definitions, we can obtain the expressions of generalized travel costs C^c and C^p:

$$C^c = VOT \cdot t_f \cdot l \left[1 + (f^c / K)^{\beta}\right] + VOT \cdot t^c + CC \cdot l \tag{2}$$

$$C^p = VOT \left[\frac{l}{v^p} 60 + t^p + \frac{60}{2f}\right] + FB \tag{3}$$

The cost C^c is an increasing function of f^c (in other words, it increases with congestion). A users moving towards the airport chooses to travel by car if and only if $C^c < C^p$. If all users perceive the cost in the same way (*deterministic hypothesis*) no user chooses transit system if:

$$VOT \cdot t_f \cdot l \left[1 + (f^c / K)^{\beta}\right] + VOT \cdot t^c + CC \cdot l < C^p \tag{4}$$

Or, at the same time, until $d < \bar{f}^c$, where:

$$\bar{f}^c = K \left[\frac{C^p - VOT(t_f \cdot l + t^c) - CC \cdot l}{VOT \cdot t_f \cdot l}\right]^{1/\beta} \tag{5}$$

When $d > \bar{f}^c$, according to the deterministic hypothesis, the users travelling by car will be as much as $\bar{f}^c$, while transit system users will be $f^p = d - \bar{f}^c$.
Under the hypothesis of random probabilistic distribution of the perceived cost among the travellers, being C^c and C^p the average values, it is possible that a traveller chooses the public transit system even when $C^c < C^p$, in particular when the dispersion is high. If the travel costs of both the two transport modes are distributed according to the Weibull-Gumbel probabilistic law, with the same multiplicative parameter α, whose average values are given by (2) and (3), we obtain that the flow f^c is given by:

$$f^c = \frac{d}{1 + \exp \alpha \left[VOT \cdot t_f \cdot l (1 + (f^c / K)^{\beta}) + VOT \cdot t^c + CC \cdot l - C^p\right]} \tag{6}$$

We see from Eq (6) that, to obtain that $f^p = d - f^c$ is a remarkable part of the total demand *d*, the average generalized cost C^c by car has to be not too less than C^p. In particular, the demand d is equally distributed between the two transport modes, when $C^c = C^p$ and $f = \bar{f}^c$.

As an example, fig. 1 describes the relationship of flow f^c as a function of demand *d*, in both the deterministic and Weibull-Gumbel probabilistic distribution hypothesis, on varying values of the parameter α.

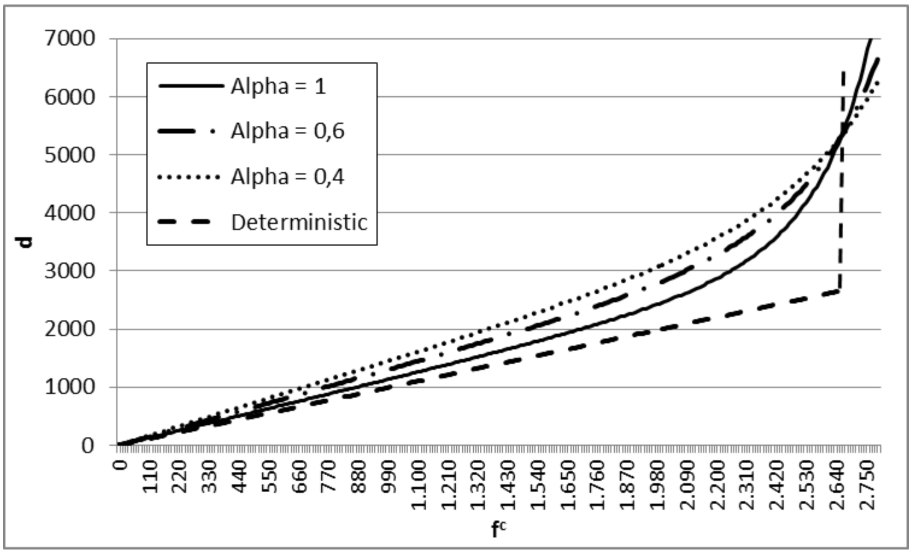

Fig. 1. Relationship among flow f^c and demand *d*

The relation between f^c and *d* under the deterministic hypothesis is represented by the dashed line: as far as $d < \bar{f}^c$ the diagram follows the bisector of the plane (f^c, d) and then it is a constant value. Under the probabilistic case the relations between f^c and *d* is represented by a curve located above the dashed line, with intersection in correspondence of $d^* = 2\bar{f}^c$. Demand *d** makes the generalized transport cost equal for both the alternatives and hence the demand splits into equal parts in both the deterministic and probabilistic cases, whatever is the value of α. The horizontal distances between the broken line and the curves represent the number of users travelling by transit system. It is relevant to notice that, as far as $d < \bar{f}^c$, f^p is small even in the case that the perception of the trip cost is highly dispersed in the travellers' population. In order that f^p represents a substantial proportion of the travel demand *d*, the latter should have a value $\bar{d}$ remarkably greater than $\bar{f}^c$.

3 Application

If an efficient public transit system on its infrastructure is realized to serve an urban airport, already served by a road network with a demand *d*, the condition $d = \bar{d}$ is very difficult to be attained, because it would generate unacceptable transport costs for passengers travelling to the airport by car. This confirms that even an efficient, well designed and punctual public transit system would attract only a little share of total demand in almost every condition.

As it was previously introduced, things might change if we modify the cost function in the road network in such a way that the new cost function returns trip cost by road transport equal to the cost of public transit system to allow the shift of a relevant share of transport demand from the road system. That could be obtained in two ways: a) by imposing an additional monetary cost to car users (market-based strategy); b) by reducing the capacity of some road links or nodes of the network (infrastructural or control strategy).

In the first step we suppose that the municipality realizes a public transit system and applies a policy aimed at reducing the car flow on the existing network to a value $\bar{f}^c$ as such as $\bar{f}^c = \xi d$. Under the hypothesis of probabilistic distribution and a road pricing scheme represented by a surcharge θ imposed to car users, we have:

$$\bar{f}^c = \frac{d}{1+\exp\alpha\left[VOT \cdot t_f \cdot l(1+(\bar{f}^c/K)^\beta) + VOT \cdot t^c + CC \cdot l + \theta - C^p\right]} \tag{7}$$

and we derive θ as a function of *d* and $\bar{f}^c$:

$$\theta = \frac{1}{\alpha}\ln\frac{d-\bar{f}^c}{\bar{f}^c} + C^p - VOT \cdot t_f \cdot l\left[1+(\bar{f}^c/K)^\beta\right] - VOT \cdot t^c - CC \cdot l \tag{8}$$

A second scenario is introduced, opting for a reduction in road capacity rather than the road pricing scheme; under this assumption, the new value $\overline{K}$ of the road network capacity will be again derived from equation (7):

$$\overline{K} = \bar{f}^c\left[\frac{VOT \cdot t_f \cdot l}{\frac{1}{\alpha}\ln\frac{d-\bar{f}^c}{\bar{f}^c} - VOT \cdot t_f \cdot l - VOT \cdot t^c - CC \cdot l + C^p}\right]^{1/\beta} \tag{9}$$

To make things clearer by an example, we suppose the existence of a road transport system between the two nodes *O* and *A* and a demand from *O* to *A* equal to *d* = 1800 users/hour; each car is occupied by only one passenger. The municipality opts for building a transit system from *O* to *A*, so that the demand splits in equal parts between the two alternatives. By supposing that the parameters of the cost functions of the two alternatives are those considered in fig. 1, we obtain from equations (8) and (9) θ = 1.92 € and $\overline{K}$ = 1170 vehicles per hour, with α =1.

Soon after the reduction of road demand has been attained, we suppose that the demand *d* begins to increase for any reason (i.e. improvement of airport connectivity, or growth of air transport demand). Fig. 2 shows the relationships between f^c and *d*, derived from equation (7), both in the cases of road price scheme (surcharge θ = 1.92 €) and the road capacity reduction to $\overline{K}$ = 1170 cars per hour, assuming a Weibull distribution of costs perceived by users, with parameter α = 1. It can be observed that the effects of the two approaches are very different with growing the demand *d*. Where the additional monetary cost imposition cannot prevent a substantial increase in car flow, the capacity reduction permits a strict control of f^c growth.

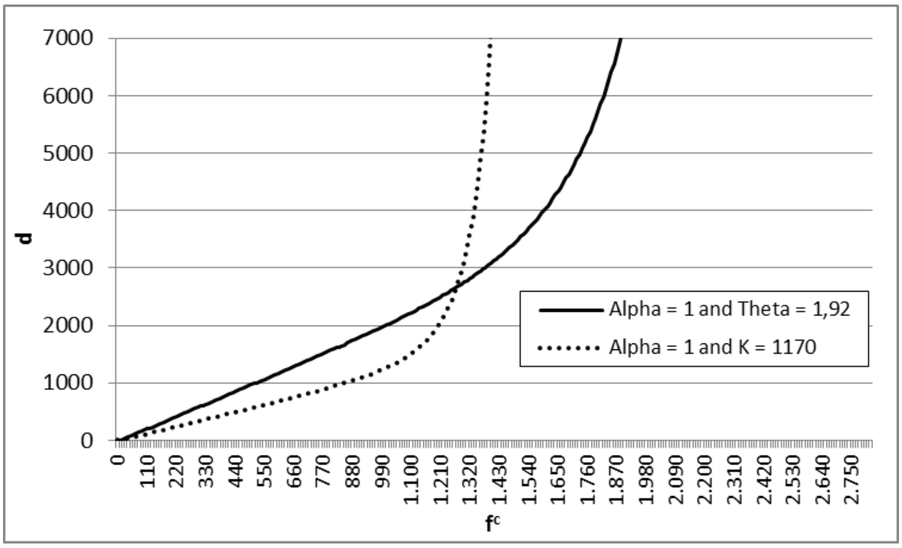

Fig. 2. Relationship among flow f^c and demand *d* for both road pricing or capacity reduction scheme.

Both the alternative policies aim at increasing the trip cost for road users with respect to the value corresponding to $\bar{f}^c$ = 900 users per hour and the original capacity of road transport system, *K*. The solution of imposing a surcharge keeping the capacity unchanged returns a small $(f^c/K)^\beta$ value. Thus the exponential value within the denominator of equation (6) is almost constant and f^c increases with *d* following a linear law. Instead, if the road capacity is dropped from *K* to $\overline{K}$, the value $(f^c/\overline{K})^\beta$ corresponding to f^c = 900 users per hour is large and highly dependent from f^c; thus, the value of f^c, solution of Eq (6), is kept around 900 users per hour even for large increases of total airport demand *d*.

4 Conclusions

This paper gives a contribution to explain the substantial inability of rail transit systems to reduce congestion on road network, in the specific case of airport passenger ground access. In particular, this is essentially due to the fact that the point-to-point generalized cost on a public transit system, even in the case of system with separate infrastructure, is in general higher than the point-to-point generalized cost by car, on the existing road network, under free flow conditions (or in low saturation conditions). Thus, in order to make the perceived generalized transport costs of both transport systems closer, so that the public transit system could attract a remarkable proportion of transport demand, we need a high level of congestion on road network. If a competing public transit system is introduced on the same origin-destination market, so that the generalized transport costs of the two systems are similar, a small proportion of users begins to shift from road system to transit system. But, since the first derivative of road cost function evaluated at high congestion level is high, this little reduction in vehicular traffic catalyses such a reduction in generalized transport cost on road network as to discourage further shifts of demand towards public transport. The paradoxical conclusion is that the public transit system is able to attract only a negligible part of the airport demand, and has only little effects on road congestion, unless it is combined with an illogical but feasible reduction of road network capacity (both in terms of infrastructure and traffic control systems).

References

[1] D. Bouf and D.A. Hensher, The dark side of making transit irresistible: The example of France, *Transport Policy*, **14** (2007), no. 6, 523-532. https://doi.org/10.1016/j.tranpol.2007.09.002

[2] T. Budd, S. Ison and T. Ryley, Airport surface access management: issues and policies, *Journal of Airport Management*, **6** (2011), 80-97.

[3] Bureau of Public Roads, Traffic Assignment Manual, U.S. Dept. of Commerce, Urban Planning Division, Washington D.C. (1964).

[4] R. Cervero and P. Kockelman, Travel demand and the 3Ds: density, diversity and design, *Transportation Research Part D*, **2** (1997), no. 3, 119-219. https://doi.org/10.1016/s1361-9209(97)00009-6

[5] R. de Neufville, Planning airport access in an era of low-cost airlines, *Journal of the American Planning Association*, **72** (2006), 347-356. https://doi.org/10.1080/01944360608976756

[6] R. de Neufville and A. Odoni, *Airport Systems: Planning, Design and Management*, McGraw Hill, New York, 2003.

[7] P.J. Foote, S.J. LaBelle and D.G. Stuart, Increasing rail transit access to airports in Chicago, *Transportation Research Record: Journal of the Transportation Research Board*, **1600** (1997), 1-9. https://doi.org/10.3141/1600-01

[8] G. Francis, I. Humphreys and S. Ison, Airports' perspectives on the growth of low cost airlines and the remodeling of the airport-airline relationship, *Tourism Management*, **25** (2004), no. 4, 507-514. https://doi.org/10.1016/s0261-5177(03)00121-3

[9] I. Humphreys and S. Ison, Planning for Sustainability: The Role of Airport Surface Access Strategies as a means of reducing the dependency on the private car for airport access trips?, Association for European Transport, 2002.

[10] I. Humphreys and F. Graham, Performance measurement: a review of airports, *International Journal of Transportation Management*, **1** (2002), no. 2, 79-85. https://doi.org/10.1016/s1471-4051(02)00003-4

[11] I. Humphreys and S. Ison, Ground access strategies: lessons from UK airports', TRB 2003 Annual Meeting.

[12] M. Kouwenhoven, *The Role of Accessibility in Passengers' Choice of Airports*, Discussion paper no. 14, Joint Transport Research Center, 2008. https://doi.org/10.1787/235278552305

[13] T. Litman, Social inclusion as a transport planning issue in Canada, Victoria, Victoria Transport Policy Institute, 2003.

[14] L. Mantecchini, Optimization of airport parking facilities size, location and connection, *ARPN Journal of Engineering and Applied Sciences,* **10** (2015), no. 2, 753-758.

[15] E. Pels, P. Nijkamp and P. Rietveld, Access to and competition between airports: a case study for the San Francisco Bay area, *Transportation Research Part A*, **37** (2003), no. 1, 71-83. https://doi.org/10.1016/s0965-8564(02)00007-1

[16] M.N. Postorino and L. Mantecchini, A transport carbon footprint methodology to assess airport carbon emissions, *Journal of Air Transport Management*, **37** (2014), 76-86. https://doi.org/10.1016/j.jairtraman.2014.03.001

[17] M.N. Postorino and L. Mantecchini, A systematic approach to assess the effectiveness of airport noise mitigation strategies, *Journal of Air Transport Management*, **50** (2016), 71-82. https://doi.org/10.1016/j.jairtraman.2015.10.004

[18] A. Reynolds-Feighan and P. McLay, Accessibility and attractiveness of European airports: a simple small community perspective, *Journal of Air Transport Management*, **12** (2006), 313-323. https://doi.org/10.1016/j.jairtraman.2006.07.009

[19] M.L. Tam, W.H.K. Lam and H.P. Lo, The impact of travel time reliability and perceived service quality on airport ground access mode choice, *Journal of Choice Modeling*, **4** (2011), 49-69. https://doi.org/10.1016/s1755-5345(13)70057-5

[20] B.D. Taylor, The politics of congestion mitigation, *Transport Policy*, **11** (2004), no. 3, 299-302. https://doi.org/10.1016/j.tranpol.2004.04.001

[21] S. Wixey, P. Jones, K. Lucas and M. Aldridge, Measuring accessibility as experienced by different socially disadvantaged groups, London, Transit Studies Group, University of Westminster, 2005.

[22] T. Yigitcanlar, N. Sipe, R. Evans and M. Pitot, A GIS-based land use and public transport accessibility indexing model, *Australian Planner*, **44** (2007), no. 3, 30-37. https://doi.org/10.1080/07293682.2007.9982586

Received: September 8, 2016; Published: October 18, 2016