ADVANCING THE CONCEPT OF CAR-BUS INTERMODALITY IN THE UK

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Abstract

The UK offers 40 years of experience with a model of car-bus intermodality that has become a popular policy option. This concept, with interchange sites located close to their host cities and served by dedicated buses, has changed very little despite concerns that it may have a detrimental effect on car use. The aim of this paper is to consider the impact of current interchange schemes and propose a number of alternative concepts for car-bus interchange, primarily by adjusting interchange site location and bus operation. The impacts of such concepts on car use are then modelled. The results suggest that while current intermodality generally increases car use, considerable relative benefits can be derived from the alternatives.

1 INTRODUCTION

Car-bus intermodality, or Park and Ride (P&R), has been used internationally as a means of reducing car use and its negative externalities such as traffic congestion and air pollution. It was first used in the UK around 40 years ago by small historic cities but it has subsequently grown in popularity and there are over 100 interchange sites currently operating (*1*).

Despite a popular policy goal being to reduce car use, there is a growing body of academic evidence which suggests that P&R in some cases increases the vehicle kilometres travelled (VKT) of its users. This body of evidence has developed from surveys of users in the relative infancy of UK P&R (e.g. *2*, *3*) indicating that some users were those transferring (abstracted) from conventional public transport or not making trips at all, with the intermodality thus inducing modal shift to the car for the access portion of the trip. More recently, the debate has grown into one specifically considering the VKT of users. The UK government for instance commissioned a study into the travel impacts of interchange (*4*), the results of which suggested it having a positive effect. Upon a re-evaluation of the data published in the study however, Parkhurst (*6*) indicated that there were limitations, including the exclusion of abstracted users and the VKT of the dedicated buses serving interchange sites. Parkhurst thus found, after including bus mileage, that there was a VKT increase in three out of the eight case study cities. His finding nevertheless, due to a lack of available data, still did not account for the VKT of generated and abstracted trips (see *7* for a comprehensive discussion of the evidence).

Even with the effectiveness of UK P&R cast into doubt, its popularity remains widespread, with both the motorist and the policymaker. Yet little has been proposed as a way forward for car-bus interchange in the UK, capitalising upon its popularity but operating it as a more efficient means to reduce car use. The aims of this paper are to first, add to the body of evidence on the travel effects of car-bus interchange by considering the VKT implications of the sites currently operating in the UK. Second, the paper will look towards the future and propose a numbers of ways in which the interchange concept can be developed to improve its role in reducing car use.

As such, the following section looks at how P&R is currently used in the UK, hereafter termed the Current Concept, drawing on a database of the interchange sites currently in use. The various ways in which the Concept can be advanced upon is then discussed, primarily by adjusting the location of interchange sites and the way in which bus services operate. Section 3 then goes on to outline the formulation of the model used to evaluate the VKT impacts of the concepts and its results for both the Current and alternative concepts. The findings are then discussed and conclusions offered.

2 CONCEPTS OF CAR-BUS INTERMODALITY

This section discusses the Current Concept of intermodality and then some of the ways on which it can be advanced upon. Specifically, the Demand-led Concept is based on the reduced frequency of the dedicated bus services use for interchange, while the Integrated Concept looks at how conventional bus services can be used to serve interchange sites. The Hub-and-Spoke Concept proposes the use of small, feeder services for the interchange site to both reduce public transport abstraction and stimulate its overall use, while the Remote Site Concept extends the portion of the interchange trip made by public transport. These concepts have been determined largely as a result of considering the shortcomings in the design of existing schemes, although some have been developed from schemes used in the UK and internationally, in which case the examples are provided. Although the final, Link and Ride Concept, is based on the work of Parkhurst (*8*), which uses a series of small interchange sites with conventional bus services linking to the host town centre.

2.1 The Current Concept

P&R was first used in the UK in the historic city of Oxford in the 1960s. Since then, P&R has grown in popularity and it is a policy that has diffused across the UK. The concept has however, remained relatively similar to its first uses. To explore the Current Concept in detail, the TAS Partnership (*1*) inventory of sites was used, which provided details of all the UK sites that existed at the end of 2006, including: the year in which they were established, the facilities on-site, details of the bus service used, the cost of P&R use to the user and the cost of the town-centre parking alternative.

Although there is a common model of P&R that has emerged in the UK, the Current Concept, there were five schemes in the database that had deviated from this and were examples of the Remote Site and Integrated Model, discussed below. There were then, 53 Current Concept schemes (towns in which interchange is used) which consisted of 113 individual sites. There were two schemes which operated only shared-use sites while 5 others operated a combination of both dedicated and shared-use sites. Although such sites may avoid some of the disbenefits of the construction of dedicated sites, there is little difference in terms of their effects on car use as they share all other characteristics with dedicated sites. For the current analysis then, these sites were treated as Current Concept sites.

Sites are generally well equipped with passenger facilities. CCTV was provided by 91%, 77% had on-site staff, 67% provided a passenger waiting area, and 58% provided toilet facilities. The size of P&R site ranged from 58 spaces at Perth's Angus Road site, although this was an outlying value as the second smallest site at Windsor had 148 spaces and capacity rose gradually across all sites with Bristol's Long Ashton site being the largest single site at 1500 spaces. The mean capacity of sites was 599 spaces.

The main causes of inefficiency associated with the Current Concept are public transport abstraction, trip generation, the operation of high-frequency dedicated buses and the edge-of-town location of P&R sites (*6*). Abstraction encourages additional VKT from modal shift towards the car for the access trip. The generation of new trips by P&R similarly encourages car use for access trips but has more impact in terms of VKT because of the creation, rather than the replacement, of trips. The fundamental reason behind both the abstraction and generation of trips is the lowering of the generalised cost of travel by P&R which is made possible as schemes are often supported by subsidy. Regular bus services on the other hand, are generally operated commercially. Evidence on the alternative travel behaviour of P&R users (TABLE 1) shows how the scale of abstraction and generation is indeed significant.

TABLE 1 Evidence on the alternative behaviour of interchange users

Source	Centre (Site)	n	Alternative Behaviour (% of users)			Travel Elsewhere (%)	Not Travel (%)
			Public Transport	Car	Green Mode		
Weekday							
WS Atkins (*4*)	Brighton	220	41	26	0	9	19
Bristol City Council (*11*)[1]	Bristol (Bath Road)	674	42	55	0	1	2
EHTF (*10*)	Bristol (Long Ashton)	651	22	71	-	2	3
WS Atkins (*4*)	Cambridge	204	24	39	8	5	8
WS Atkins (*4*)	Coventry	208	21	50	2	9	11
WS Atkins (*4*)	Norwich	204	29	53	0	5	7
Parkhurst and Stokes (*5*)	Oxford	741	31	57	2	-	-
White (*3*)*	Oxford	208	30	57	-	-	-
WS Atkins (*4*)	Plymouth	208	32	47	1	3	8
WS Atkins (*4*)	Reading	220	31	43	0	6	12
WS Atkins (*4*)	Shrewsbury	205	18	53	0	3	10
Cooper (*13*)*	York	154	35	59	-	-	-
Parkhurst and Stokes (*5*)	York	288	26	56	4	-	-
WS Atkins (*4*)	York	221	26	57	4	1	6
		Mean %	**29.14**	**51.64**	**1.91**	**4.40**	**8.60**
Saturday							
Bristol City Council (*11*)[1]	Bristol (Bath Road)	902	18	70	0	4	8
EHTF (*10*)	Bristol (Long Ashton)	1211	14	80	-	2	3
Parkhurst and Stokes (*5*)	Oxford	1000	20	57	1	-	-
White (*3*)*	Oxford	207	22	68	-	-	-
Parkhurst and Stokes (*5*)	York	310	9	68	2	-	-
		Mean %	**16.60**	**68.60**	**1.00**	**3.00**	**5.50**

* Reported by Parkhurst (*9*)

[1] Alternative behaviour is reported for parties of users not individuals

Source: Parkhurst (9) with additional data from EHTF (10) and WSA (4).

High-frequency dedicated P&R buses further reduces the potential efficiency of the Current Concept by excluding the non-motorist from services, either by not serving suitable routes or not operating inter-carrier or inter-route ticketing. None of the Current Concept sites are served by regular bus services, defined for this analysis as services with more than one bus stop upstream of the site. There are some cases where stops are made downstream of P&R sites, prior to reaching the town centre, but these are mostly egress points for P&R users, for instance at major employment or retail centres. Furthermore, high-frequency operation results in low average load-factors and thus the VKT savings for the motorist from P&R, in car-equivalent terms, are either partially or entirely offset (*6*). Indeed, the mean peak frequency of all Current Concept sites was 10.7 minutes with little variation ($\sigma = 3.1$). Mean inter-peak frequency was similar at 12.1 minutes ($\sigma = 3.6$).

Current Concept P&R sites are generally located at the edge of the host town. FIGURE 1 for example provides a representation of the Current Concept, similar in form to that constructed by Parkhurst (*8*). Although this is not to scale or based on any town in particular, it shows the typical geography of many P&R-hosting towns, with the urban area encircled by a ring road, linked to satellite settlements with radial routes. The interchange site attracts users from the hinterland and the traffic flow for P&R access increases further downstream towards the site. Thus, a relatively large car trip has to be made prior to transferring to P&R, where potential VKT savings can be made.

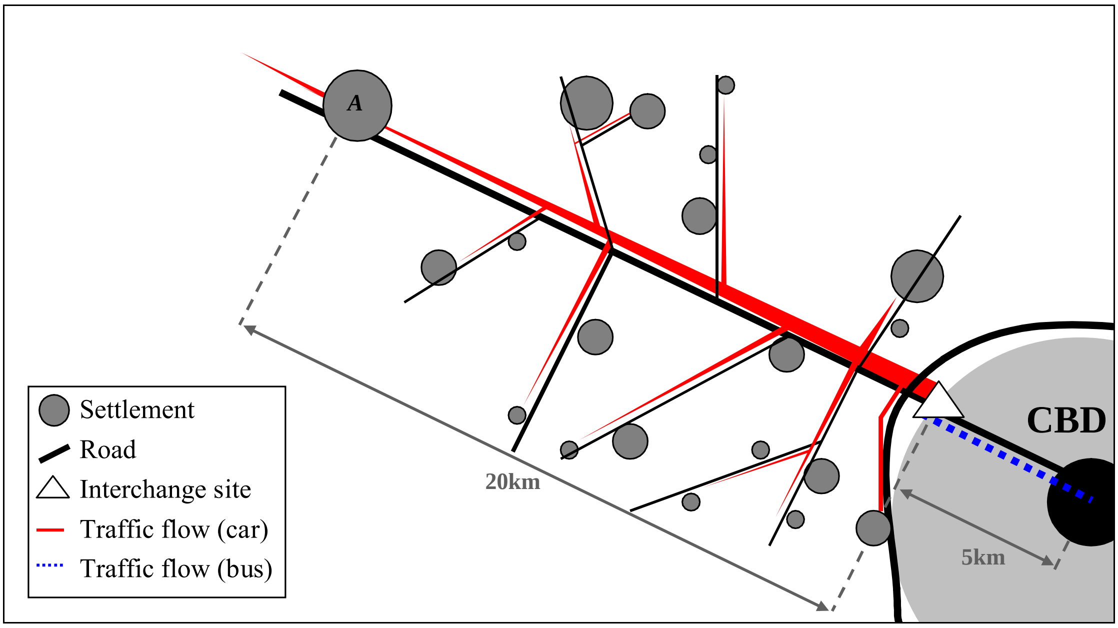

FIGURE 1 The geography and traffic flow implications of the Current Concept of P&R

This is an argument reinforced well by the national situation. The postcode (zip code) for each Current Concept site was added to the site database, using details from schemes' web pages and the Royal Mail postcode finding service (*14*). The shortest distance by road between each site and the town centre that is serves was then found (*15*). The mean distance between P&R sites and their host centres was 4.6km ($\sigma = 2.2$) and 79% were located 2-8km away.

The close proximity of sites to their host centres infers a relatively long distance between users' origins and the P&R site. There is a dearth of such data although some exists, albeit rather dated, for the Oxford, York (*5*) and Bristol (*11*) schemes. In Oxford and York, the mean distance travelled to P&R sites was 20.2km and 13.2km respectively. These values however, are straight-line distances so road distances will be higher. P&R sites in Oxford were located at a mean distance of 5.5km from the city centre and in York was 5.3km away. In Bristol, the site was 5.5km from the centre, while mean access journeys were 11.4km on Bristol City Council's (*11*) Thursday survey and 13.1km on Saturday.

So the UK situation thus suggests that the Current Concept of P&R is, by design, potentially inefficient in its role to reduce the VKT of its users. The following sections of this paper therefore explore ways in which the car-bus interchange concept can be developed as a way to improve this.

2.2 The Demand-led Concept

An inherent characteristic within the Current Concept is the use of high-frequency buses and this is a significant contributor to its inefficiency. High-frequency bus services, as outlined above, leads to a situation whereby bus capacity far outweighs the parking capacity provided by interchange sites. The demand for P&R is not however consistent and it does experience a significant degree of peaking. This is particularly so on weekdays, where P&R attracts mainly commuter traffic.

For example a particularly informative survey of Bristol's Bath Road P&R site (*11*), revealed that 73% of Thursday users were commuters or made work-related trips, whilst 18% used P&R for shopping trips. Of the Saturday users however, 78% were shoppers whilst 10% made commuting or work-related trips. This split of journey purpose is reflected by the load factors of buses serving the site. The report suggested two definite peaks in Thursday load factors in the morning and late-afternoon periods. Yet during the inter-peak periods, load factors were very low. Saturday load factors were more consistent throughout the day although demand diminished at the end of the day for inbound trips and was very low at the start of the day for return trips.

This supply-driven approach to the bus service is clearly seen by P&R providers as important to the user in terms of convenience and minimising the transfer time penalty. The implications of such low utilisation of bus services however, is excessive bus VKT. One way to address this problem is to take a more demand-led approach to P&R bus services. In particular, bus frequency could be reduced in the inter-peak period where low numbers of users arrive, thus increasing load factors. FIGURE 2 for instance shows how a variable frequency can be more demand responsive, using the passenger arrival data from Bristol City Council (*11*). Frequency remains at ten minutes in peak periods but inter-peak services are much lower in frequency and load factors are increased. The total number of daily services is reduced from 66 with a mean load factor of 14, to 45 services with a mean load factor of 22.

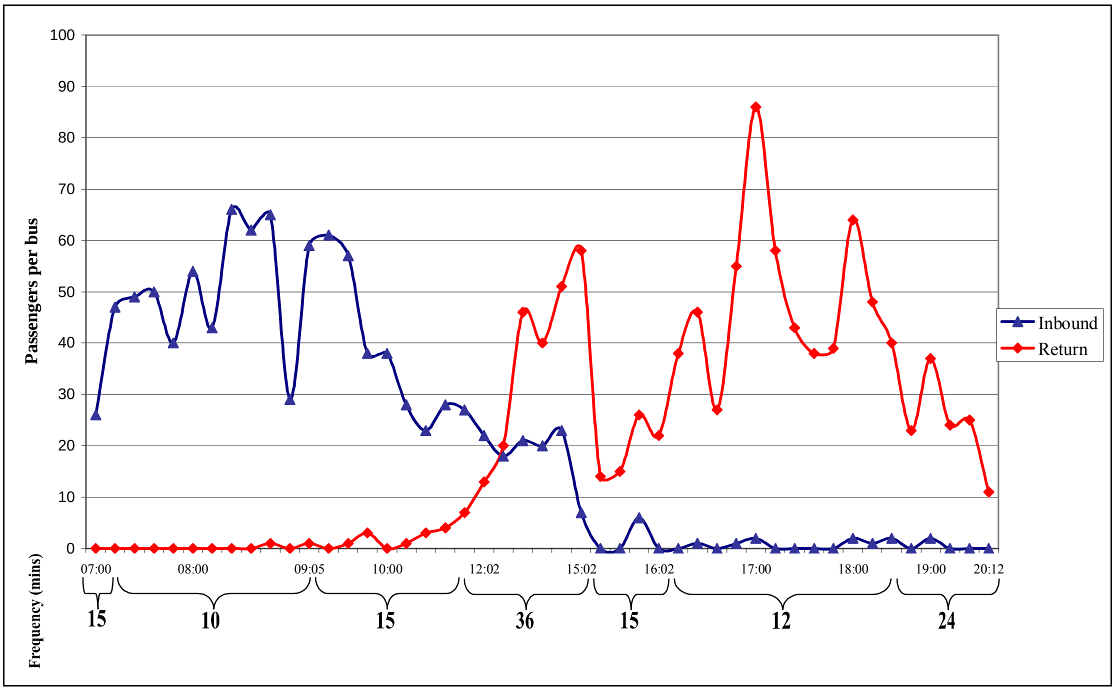

FIGURE 2 Reduced bus frequency for Bristol Bath Road P&R (Thursday data)
Adapted from Bristol City Council (11)

2.3 The Integrated Concept

Dedicated bus services are generally quicker, more convenient and of an overall higher quality than conventional bus services. Also, because P&R is often subsidised, the cost to the user is usually lower than conventional bus services. It is unsurprising then that P&R attracts a significant proportion of its users from conventional services. Furthermore and as discussed above, dedicated services suffer from low load factors because of the heavy peaking experienced by P&R in the morning and late-afternoon. Another potential effect of dedicated services is the exclusion of users of conventional services, where these passengers are unable to take advantage of the relative benefits of P&R services because ticketing may not be integrated.

These problems could of course be mitigated by using conventional buses to serve P&R sites. For instance, a conventional service could operate along the access corridor, between the host centre and settlement *A* in FIGURE 1. This service would be enhanced in quality, similar to Current Concept vehicles. Along this route and prior to serving the P&R site, passengers would access the service. For the users accessing the service by car at the P&R site itself, the bus service becomes essentially the same as a P&R service.

This is uncommon in the UK and none of the Current Concept sites are served by regular buses. There three schemes however that are examples of the Integrated Concept, in Leeds, Doncaster and Hanley (Stoke-on-Trent). The parking and bus elements in this concept are operated independently so the user pays for both elements separately. Considering that the time taken to transfer to P&R is perceived as an important attribute of P&R by users (*16*), this may have an adverse effect on the popularity of the Integrated Concept, although the costs of parking at the bus service could be combined so that a single payment would be made at the P&R site, which is common in the Current Concept. It is clearly important though that the price of the service is higher if the parking element is used, as this is an extra, premium service. The charging structure needs to be promoted to potential users as such, to avoid users driving to the P&R site when the bus service is accessible.

The result of operating the Integrated Concept would essentially be a reduction in the number of abstracted passengers who, as discussed above, considerably offset the potential VKT savings that can be made by car users as a result of using interchange. Furthermore, because of their commercial operation, conventional services would reduce the frequency of services and combined with their use by conventional bus users, would increase load factors.

2.4 The Hub-and-Spoke Concept

Rather than operating a single-corridor bus feeder service, as with the Integrated Concept, an alternative approach for many of the same reasons is to operate smaller, multiple services ('spokes') to feed the interchange site ('hub'), located farther away from the host centre than the Current Concept (FIGURE 3). Note that routes are shown extending beyond the area shown in the diagram to indicate a much wider reach of services. Although the UK has limited experience with this concept (although it is used for conventional bus routes), it is recognised and operated in the US. For example, in the Seattle Metropolitan Area a policy has been adopted whereby P&R sites are used as transit centres and are limited in terms of parking capacity but are heavily served by local buses, both as feeders and to allow passengers to interchange between local services (*17*).

One advantage over the Integrated Concept is the potentially larger reach of feeder services. This would further reduce the proportion of passengers abstracted from conventional bus service as, in effect, feeder bus services would be based on those existing to serve the catchment area. The focus of the hub is thus shifted from a P&R site to a transport interchange with a larger scope. An important point to note is that while some users would travel upstream to the hub, this is likely be inconsequential in terms of VKT because of the VKT savings made by reductions in the number of public transport abstracted passengers.

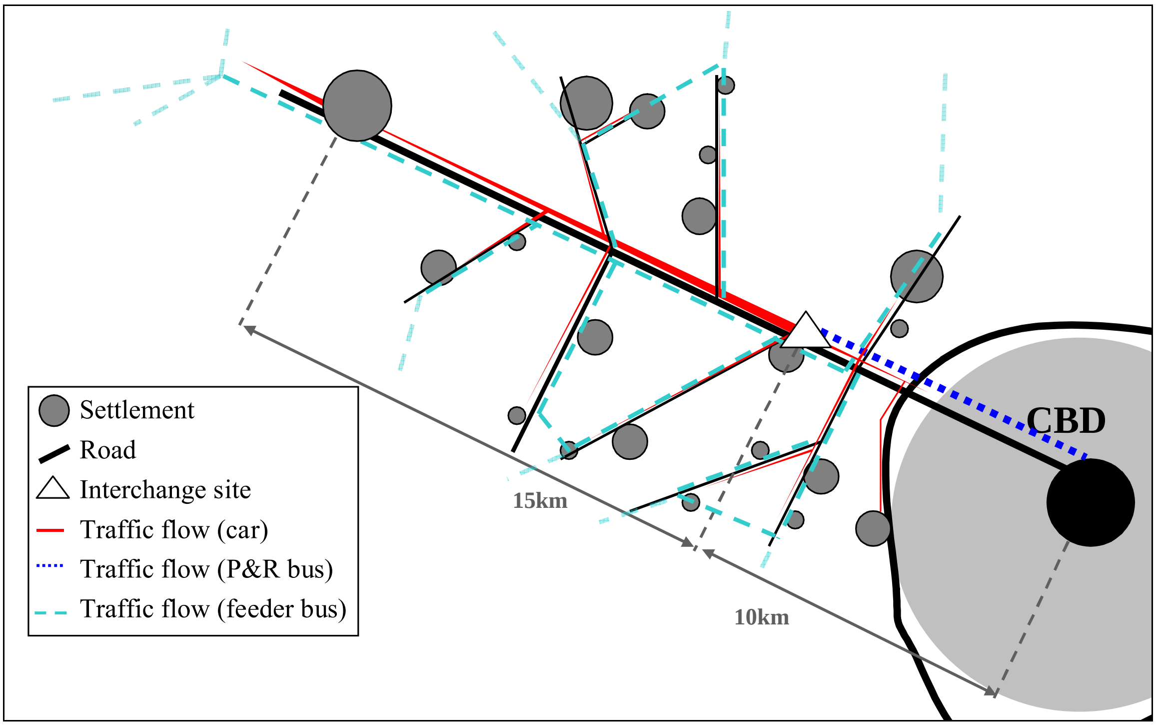

FIGURE 3 The Hub-and-Spoke Concept

2.5 The Remote Site Concept

While most Current Concept sites, as discussed above, are located 2-8km from their host centres, it is possible for sites to be located much farther away, for instance close to settlement *A* in FIGURE 1, with the bus service operating along the corridor downstream of the site. Such a format is used in the US between city pairs and although it is not a new concept in the UK, it is uncommon. Two sites in Scotland, Ferrytoll serving Edinburgh and Ellon serving Aberdeen, operate at approximately 21km and 27km away from their host cities respectively. Services linking the site with the host centre are conventional bus services, thus allowing non-car using passengers to access the service between the site and the centre. While this concept will reduce public transport abstraction, in a similar way to the Integrated and Hub-and-Spoke concepts, but it can also have a beneficial effect in terms of reducing car access mileage. Because the site is located farther upstream and essentially closer to the origin of users from farther away, the VKT of cars accessing the site will be reduced. Furthermore, the use of conventional commercial bus services means that their frequency is reduced are more aligned with demand, thus reducing bus VKT.

Although these two UK sites are operated on this basis, these were introduced in 2000 and similar schemes have not subsequently been introduced elsewhere. There are however, some indications that it is a concept that may diffuse to some extent and surprisingly, this has been in one of the centres where the Current Concept of P&R is perhaps most associated; in Oxford, the local authority has plans to investigate using the Remote Site concept to attract increased number of users from its commuter settlements (*18*).

2.6 The Link and Ride Concept

Combining the elements of conventional bus services and a change in site location, the Link and Ride Concept has been proposed as an improved, if not optimal, car-bus interchange model by Parkhurst (*8*). The Concept, shown in FIGURE 4, consists of a series of small interchange sites staggered along the main access corridor to the host centre. Conventional bus services operate along the corridor, serving both interchange passengers and conventional bus users. In contrast to the Current Concept, bus frequency is likely to be reduced thus increasing passenger waiting time to some extent. The abstraction induced by this Concept is nevertheless, likely to be reduced considerably. Indeed, the Concept could improve overall public transport ridership by improving its accessibility and image.

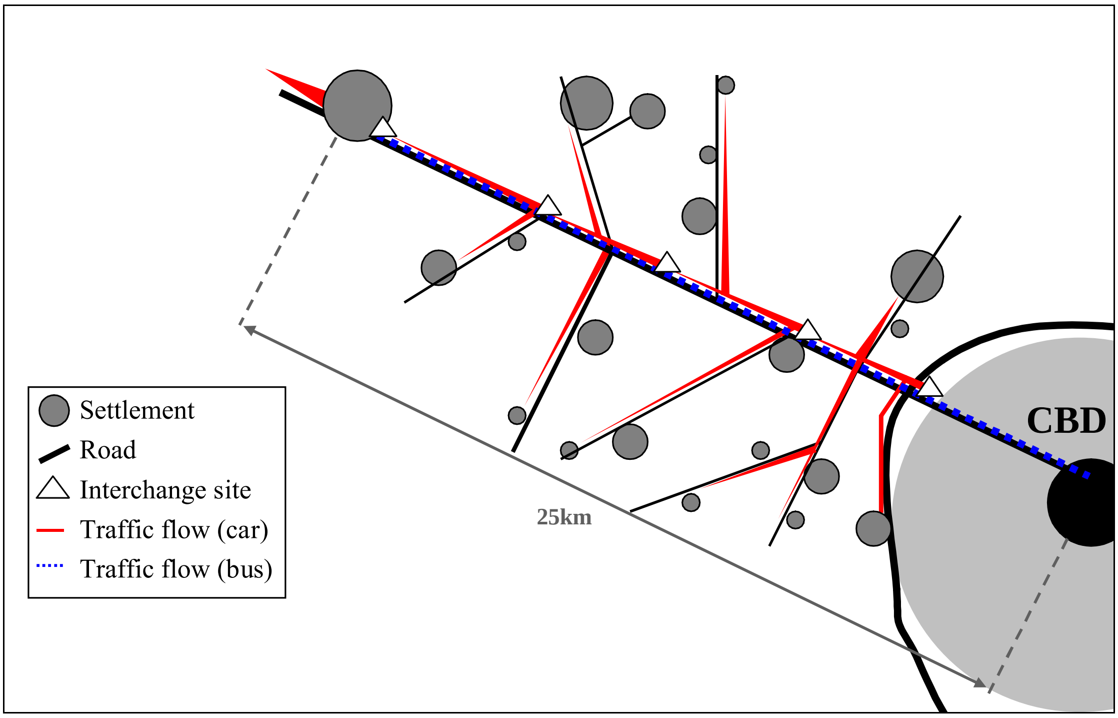

FIGURE 4 The Link and Ride Concept
Adapted from Parkhurst (8)

While the Link and Ride concept is departs considerably from the Current Concept, there are plans to implement a scheme similar in format in Cambridge as part of a guided busway scheme. Construction began on the busway in 2007 which is expected to be completed in 2010. There will be up to three interchange sites, located near to major residential areas, the farthest being approximately 25km away from the city (*19*).

3 EVALUATING VKT IMPLICATIONS

The aims of this analysis were to estimate the VKT effects of both the Current Concept of car-bus interchange and those resulting from the alternative intermodality concepts outlined above. Analyses were performed using a spreadsheet model incorporating, where possible, data derived from empirical studies. There was however, a dearth of data in a number of instances so a series of assumptions had to be made to complete the model, which are outlined in this section.

3.1 Model formulation

VKT estimates were made for each site within the database of Current Concept sites. First, the alternative behaviour of users was considered. The alternative VKT for the P&R users of site *i* whose alternative is car use, VKT_c^i , is expressed as:

$$VKT_c^i = \frac{u_c^i}{a}\ 2(d_{ai} + d_{is}) \tag{1}$$

where

u_c^i number of users of site i whose alternative to P&R is car use or travelling elsewhere
a mean car occupancy
d_{ai} mean distance between users' origins, a, and interchange site i
d_{is} mean distance between P&R site i and town centre, s

It was assumed that the distance that the user would travel from their origin directly to the town centre in the absence of P&R was equal to the distance between their origin and the P&R site, d_{ai}, and the distance between the P&R site and the town centre, d_{is}. For d_{ai}, the available data on access trips (*4*, *5*, *11*) for ten centres, j, was used to derive a mean distance travelled from origins to the town centre, d_{ajs}, weighted by the capacity of each site, g_j:

$$\overline{d}_{ajs} = \frac{\sum_{j=1}^{n} g_j d_{ajs}}{\sum_{j=1}^{n} g_j} \tag{2}$$

For the model, this was included to estimate the distance travelled to each site, $d_{ai} = \overline{d}_{ajs} - d_{is}$.

Some trips made to interchange sites are diverted from other towns. In the absence of data on these trips however, these users were included in the VKT_c^i group. Theoretically, the Current Concept induces longer trips by lowering the generalised cost of travel, so this will reflect favourably on the Current Concept in the model.

In terms of the occupancy of cars entering interchange sites, a, the available data aligns well with national average occupancy. In particular, mean occupancies reported by Parkhurst and Stokes (*5*) and Bristol City Council (*11*) are within 0.1 of those obtained by the UK National Travel Survey (*20*) for weekdays and their mean represents only 0.07 variance for Saturday occupancy. Thus, the Travel Survey (*20*) figures of 1.2 for weekdays and 1.7 for Saturdays were use. Car occupancy was assumed equal for both alternative behaviour and for the car arrivals at P&R sites. Although this assumption is not thoroughly robust, journeys made by P&R are essentially to the same destination as would be made otherwise so car sharing behaviour is likely to be similar.

For the VKT of users whose alternative to interchange is public transport, VKT_p^i, the relatively small amount of train use was excluded so the distance travelled by these users was estimated as:

$$VKT_p^i = u_p^i \frac{2(d_{ai} + d_{is})e}{f} \tag{3}$$

where

e car-equivalent factor applied to buses
u_p^i number of users of site i in a day whose alternative to P&R is public transport use
f mean payload (passengers) of the alternative conventional bus service

The car-equivalent factor was applied to buses to take account of their larger size and emission of higher levels of pollution. Parkhurst (*6*) for instance applied a factor of 2.5 after considering a range of alternatives, a figure that was used here for both conventional (alternative behaviour) bus trips and single-decker interchange buses. Current Concept sites however, use a variety of bus sizes so the factors assigned were: minibus, 1.5; midibus, 2; double-decker, 3. Where a mix of both single- and double-decker buses are used, a factor of 2.75 was applied.

For the payload of buses, a somewhat optimistic estimate of a 45% load factor was assumed (derived from *21*), considering that the majority of passengers would use conventional services in peak periods on a busy intercity route. This gives an average payload of 18.7 passengers, when using a bus capacity from the weighted average of the UK bus fleet (*22*).

The total users of each site, u_i, was estimated by assuming an 85% usage rate from the parking capacity. In order to estimate the proportion of travellers opting for different modes as alternative behaviour, a mean value was derived from the empirical evidence shown in TABLE 1, sufficiently small in range to use in the model.

For the VKT of users as a result of using the Current and alternative concepts, those arriving by car, bus or green mode were treated separately. For car-arriving users of site i, the VKT for P&R use, VKT_{car}^i, was estimated as:

$$VKT_{car}^i = \frac{u_{car}^i}{a} 2d_{ai} + \frac{2d_{is}h_i e}{u_i} u_{car}^i \qquad (4)$$

where

u_{car}^i number of P&R users accessing site i by car
u_i total number of users of site i
h_i bus circuits per day

It was assumed that peak services operated for four hours per day. Thus, the number of circuits made per day by buses serving site i, h_i, was estimated using the database of sites by:

$$h_i = 4c_{peak}^i + c_{off}^i (o_i - 4) \qquad (5)$$

where

c_{peak}^i peak circuits per hour
c_{off}^i off (inter)-peak circuits per hour
o_i number of operating hours per day at site i

For the VKT for those accessing P&R by green mode, VKT_{gre}^i:

$$VKT_{gre}^{i} = \frac{2d_{is}he}{u_i} u_{gre}^{i} \tag{6}$$

where

u_{gre}^{i} number of users accessing site *i* by green mode

For some of the alternative concepts, regular bus services were used for interchange so the for users accessing the service by bus upstream of sites who would otherwise use the car, u_{bus}^{i}, the bus access VKT was included, thus for the total trip, VKT_{bus}^{i}:

$$VKT_{bus}^{i} = \frac{2d_{ais}he}{f + \frac{u_i}{h_i}} u_{bus}^{i} \tag{7}$$

Furthermore, for those accessing by car or green mode, equations (4) and (6) were updated to account for the change in load factor as a result of bus service integration, with u_i becoming $u_i + fh_i$.

Some further assumptions were made for alternative concepts given their novel nature, although for the Link and Ride Concept, most variables were included in the model on the basis of the assumptions made by Parkhurst (*8*). These assumptions are outlined in Section 3.3 after the results of the model for the Current Concept are described.

3.2 The VKT effects of the Current Concept

Estimates were provided separately for both weekdays and Saturdays for each site. The results of the model for both alternative behaviour and the Current Concept are shown in TABLE 2 .

TABLE 2 Difference in VKT from Current Concept use

	Weekday		**Saturday**	
	Total VKT (km)	**VKT per user (km)**	**Total VKT (km)**	**VKT per user (km)**
Alternative VKT (Mean)				
Car / Alternative Destination	7879.25	28.88	11536.81	31.07
Public transport (bus)	734.22	4.63	638.17	7.06
Green mode	0	0	0	0
No trip made	0	0	0	0
Total / Each	8621.96	17.15	12174.99	24.08
P&R VKT (Mean)				
Car access	10748.46	24.17	13774.90	28.67
Green mode access	191.58	3.41	85.60	3.35
Total / Each	10940.04	21.84	13860.51	27.39
Difference in VKT (Mean)	(+) 2318.09	(+) 5.33	(+) 1685.52	(+) 4.02
Difference in VKT (Max)	(+) 6153.74	(+) 11.45	(+) 6121.32	(+) 15.33
Difference in VKT (Min)	(-) 3519.99	(-) 3.51	(-) 2705.14	(-) 3.3

Clearly there is a considerable range in the VKT effects of the Current Concept. This is strongly influenced by the size of the bus used (its car-equivalent factor) and the frequency of bus services, which by increasing the number of circuits made per operating day, increases the bus VKT which is allocated to each user (equations 3 and 5). This should not be considered in isolation however, as some of the sites changing VKT the least operated high-frequency or large buses. Rather, it is the relationship between parking capacity (and sites' assumed use) and bus capacity that influences the VKT effects significantly. In particular, those sites where parking capacity is comparatively proportional to bus capacity are those where the larger VKT savings are made. The distance between the site and the town centre had an unsurprisingly strong influence with the most VKT-reducing interchange sites generally being located farther from their host centre.

3.3 The potential value of alternative concepts

The mean values of the variables distinguishing the Current Concept were used as a base for modelling the VKT impacts of the alternative concepts of car-bus interchange outlined in section 2. The results of the model are shown in TABLE 3 as well as the main assumptions made for each concept, shown in bold. The VKT estimates were made using weekday data as this is when the most detrimental use of interchange occurs.

The daily usage of sites was estimated on the basis of Concepts' likely popularity to users. The Demand-led and Integrated Concepts were considered to remain the same at 85% usage of site capacity since these differ only slightly from the Current Concept. The usage shown in the table does not necessarily imply the cars using the site but rather it was used to indicate the number of users, irrespective of their arrival mode. While the Hub-and-Spoke Concept for instance, would not induce more cars to arrive at the site, the usage was assumed to increase from the use of a feeder network of buses. Hence also the higher proportion of users accessing the site by bus (and lower car access) and the longer mean access distance to the site. The number of circuits operated was assumed to remain relatively high for this concept given the combination of passenger from both the conventional and interchange bus services. The model did not account for the VKT of existing conventional bus users, although users transferring from car access and the new bus arriving users attracted to the site were included. All bus users were however considered in the load factors of buses serving interchange sites.

TABLE 3 The VKT effects of alternative concepts

	Current Concept	Demand-led Concept	Integrated Concept	Hub-and-Spoke Concept	Remote Site Concept	Link and Ride Concept
Site capacity	599	599	599	599	599	599
Daily usage (% of capacity)	85%	85%	85%	**95%**	**60%**	**80%**
P&R site - town centre distance (km)	4.76	4.76	4.76	**10**	**25**	**14**
Origin - P&R site mean distance (km)	12.57	12.57	12.57	**15**	**10**	**2**
ALTERNATIVE BEHAVIOUR						
Car (and alternative destination)						
% of users	54%	54%	54%	**51%**	**45%**	**86%**
Car occupancy	1.2	1.2	1.2	1.2	1.2	1.1
Bus						
% of users	31%	31%	31%	**39%**	**40%**	**5%**
Payload (passengers)	18.7	18.7	18.7	18.7	18.7	18.7
Car equivalent factor applied to buses	2.5	2.5	2.5	2.5	2.5	2.5
Green Mode						
% of users	4%	4%	4%	**2%**	**4%**	**0%**
Generated Trips						
% of users	11%	11%	11%	**8%**	**11%**	**9%**
P&R USE BEHAVIOUR						
Bus circuits per day	70	**45**	**60**	**60**	**50**	**36**
Car-equivalent factor applied to buses	2.49	2.49	2.49	2.49	2.49	2.49
Arrived by Car						
% of users	88%	88%	**70%**	**64%**	**65%**	**90%**
Car occupancy	1.2	1.2	1.2	1.2	1.2	1.1
Arrived by Green Mode						
% of users	12%	12%	11%	**11%**	**25%**	**0%**
Arrived by Bus						
% of users	0%	0%	**19%**	**25%**	**10%**	**10%**
VKT CHANGE						
Daily variance from alternative behaviour (km)	2318.09	1787.3	-401.18	-1543.62	-1034.34	-8113.63
Per user variance from alternative behaviour (km)	4.47	3.5	-0.78	-2.71	-2.88	-16.93
Daily variance from Current Concept (km)		-530.79	-2719.27	-3861.71	-3352.43	-10431.72
Per user variance from Current Concept (km)		-0.97	-5.25	-7.18	-7.35	-21.40

For the Remote Site Concept, usage would diminish since the site would be less accessible to those living relatively close to the urban centre. The proximity of the site to users still using the interchange service by backtracking was reflected by the relatively high mean access distance. For this Concept, the service was assumed to stimulate bus use on the corridor through the service's enhancements.

For the Link and Ride Concept, the chain of sites would reduce access distance considerably so the higher proportion of users accessing by car does not have a detrimental effect on the VKT. Bus frequency was assumed to reduce considerably in both the Link and Ride and Demand-led Concepts, the latter reduction being based on the Bristol example outlined above in 2.2 where bus capacity was altered having minimal effects on the transfer penalty to users and thus the Concept's popularity.

The improvement in VKT reductions shown in TABLE 3 is, in some cases, considerable. There are, it seems, significant VKT savings with the Link and Ride Concept although this Concept combines many of the beneficial aspects of the other concepts.

4 DISCUSSION AND CONCLUSIONS

There has been growing concern over the effectiveness of the Current Concept of car-bus intermodality in the UK. Academic studies have hitherto indicated that it may not, by design, reduce the VKT of its users which is a policy goal that is likely to grow in importance in the future as a result of increasing concern over the environmental- and traffic congestion-related effects of private car use. The aims of this paper were both to contribute to the body of evidence over the effects of the Current Concept on VKT by using a comprehensive dataset of the existing UK sites, as well as to consider how the concept of car-bus intermodality can be advanced to improve its role in reducing the VKT of its users.

The results of the first part of this analysis conform to foregoing studies and indeed indicate that sites generally increase VKT. The latter part of the analysis suggests that the alternative ways by which car-bus interchange can be implemented offer considerable relative benefits. Indeed, this provides a somewhat original approach within the literature by looking towards the future, with the exception of Parkhurst's (*8*) proposition and analysis of the Link and Ride Concept. Parkhurst suggested that Link and Ride may reduce VKT to the equivalent (factored from annual to daily) of 5263km - 13397km daily for low (395 spaces) and medium (791 spaces) capacity systems respectively, a range within which the 8114km estimated here for a 599 space scheme, fits comfortably, using a different approach.

The Current Concept of car-bus intermodality has over the past 40 years been successful with regards popularity. What this paper has not fully considered is the impact that alternative concepts would have on the same terms. The considered concepts vary in their similarity with the Current Concept. Some however, such as the Demand-led and Hub-and-Spoke Concepts are only likely to affect the traditional user to a relatively minor degree. Furthermore, the paper has not considered the costs of operating alternatives but none of those suggested appear excessive in this sense. A further potential shortcoming of this analysis is the number of assumptions adopted to construct the model, the most unreliable of which being the data on the distance travelled by users to interchange sites, owing to the dearth of research in this area. Further research is thus required to address issues of acceptability, financial cost and data reliability used to estimate the VKT effects of the concepts.

Nevertheless, the model provides useful indications of the comparative benefits of the concepts and the determinants to their VKT impacts. Lessons contained within this paper are also applicable outside of the UK. Stakeholders internationally should consider carefully the effects of measures to promote intermodality including their popularity with the non-intended user. The matters of popularity, likely patronage and actual effectiveness have to be carefully balanced. Non-market based transport measures aiming to persuade, rather than force, motorists into more sustainable travel choices clearly need to be acceptable to become viable, but their practical efficacy must be founded a priori otherwise a contradiction of policy goals, and increase of societal costs, may occur.

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