wctr'04
4-8 july 2004 / istanbul-turkey

THE FUTURE EVOLUTION OF URBAN TRANSPORT: TOWARDS A NEW MODAL FIT

Stephen Marshall
Bartlett School of Planning, University College London
s.marshall@ucl.ac.uk

Abstract

The paper demonstrates a framework for relating different modes of movement to a variety of network parameters and performance characteristics. This demonstrates how it is possible to relate different modes with different kinds of urban form and layout, to inform policy paths towards viable and potentially more sustainable transport / urban packages in the future. In particular, the paper suggests the possibility of 'evolving' from existing modes towards more efficient and 'sustainable' modes, with the possibility of relating new categories of vehicle and regulation with different urban layouts and street management policies. For example, a policy of 'compact cars for compact cities' might be able to combine synergies of selected modes and selected urban forms.

Keywords: Urban transport; Modal relationship; Modegram
Topic Area: F2 Urban Patterns and Transport

1. Introduction

The future evolution of urban transport involves more than the extrapolation of a single variable, but involves interaction of different transport modes with their urban environment. Just as new urban patterns were created by the advent of new transport modes, new modes have evolved to serve the resulting suburban patterns.

After a relatively stable period for transport technologies over several previous decades, we now see a potentially significant diversification of new modes and technologies, including small motorised vehicles and alternative fuel vehicles, that could serve as alternatives to the conventional internal combustion or diesel vehicle. These alternatives will increasingly be competing for viability in today's and tomorrow's cities aiming to minimise sprawl and maximise sustainability.

The challenge is to understand how knowledge of existing and historic relationships between different modes of movement and networks can inform the development of future urban forms and networks to fit with emerging modes of transport.

This paper first introduces the concept of 'modal fit' with reference to the co-evolution of transport and urban forms, and then sets out a graphic device – the 'modegram' – for exploring relationships between different transport modes. The paper then uses understanding of these relationships to explore how a future fit could be made between a combination of existing and emerging vehicle types and network structures.

2. Modal fit

Different modes of movement have been historically associated with different kinds of urban pattern. At a very broad spatial level, we can recognise the compact, pedestrian-oriented city; the radial public transport-oriented city, and the dispersed car-oriented city. Indeed, historically, it is possible to note how transport systems have significantly contributed to the emergence of cities in the first place (Clark, 1958).

Robert Cervero, discussing cities and their transport systems, notes

> "… a tight 'hand in glove' fit between their transit services and settlement patterns. In particular, these places are highly adaptive – either their cityscapes are physically and functionally oriented to transit or transit is well tailored to serving their cityscapes." (1998:xi).

He suggests that these places have been 'superbly adapted, almost in a Darwinian sense' (1998:5).

The overall notion of 'modal fit' is that each mode of transport is adapted to its urban environment, and has to some extent co-evolved with it: the mode shapes the environment, and the environment shapes the mode. 'Modal fit' can be used as a shorthand for the relationship between a transport mode and its 'environment' – which is interpreted immediately in this paper as the physical environment of infrastructure and urban form, but which might also include wider interpretations of cultural, political, institutional or financial 'environments'. The implied relationship is dynamic, and (co) evolutionary.

Effectively, each mode of movement can therefore be seen to occupy an 'evolutionary niche' in the urban environment. For example, metro systems thrive in densely packed cities, along corridors of high demand, and are competitive where street-based modes subject to congestion are not. However, the bus is more flexible than the metro for penetration of the more diffuse outer suburbs, though in the lowest density areas it may find only meagre sustenance. Cars, however, are well suited to the dispersed suburbs – as well as helping to create them in the first place: cars are symbiotic with sprawl.

Cycling and particularly walking are confined in range, and are disadvantaged by the long distances of suburbia, but are versatile and can find niches beyond the reach of other modes. The limited speed and range of walking is compensated by the fact that the pedestrian has the widest possible accessibility, right up to the doors of building, and onwards inside.

Finally, we see how some modes become 'extinct' – the horse-drawn tram combines the disadvantages of low speed and inflexible routeing. It only exists as a museum piece.

In some cases, new modes have evolved to fit the new urban conditions. Demand-responsive transport (e.g., dial-a-ride services) can be seen as an 'evolutionary response' to the creation of dispersed suburbs which cannot support conventional public transport. Similarly, the guided bus may be seen as an adaptive response to the combination of congested inner city areas (where a segregated route is a competitive advantage) and dispersed suburbs (where flexible routeing can maximise access closer to more destinations).

These last cases represent solutions dealing with the 'mobility-led' problem of serving urban areas with transport. However, the problem can also be approached from the other side: the design of the built environment. Physical planning, urban design and transport provision can all change the 'ecosystem' of the different modes, as it were, to favour one type over another, whether by helping to 'feed' public transport, or by differentially favouring routes for non-motorised modes – or, at least, by ensuring that there are plenty of convenient niches where walking and cycling can naturally flourish.

This angle – the design of streets and patterns to accommodate different modes of movement – is the concern of this paper, because it ultimately relates to possibilities for promoting future emerging modes, such as clean vehicles. To see how these would potentially fit with existing modes, we can explore a variety of relationships between modes.

3. Modal relationships: The Modegram

3.1 Key modal relationships

In the contemporary context oriented towards sustainable transport and urbanism, the challenge of modal fit is effectively to devise urban layouts that are more amenable to walking, cycling and public transport use, and less dependent on the car (Banister and Marshall, 2000).

We may tend to think of the car on one side, and public transport and the non-motorised modes on the other. Public transport and pedestrians seem to go together in a virtuous package. But they ‘go together’ not because they are alike, but because they are complementary – in the words of Garbrecht, they are ‘two sides of the same coin’ (1997:207).

Indeed, public transport and non-motorised modes are complementary precisely because they are unalike. What is more, the ways in which they are unalike are the same ways in which each separately shares a likeness with the car. The car and public transport are both motorised forms of transport, while walking is unassisted human locomotion. By the same token, the car and pedestrian share the characteristic of being individualistic, whereas public transport is a collective mode (Figure 1).

Effectively, Figure 1 represents three extrema, which correspond to three distinct kinds of mode of movement (Table 1).

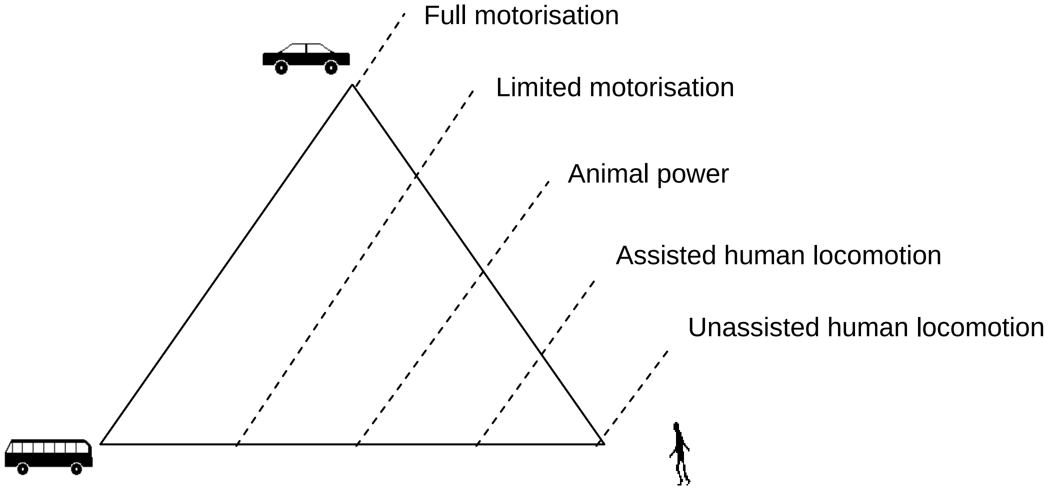

Figure 1. Relationships between key modes.

Table 1. Three modal extrema

Icon	Short label	Long label	Explanation
	Foot	Individual non-motorised (Solo no-moto)	Pedestrian; unassisted human locomotion, with limited range but fine networks and door-to-door access
	Auto	Individual motorised (Solo-moto)	Single occupancy motor transport; includes the car, van, lorry, motorcycle; unlimited range, door-to-door access; intermediate network coarseness
	PT	Collective motorised (Co-moto)	High capacity collective transport, typically with coarse networks and limited points of access; unlimited range

We can use the relationships in Figure 1 to structure investigations into relationships between modes, by recognising two basic attributes of movement – ‘mechanisation’ and ‘vehicle occupancy’ – which are of importance to urban layout. A wide range of modes can be considered in terms of these two basic attributes, which act like more or less independent dimensions in the investigation (although, they are related in some respects in practice, in that normally a certain degree of power or mechanisation is a prerequisite for vehicle occupancy of any magnitude).

3.2 Mechanisation or 'power'

In terms of mechanisation, we can observe a spectrum from the pedestrian (unassisted human locomotion) to the full mechanisation of motorised modes such as cars, buses and trains (Table 2, Figure 2).

Table 2. The spectrum of mechanisation (power)

Degree of mechanisation (power)	Examples of transport modes
Unassisted human locomotion	Pedestrian walking
Human carriage of another person	Person carried on piggyback
	Sedan chair
Human power assisted by vehicle, gears, etc.	Bicycle
	User-propelled wheelchair
Human propelling another human	Accompanied wheelchair
	Rickshaw, Trishaw, etc.
Animal power	Pack animal
	Animal cart, sled, etc.
	Horse, elephant, etc.
	Horse and carriage, horse-drawn tram, etc.
Limited motorised	Power-assisted bicycle
	Battery electric vehicle
Fully motorised	Motorcycle
	Car, Van, Lorry
	Minibus, Bus, Tram, Train, etc.

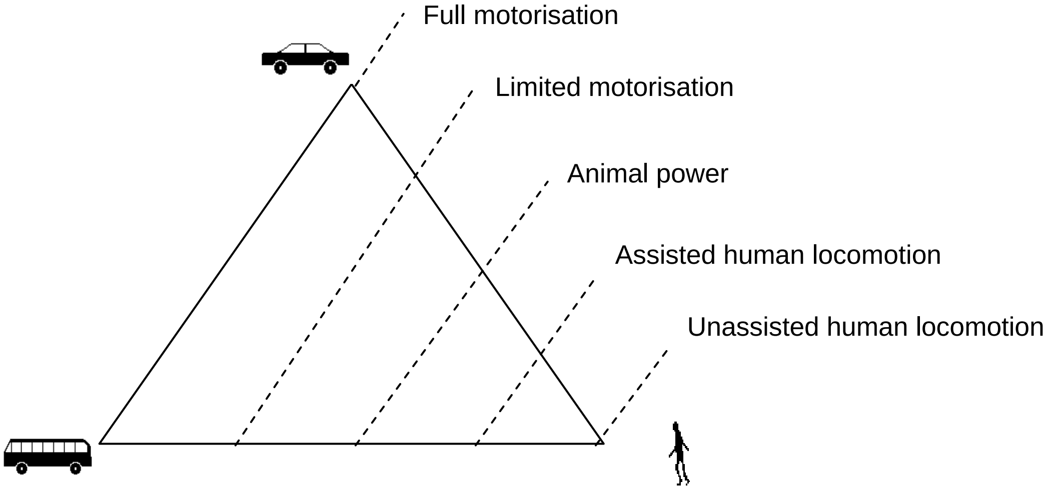

Figure 2. Degree of mechanisation (power) (See Table 2)

3.3 Public transport

Public transport may be distinguished from other modes by a number of possible factors:

- Public versus private (ownership/ operation/ availability);
- Collective versus individual (occupancy/ capacity);
- Fixed versus 'free range' (service/schedule/route versus point-to-point movement);
- Direct farebox payment versus combination of vehicle investment, fuel, tax, etc.;
- 'Access hierarchy' – the degree to which one mode is used to access another, based on proximity to point of accessing mode and network contiguity or 'arteriality' (Marshall, 2004).

Table 3. The spectrum of public transport

Transport mode	Public v private	Typical vehicle occupancy/ capacity[a]	Pattern of movement	Payment
Pedestrian	Private	1	'Free range'	Combination
Bicycle	"	1-2	(direct point-to-	"
Motorcycle	"	1-2	point)	"
Car	"	1-6		"
Taxi	Semi	1-6		Direct per trip
Demand-responsive	Semi	-	Intermediate	"
Hail & ride	Public	-	Fixed route	"
Minibus	"	15-40	Fixed route	"
Bus	"	55-85	and stops	"
Tram / Light rail	"	354-460	"	"
Rail / Metro	"	1300-2300	"	"

[a] Occupancy/capacity figures from Harwood (1992:46); Dimitriou (1995:108). Note there will be distinctions between capacity (seating and standing capacity) and actual operating occupancy.

Table 3 gives some suggested values. Only 'occupancy/capacity' and 'access hierarchy' really provide a finely graduated spectrum that differentiate between all public modes (a train is not 'more public' than a tram). Of these, only 'access hierarchy' provides a stable systematic ordering (unlike occupancy/capacity which may vary by individual vehicle make or journey). 'Access hierarchy' is not specified explicitly in Table 3 but the whole table is ranked by this criterion (indeed, 'access hierarchy' can be used to rank all modes, Marshall, 2004). However, for the purposes of this paper, the more conventionally recognised concepts of vehicle occupancy/capacity will be used to distinguish the 'public transport axis' (Figure 3).

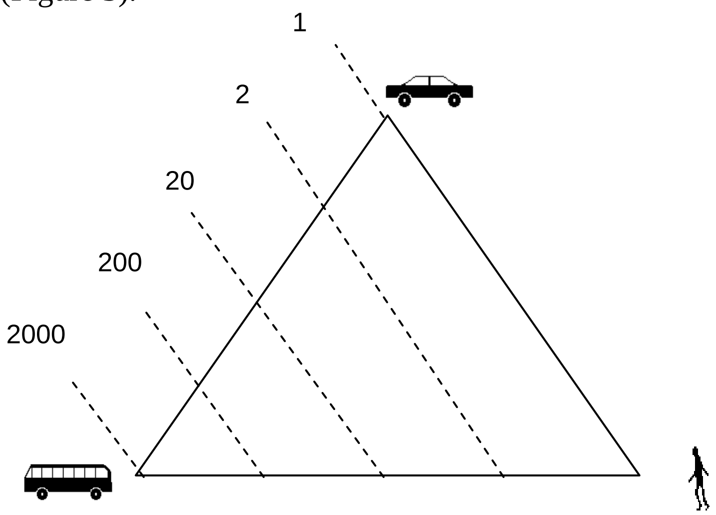

Figure 3. Vehicle occupancy.
Values are indicative only. (see also Table 3)

3.4 The Modegram

Taken together, it is possible to construct a triangular diagram, where the three vertices are the car, the pedestrian and public transport (as in Figure 1, Table 1), the right-hand bound equates with the spectrum of mechanisation (Table 2, Figure 2) and the left-hand bound equates with the 'vehicle occupancy axis' from solo car to public transport (Table 3, Figure 3). We can call the resulting diagram the **modegram** (Figure 4).

Although originally generated from basic parameters that differentiate walk, car and public transport modes – degree of mechanisation and vehicle occupancy – the modegram may be used to explore relationships between modes, based on a wide range of other parameters, which are now summarised upfront in Table 4.

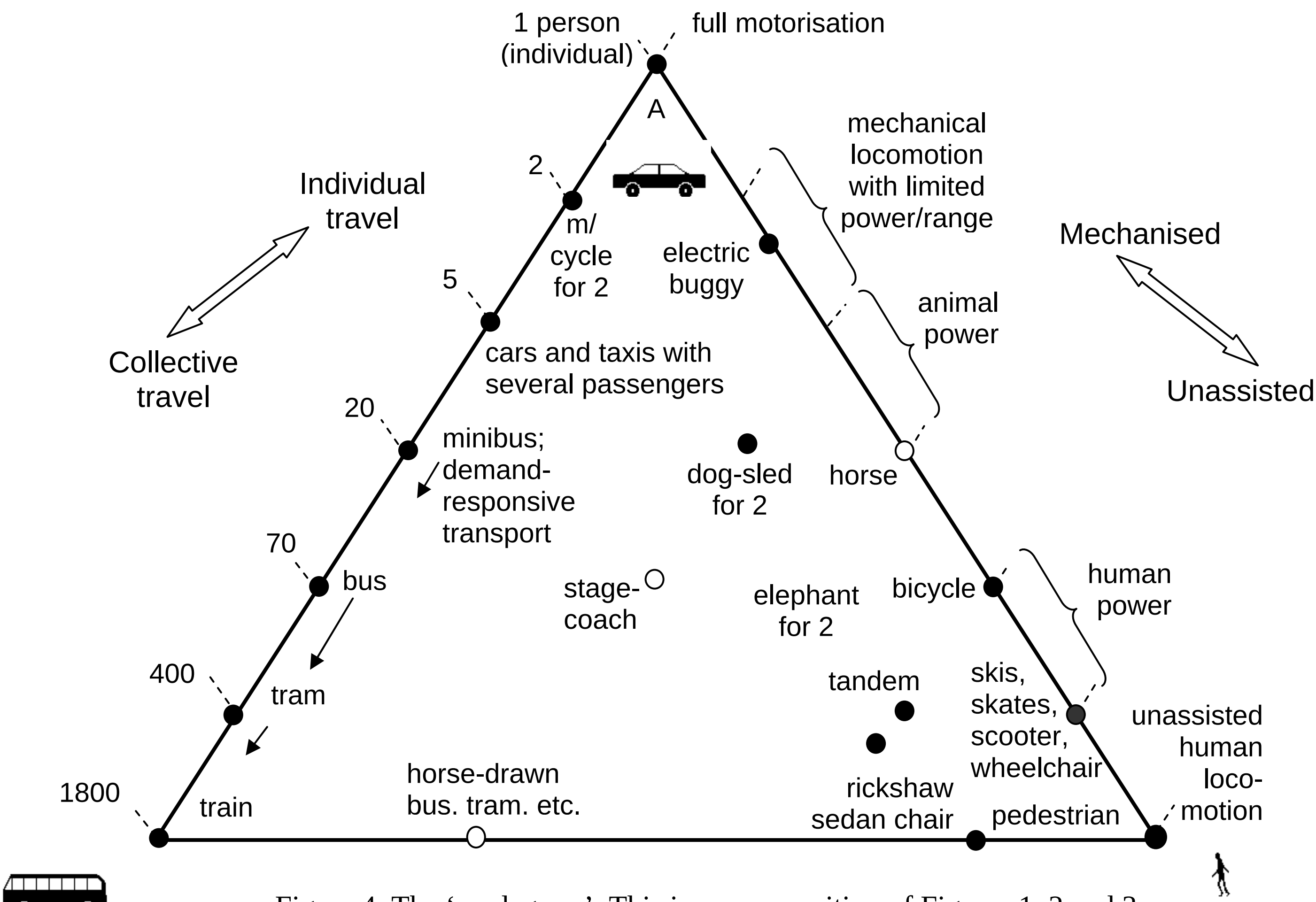

Figure 4. The 'modegram'. This is a superposition of Figures 1, 2 and 3.

Table 4. Parameters considered for mapping to the modegram

Parameter	Unit	Notes	Figure (Table)
Range	m or km	Daily range or range to access another mode	5 (5)
Speed	km/h	Route distance/ journey time	5 (5)
Energy	MJ/veh.km; MJ/pass.km	Per veh.km or pass.km	5 (5)
Stop spacing	m	Per length of route	6 (6)
Access density	per m^2 or km^2	Equates with 'penetration'	7 (7)
Access distance	m	Equates with 'access hierarchy'	7
Route density	km/km^2, etc.	Inverse of network coarseness	7
Network coarseness	km^2/km	Inverse of route density	7
Access distance	m, km, etc.	From selected location(s) to nearest access point	7
Catchment radius	m, km	Equates with access distance	-
Catchment area	km^2	Calculable from catchment radius	-
Directness	m/m, km/km, etc.	Ratio of actual route to straight line distance	7
Vehicle capacity	persons per vehicle	Capacity for given vehicle	8
Vehicle occupancy	persons per vehicle	Actual number for given trip	8

3.5 Range, speed and energy

Figure 5 and Table 5 show three factors relating directly to 'power'. Here, 'power' does not mean the specific physical quantity (Js-1), but a roughly divided spectrum of mechanisation (from unassisted human locomotion to full motorisation).

Within this simple conceptual framework, range may be considered to be directly proportional to power, that is, full power modes are assumed to have the highest range (unlimited at the urban scale) and unassisted human locomotion to have the most limited range.

Speed is a rather variable property, which will depend a lot on operating conditions (e.g. congestion). Depending on circumstances, at least two clear extremes are possible, shown in Figure 5: (a) in which all full-motor-power modes have equally high speed; (b) in which the higher occupancy modes are recognised to have higher operating speeds, due to segregation, etc.

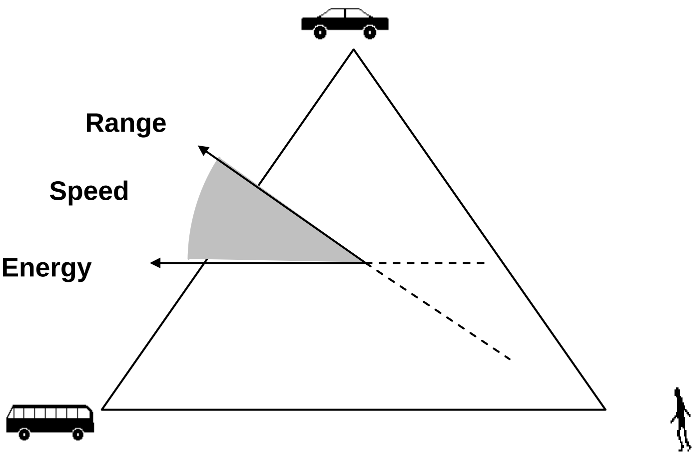

Figure 5. Range, Speed and Energy (See Table 5)

Table 5. Range, Speed and Energy

Degree of mechanisation	Examples of transport modes	Range [(a)]	Speed (km/h) [(b)]	Energy (MJ/veh.km) [(c)]
Unassisted human locomotion	Pedestrian walking	Limited	4–5	-
Assisted human locomotion	Bicycle		10-20	
Animal power	Pack animal		5	-
	Donkey cart (1 donkey)		4–5	-
	Ox cart (2 oxen)		3–4	-
Fully motorised	Motorcycle	Unlimited	15–90	-
	Car	range	12–100	3.5
	Lorry	(at urban	-	-
	Minibus	scale)	10-60	7.1
	Bus		10-60	14.2–16.2
	Tram / Light rail		10-50	47
	Train		25-50	74–122

(a) Range will depend on many factors, including loading of vehicles, the strength and stamina of individual people, and the availability of other modes. For example, in the context of developing countries, Njenga and Davies (2003) give daily walking range as 15-20km, and bicycle as 50km, but in urban conditions in western cities, likely to be much shorter.
(b) Range of speeds from Ritter (1964), Hathway (1985), Dimitriou (1995), Richards (2001), Njenga and Davis (2003). Note that there will be key differences between average or typical journey speeds in urban conditions.
(c) Potter (2003).

Energy is also variable (as with all other parameters), but generally speaking the more powerful, higher occupancy modes use more energy (MJ/veh.km). (The bicycle may be considered an exception, if for example it is considered to have a lower energy consumption per passenger km than walking, depending on how its energy consumption is calculated).

3.6 Stop spacing (access point spacing)

Stop spacing here implies the spacing of access points along a linear route. Stop spacing tends to be greater for the higher speed, higher occupancy modes (Table 6, Figure 6).

For public transport, optimum stop spacing will be a compromise between having sufficient distance between stops to allow high speed running and faster journey times, and having sufficiently close stop spacing to minimise access distance. The latter factor will also be related to the access mode: if the access mode is assumed to be non-motorised, this will imply a shorter desirable stop spacing, whereas if access mode is assumed to be by car (e.g. an outer suburban park and ride location) then a longer access distance and hence stop spacing would be acceptable.

For pedestrians, we can assume a zero ‘stop spacing’ or access point spacing, since a pedestrian can in effect stop anywhere that could be considered a destination.

For cars, access point spacing could be assumed to be zero, where a car may stop and park at any point along a route, or could be assumed to be constrained by parking restrictions. The latter interpretation is more useful in that it provides a definite rationale for distinguishing between the accessibility of cars relative to pedestrians, and therefore this is used to generate the ‘horizontal’ interpretation of stop spacing gradient in Figure 6.

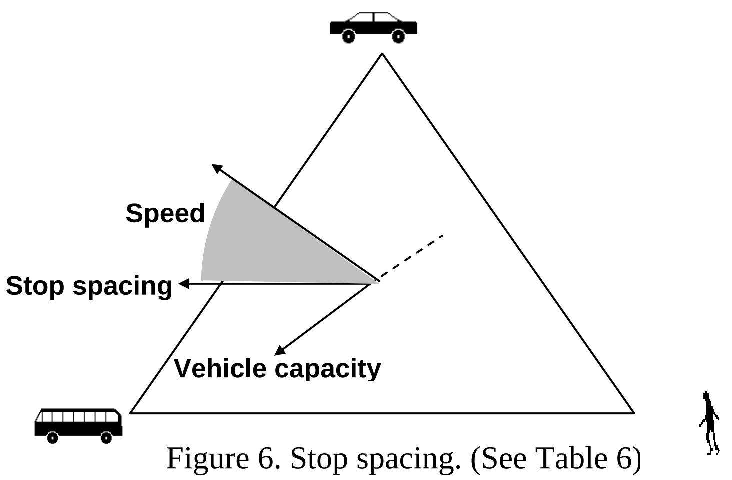

Figure 6. Stop spacing. (See Table 6)

Table 6. Suggested values of typical access point or stop spacing (Figure 6)

Transport mode	Stop spacing
Pedestrian	*Zero*
Bicycle	*Metres*
Motorcycle	*Tens of metres*
Car	*Tens of metres*
Minibus	200-500m[a]
Bus	200-550m[a]
Tram / Light rail	400-800m[a]
Rail / Metro	1km-3km[a]

[a] Llewelyn-Davies (2000) and Richards (2001)

3.7 Access distance, access density, route density and directness

Access distance is the distance from a given origin or destination to an access point of a given network (e.g. distance from home to bus stop). Access distance is often associated with catchment radius, in planning urban layouts. Typical values are given in Table 7. Access distance will tend to be inversely proportional to access density (Figure 7).

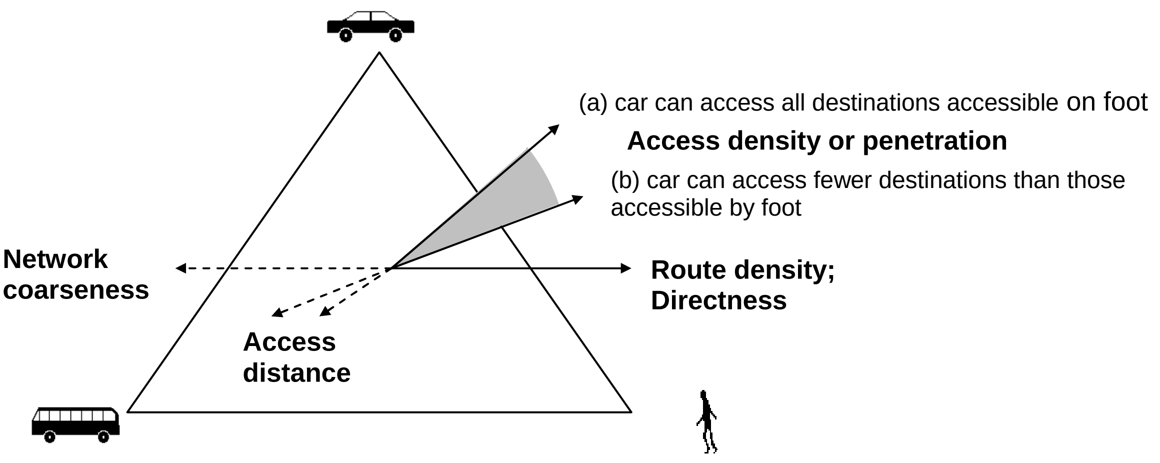

Figure 7. Access distance, access density, route density and directness

Table 7. Access distance

Transport mode	Typical access distance (catchment radius) [(a)]
Pedestrian	Door to door (and inside)
Bicycle	Door to door (parking permitting)
Motorcycle	Door to door (parking permitting)
Car	Door to door (parking permitting)
Bus	300-500m
Tram / Light rail	300-500m
Rail / Metro	Up to 1km

[(a)] Typical access distance based on idealised distance people prepared to walk. Note that in practice there will be different values for average versus maximum catchment; and these will also depend not only on mode being accessed but journey purpose (Marshall, 2001).

Access density is a slightly different parameter from access point spacing (stop spacing). Whereas stop spacing refers to linear spacing along each route, access density represents the number of locations within a given area that are served by or accessed by a given mode. Access density will typically increase for the more individualistic modes and non-motorised modes, but the exact relationship will vary with circumstances (Figure 7). For example, in a historic town with many small lanes inaccessible to cars, the access density will be greater for pedestrians (b). However, in a new town expressly designed for full accessibility, it is conceivable in principle that every location considered a 'destination' is deliberately car-accessible, in which case the access density would be the same for car and pedestrian (and presumably all modes in between) Figure 7(a).

Access density may be distinguished in principle from *route density*. Route density would be measured in linear length of route within a given area. The inverse of route density would be *network coarseness* (area per route length of network). If we take the road network used by cars as standard, then the more collective modes are progressively coarser. In the other direction, the less mechanised modes have finer networks. Bicycles can generally access more places than cars and lorries, and the pedestrian most of all.

Accessibility for people using wheelchairs has traditionally been less than for those on foot, though accessibility-oriented design aims to go some way to bridging this gap.

In principle, route density and access density are independent, but in practice, networks with higher route density will also tend to have higher access density (penetration).

Networks with greater route density could be deemed to have potentially a greater access density, if any point along any route may be considered potential destinations, in which case a fine-grained pedestrian network would in principle serve more territory (hence more potential destinations) than a coarser vehicular network. In practice, at least some pedestrian lanes or links would be considered merely links between destinations, in which case the case of a town with car accessibility equal to pedestrian accessibility is still possible in principle.

Directness is here considered to mean the ratio of actual route distance (via the network) to straight-line distance. (Directness might also be equated with parameters such as the route factor, Vaughan, 1987 and tortuosity, Taylor, 1999).

Directness will be partly influenced by route density, since in general the denser the network the more direct on average are paths between origins and destinations. Directness will also be influenced partly by *connectivity*. Connectivity is a topological parameter that is not related to metric length, but could be measured by a variety of graph-theoretic or other parameters (for example, the Beta index, the ratio of links to nodes. Connectivity would be particularly important for public transport, i.e., modes following fixed routes with fixed (limited) points of access and with fixed service times (implying connection in time as well as space). Directness could be disaggregated by individual OD (origin-destination) pair and weighted by the significance of OD pairs in terms of actual trip-making (network use or demand).

Both directness and route density are shown with a 'horizontal gradient' in Figure 7. Note, however, that in some kinds of urban development, there may only be a single network catering for motor vehicles, pedestrian and cyclists, in other words with no additional pedestrian-only or cycle routes, in which case the route density would be the same for all the private modes, and the gradient would be as per (a).

3.8 Vehicle capacity and vehicle occupancy

While vehicle capacity is fixed for a given vehicle type, actual vehicle occupancy (actual numbers carried) will vary by individual trip (Potter, 2003). Figure 8 shows two contrasting cases illustrating peak and off-peak conditions. In the first case (a) – the peak case – public transport runs full to capacity. In the off-peak case (b), public transport runs fairly empty, and the number of people carried per vehicle is relatively much closer to the number of people carried per car.

3.9 Vehicle occupancy and energy

Figure 9 shows the consequences for energy consumption per passenger km, (implicitly assuming a fixed energy consumption per vehicle km). That is, under peak conditions we would expect car use (especially solo car use) to use the most energy per person, whereas in off-peak conditions, the energy per passenger km may be roughly similar between cars and public transport.

3.10 Convenience

User convenience effectively equates with the sum of the user benefits of speed, range, door-to-door penetration and directness – and the 'private' transport benefits of the ability to go anywhere at any time (Table 8).

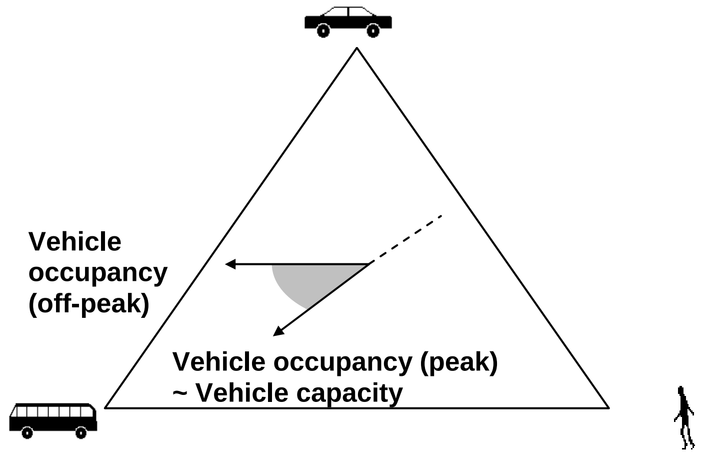

Figure 8. Vehicle capacity and vehicle occupancy.

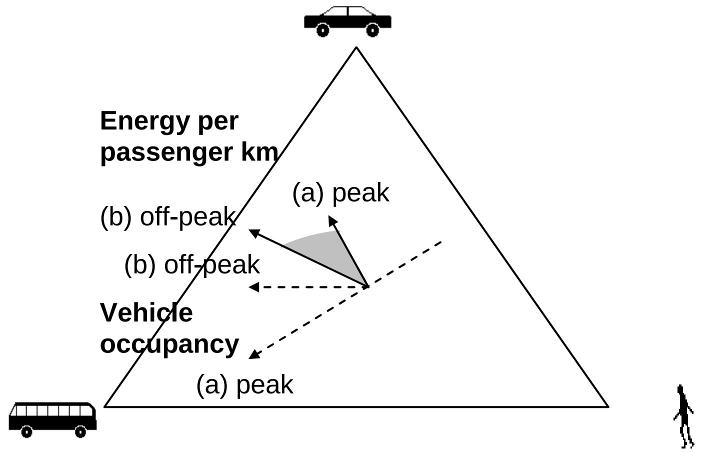

Figure 9. Vehicle occupancy and energy efficiency

Table 8. User convenience

Transport mode	Mechanisation (Fast, far and effortless travel)	Choice (any time, place) and access (directness and door-to-door penetration)	Convenience or Constraint
Pedestrian	Lowest	Highest	Constrained
Bicycle	Low	High	Constrained
Motorcycle	High	High	Convenient
Car	High	High	Convenient
Bus	High	Low	Constrained
Train	High	Lowest	Constrained

The car and motorcycle lie at the ‘apex of automobility’, in being able to take the traveller any place, over any distance, at any time.

What we can also see is that the modes labelled ‘convenient’ are comprehensive, whereas those labelled ‘constrained’ are not. Public transport and the pedestrian cannot necessarily deliver a full range of accessibility – they may deliver long range *or* door-to-door access, but not both. Broadly speaking, the more collective the mode, the less flexible it is (even a tandem requires coincidence of trips and tripmakers). Meanwhile, the less power-assisted, the more limited is the range.

These 'constrained' modes can however form part of a comprehensive system that provides an alternative system to the car. This is why these constrained modes can be considered complementary. When comparing or contrasting the car with the alternatives, it is really the combined complementary system that ought to be compared, for example, bus plus walk, or train plus bike, rather than the individual modes on their own.

3.11 'Green-ness'

Sustainability is a complex issue. Using one's car to take bottles to the recycling plant, or working from home but living further from work, or using environmentally-friendly materials that must be imported over long distances each involve trade-offs that mean recognising 'sustainable' outcomes is not always a straightforward issue (Marshall, 2004). This paper cannot attempt to address the whole issue of sustainability, but aims to provide some pointers to help map the different modes relative to the *de facto* urban transport policies oriented to 'greener modes'.

For the purposes of this paper, we can use the term 'green' as a shorthand indication of environmental sustainability. In this sense, we can refer to buses and trains as 'greener' modes than cars, and walking and cycling as 'green modes', as a shorthand, without necessarily implying any absolute or objective indication of sustainability.

The basic relationship focused on here is that the more persons carried for less energy, the greener. Green-ness is proportional to vehicle occupancy divided by energy (cf. Figure 9). The 'green-ness' gradient here is clearly a simplification, as it does not take account of other externalities and environmental costs, such as land consumption or accidents, or factors such as health or the global distribution of costs and benefits. Taking the various factors together, however, the intention here is simply to show that, very generally speaking, the most convenient modes are the least green (Figure 10). This represents a challenge to policy-makers.

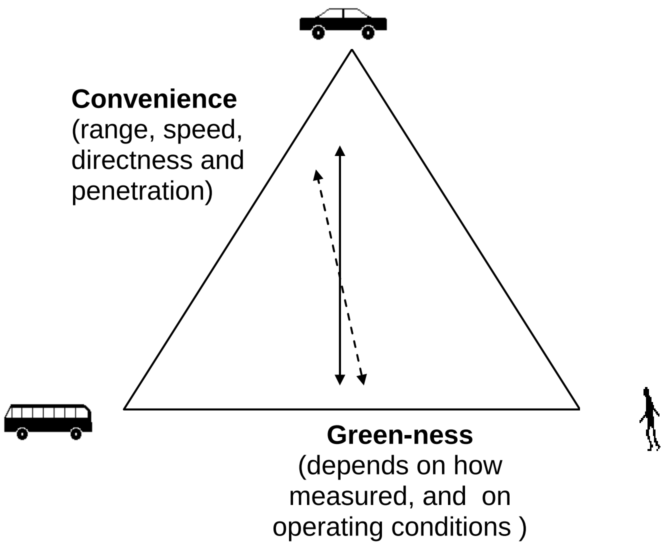

Figure 10. Green-ness versus convenience

3.12 Conclusions on the modegram

The modegram has been used to explore relationships between modes. Some indicative data has been used to demonstrate the use of the modegram, although to fully explore the relationships, more data would be needed to establish relationships and linkages in specific contexts.

In a normal graphical presentation, axes are first decided and then the plot is populated with data – ie, cases are plotted. Although the modegram can be used in this way, it can also be used the other way around: a set of modes is first laid out and then axes (parametric relationships) are added.

The reason for doing this is that often, crudely, it is modes that policy primarily deals with. That is, policy imperatives typically try to curb car dependency, to promote walking, cycling and public transport. They tend to do this, rather than promote high vehicle occupancy or energy efficiency *per se*. Therefore, the generic entities of 'pedestrian' 'car; and 'public transport' can be seen as the 'founding cornerstones' of the modegram; we later retrofit this with actual parameters or axes.

It should therefore be emphasised here that the modegram relationships are not intended to propose rigid generic relationships between parameters (for example, implying that there is a necessary direct relationship between, say, speed and energy). These relationships will all vary from place to place, time to time, and by different kinds of use of the same kinds of vehicle, in principle varying for every trip in realtime.

Rather, the modegram can be used to compare different circumstances – such as different cities – by scrutinising the different relationships relative to each other, for example, comparing a given new town with a given historic town, for which the access density 'gradient' is demonstrably different.

The modegram could therefore be seen as a rough 'sustainability indicator', in the sense of roughly indicating the 'more sustainable' circumstances, or circumstances that favour 'more sustainable modes' differentially over 'less sustainable modes'.

In addition to the parameters discussed here, the modegram could also be related to macro spatial patterns of urban development, such as localised (one to one), centripetal (many to one) and dispersed (many to many) forms – as per the 'Brotchie triangle' – demonstrating overall linkages between different transport modes, network structures and urban settlement patterns (Brotchie, 1984).

Overall, the modegram can be seen as a 'fitness landscape' – a construct demonstrating the possibility for viability of different modes. Along the left hand and right hand bounds are modes offering a clear advantage somewhere along the spectrum of trade-offs between 'individualism' and 'mechanisation'. Those modes in the interior cannot necessarily offer either a competitive degree of individualism or a competitive degree of mechanisation. The modegram therefore can help map out where we might find the extinction of old modes and potential niches for new ones.

4. Evolution of modes and modal fit

4.1 Emerging modes

There are range of possible directions for new kinds of vehicle technology, relating to alternative fuels and engine types. These include, for example, alternative fuel vehicles (AFV), battery electric vehicles (BEV); hybrid electric vehicle (HEV) and fuel cell electric vehicle (FCEV) (See for example Kemp and Simon, 2001; Johansson, 2003; Khare and Sharma, 2003).

To some extent these aspire to serve the function of existing modes (eg, the internal combustion or conventional diesel engine) but using alternative technologies. To some extent the new vehicle types might provide superior performance; but for starters, the main thrust is to provide something that is at least as attractive as existing vehicle types – for example, to produce a car that can deliver the range, speed, acceleration, comfort, etc. of conventional car.

However, the concern of this paper is to ask if it is possible that a lower performance vehicle could find a competitive niche. Here, we concentrate on alternatives to the conventional car. For example, the battery electric vehicle is considered to have relatively poor prospects for competing with or supplanting the internal combustion engine car, due to its limited speed and range (Johansson, 2003:142; Sperling, 2003: 191). Yet, this speed and range, although limited, could still in principle satisfy a reasonably substantial proportion of trips, especially in the urban context, if people could be encouraged to use those vehicles for those trips.

The barriers to viability for a new technology arise partly through the evolutionary paths taken through history, and what comes first chronologically. For example, had railways been invented before canals, perhaps canals would never have been built. Had railways not been invented at all, they might not be viable to construct from scratch today. Had the internal combustion engine not been invented, perhaps more effort would have been put into developing electric cars as a clean, fast and convenient alternative to the horse-drawn transport. As Sperling notes, "the incumbent technologies are typically 'locked in' and have a series of *network relationships* that reinforce their continued use" (2003:196; emphasis added).

The question becomes: what regulatory and network levers together could be used to encourage the emerging modes to gain a foothold?

4.2 Regulatory 'speciation'

For a start, for new car-like modes to gain a foothold, it could be beneficial to have a 'speciation' – or divergence of modes. That is, instead of having a single mode 'the car' – that covers everything from a small two-seater to large estate car – if the mode is divided into two or more variants, then it may be possible to apply differential treatment to favour the more efficient, 'sustainable' variants.

The idea of creating different classes of car – one for the highway and one for the city is not new: Lewis Mumford suggested it as far back as the early 1960s (Mumford, 1961; 1964; see also Kemp and Simon, 2001). The difference is that now, there is both the ecologically driven political imperative to do so, and the technological promise of being able to make the distinction work in terms of 'clean' as well as compact vehicles.

4.3 Evolving a new modal fit

The idea of evolving a new modal fit is compatible with the principles of 'strategic niche management'. According to Hoogma *et al.* (2002:4), strategic niche management rests on two fundamental assumptions:

> "The first assumption is that the introduction of new technologies is a social process that is neither an unavoidable deterministic result of an internal scientific and technological logic, nor a simple outcome of the operation of the market mechanisms. … The second assumption is that it makes sense to experiment with the co-evolutionary nature of technology."

Hoogma *et al.* go on to note:

> "While the initial *speciation* event might be minor in the sense that the technology does not differ substantially from its predecessor, it triggers a divergent evolutionary path" (2002:25).

In the case of modal fit, the idea would be to create new categories of vehicle type that could be promoted in different ways. This means that a clear advantage can be given to those who choose to use the smaller, cleaner, more compact vehicles. For example, streets for the sole use of compact vehicles could have dedicated 'compact' parking spaces (e.g. end-on spaces); such streets would reach more closely to destinations; they may well be less congested, at least in the first instance (due to the relative scarcity of the vehicle type) conveying an immediate step change in favourability, to help the vehicle class gain a foothold.

Once people are used to a system of accessibility based on this kind of choice of modes, it should then be easier to gradually introduce the more novel technologies, such as fuel cell electric vehicles. These vehicles will have a clear (and clean) place to go. Over time, as a greater proportion of the urban fleet becomes clean; a higher proportion of streets would become 'clean-only'. Eventually, motorway-going fossil-fuel vehicles would be confined to relatively coarse networks of streets and parking garages (see also Crawford's suggestions for parking garages on the periphery of car-free cities, 2000). This would still allow these to access most areas of the city, though not immediate access to all premises – they may rather be confined to a system of main roads and parking garages (just as dangerous but cherished wild creatures may be confined to constricted 'habitat' for their own and everyone else's good).

This would then give big interurban cars an accessibility profile closer to that of public transport. That is, walking distance to a parking space would be relatively close to the average walking distance to a public transport stop. It is also possible that they would be used for higher occupancy trips, such as out-of town holiday trips – and be therefore more akin to public transport energy efficiency per passenger kilometre, although the trip patterns would likely differ from public transport in other respects (eg, off-peak tangential versus peak radial).

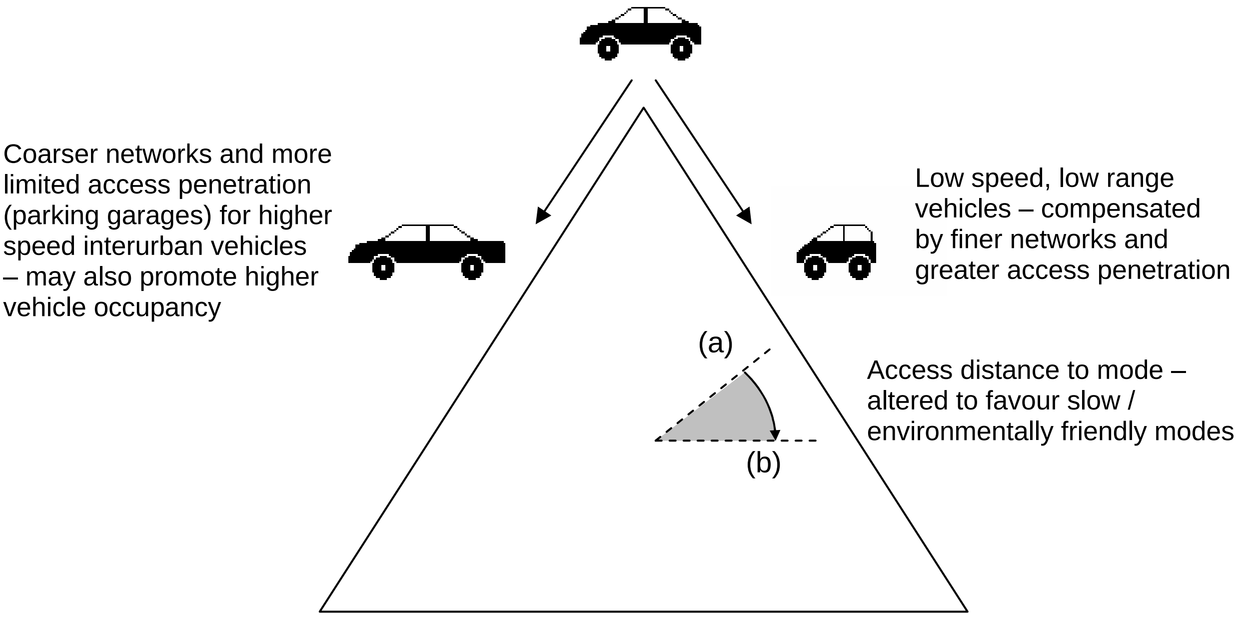

Figure 11. Speciation of modes, plus change in network-mode relationships
(a) route density and access density for cars equal to those for pedestrians (e.g. door to door)
(b) route density and access density greater for pedestrians than cars

This 'speciation' can be expressed on the modegram as shown in Figure 11. Rather than a monolithic mode of 'the car', which must be put up with or restricted indiscriminately, people have a choice, or trade-off, between different aspects of convenience (Table 9).

Table 9. Trade-offs of convenience

	Inter-urban car	Compact city car
Speed	Conventional top speed	*Limited top speed*
Range	Conventional range	*Limited range*
Directness (route density)	*Limited network directness (coarser grained)*	Conventional street network directness
Penetration (access density)	*Limited (not direct access to every destination)*	Door-to-door

The two upper right items (in italic in Table 9) are the 'new vehicle technology' interventions; the two lower left are the 'new network structure' interventions. The distinction between the two different kinds of vehicle/network itself relies on the implied new regulatory regime.

The sustainability benefit could therefore be realised in different ways; for example, lower energy per passenger km could be achieved in the case of conventional cars by boosting vehicle occupancy; for compact city cars lower energy per passenger km could be achieved by using lower energy for the same passenger km.

Note that in the foregoing discussion, a short to medium term time horizon is envisaged in which limited speed, limited range vehicles are being promoted, in advance of a longer term future in which 'clean' vehicles are not so limited in performance, or, in which all vehicles with conventional performance are 'clean'. The foregoing discussion is, in other words, addressing what could be regarded as a transitional phase – and yet, from a long term evolutionary perspective, any period could be seen as such, and it is not so much that it is a transition between a given 'before' and a given 'after', but what kind of after is arrived at, through the particular kind of transition embarked upon.

4.3 Evolving network niches

The question becomes one of whether it would be possible to deliberately create urban environmental / infrastructural niche for such vehicles to occupy. This could include, for example, clean-car only zones (Figure 12, 13). This broadly equates, for example, with the UK 'clear zones' concept (Banister, 2002).

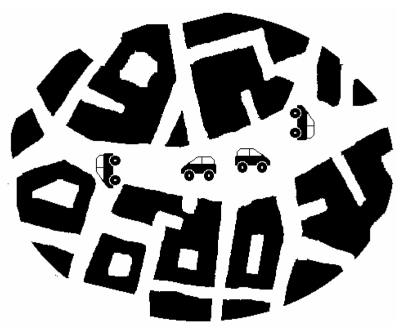

Figure 12. Compact cars for compact cities?

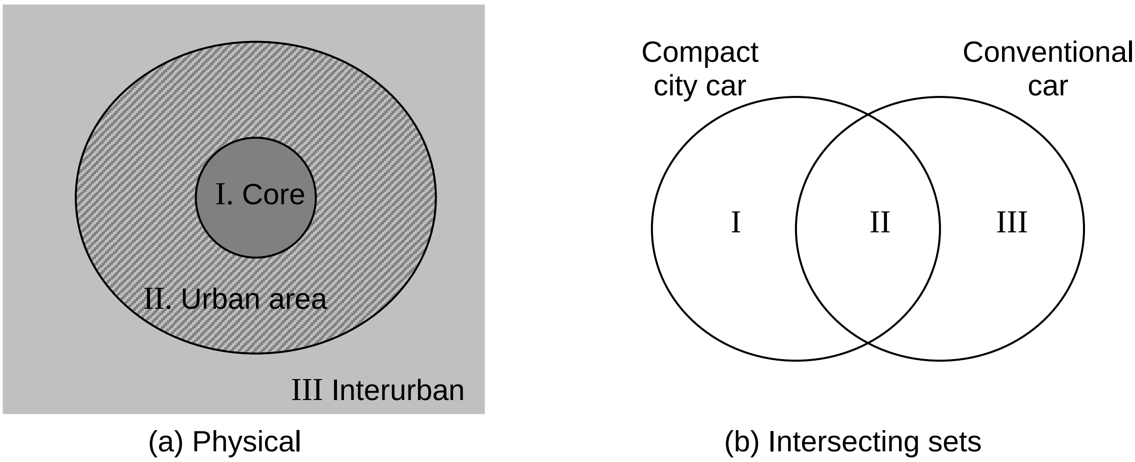

Figure 13. Zonal–concentric model for modal accessibility

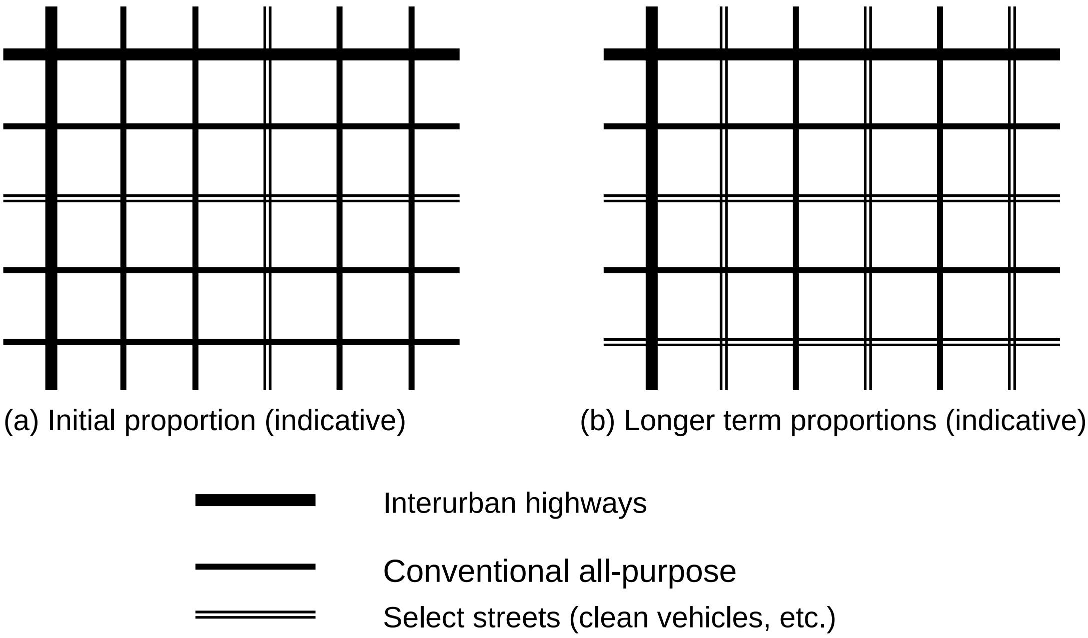

Figure 14. ‘Tartan grid’ model for modal accessibility.
Note: ‘Select street’ is so termed because it is a street type designed to selectively favour certain modes, or modal combinations (for example, bicycle and/or clean motorcycle and/or compact car).

Alternatively (or additionally), it would be possible to have an interweaving mesh of routes – like a ‘tartan grid’ pattern – where alternate streets were used by different modes (Figure 14). Such a system would allow inter-penetration of all modes to all parts of an urban area, rather than being ‘zoned off’ or having some zones inaccessible to some zones. There could be differentiation of network coarseness, for example, to have coarser networks for fossil fuel modes, and finer scale networks for ‘clean’ modes and/or slow modes. This gives the advantages of greater penetration and accessibility to the more environmentally favoured modes (Marshall, 2004).

The mesh of different type of street creates a micro-scale accessibility profile, akin to the Dutch ‘ABC’ system, but where each ‘node’ is a street intersection may be rated in terms of which streets associated with which modes are present.

This envisaged system has the advantages of gradualism – it does not mean that suddenly a whole area of the city is cut off from use by the kinds of vehicle used by the majority of the populace. Rather, there is selective curtailment of the network for the current majority (conventional) modes, and selective expansion of capacity afforded to the to-be-encouraged emerging modes.

The result of the tartan pattern is that areas accessible to the different kinds of car are spread more or less evenly across the urban area, albeit that there will be small pockets not directly accessible to one mode or the other, although these pockets would be on a finer scale than a blanket area ban.

5. Conclusions

People like cars – so much so, that policy-makers or politicians are fearful of antagonising the car-loving majority. But if there were more car-like alternatives available that combined some of the advantages of the car, but with limited speed and range, then it might be possible to evolve a better 'fit' between people's needs, their vehicles and urban forms. Moreover, the gradual evolutionary policy steps to get there could potentially ease the transition away from dependence on the conventional car, where a leap from the car-dependent to the car-less is too great a step presently for the majority to make.

This could be done, it is suggested, by creating a distinct more favourable 'network environment'; this paper has done so by suggesting how different 'network structure levers' – a combination of access density (penetration) and route density (or directness) – in conjunction with regulatory levers (eg, recognition of city car as a separate mode) can differentially favour the more clean, compact modes – 'compact cars for compact cities'.

This possibility has been explored using a conceptual device, the 'modegram', which can help conceive and explore different network parameters, policy degrees of freedom and potential interventions, and their differential effects on different modes. This may be used to assist understanding towards the further evolution of a new 'modal fit' between new kinds of modes and new forms of networks.

References

Banister, D., 2002. Transport Planning (2nd Edition), Spon, London.

Banister, D., Marshall, S., 2000. Encouraging Transport Alternatives: Good Practice in Reducing Travel, The Stationery Office, London.

Brotchie, J. F., 1984. Technological change and urban form, Environment and Planning A 16 583–596.

Cervero, R., 1998. The Transit Metropolis: A Global Inquiry, Island Press, Washington, DC and Covelo, CA.

Clark, C., 1958. Transport – maker and breaker of cities, The Town Planning Review 28 (4) 237–250.

Dimitriou, H., 1995. A Developmental Approach to Urban Transport Planning. An Indonesian Illustration, Avebury, Aldershot.

Garbrecht, D., 1997. Walking and public transport: two sides of the same coin. In: Tolley, R. (Ed.), The Greening of Urban Transport, John Wiley & Sons, Chichester.

Harwood, D., 1992. Traffic and vehicle operating characteristics. In: Pline, (Ed.) Traffic Engineering Handbook (4th Edition), Prentice Hall, Englewood Cliffs.

Hathway, G., 1985. Low-Cost Vehicles, Options for Moving People and Goods, Intermediate Technology Publications, London.

Hoogma, R., Kemp, R., Schot, J. and Truffer, B., 2002. Experimenting for Sustainable Transport: The Approach of Strategic Niche Management, Spon, London.

Johansson, B., 2003. Transportation fuels – a system perspective. In: Hensher, D. A. and Button, K. J. (Eds.), Handbook of Transport and the Environment, Elsevier, Oxford.

Kemp, R. and Simon, B., 2001. Electric vehicles: a socio-technical scenario study. In: Feitelson, E. and Verhoef, E. T. (Eds.), Transport and Environment. In Search of Sustainable Solutions, Edward Elgar, Cheltenham.

Khare, M. and Sharma, P., 2003. Fuel options. In: Hensher, D. A. and Button, K. J. (Eds.) Handbook of Transport and the Environment, Elsevier, Oxford.

Llewelyn-Davies, 2000. Urban Design Compendium, English Partnerships, London.

Marshall, S., 2001. Public transport orientated urban design. In: Feitelson, E. and Verhoef, E. (Eds.), Transport and Environment: In Search of Sustainable Solutions, Edward Elgar, Cheltenham.

Marshall, S., 2004. Streets and Patterns, Spon Press, London (in press).

Mumford, L., 1961. The City in History. Its Origins, its Transformations, and its Prospects, Harcourt, Brace and Company, San Diego.

Mumford, L., 1964. The Highway in the City, Secker and Warburg, London.

Njenga, P. and Davis, A., 2003. Drawing the road map to rural poverty reduction, Transport Reviews 23 (2) 217–241.

Potter, S., 2003. Transport, energy and emissions: urban public transport. In: Hensher, D. A. and Button, K. J. (Eds.), Handbook of Transport and the Environment, Elsevier, Oxford.

Richards, B., 2001. Future Transport in Cities. Spon Press: London and New York.

Sperling, D., 2003. Cleaner vehicles. In: Hensher, D. A. and Button, K. J. (Eds.), Handbook of Transport and the Environment, Elsevier, Oxford.

Taylor, M. A. P., 1999. Using network reliability concepts for traffic calming: permeability, approachability and tortuosity in network design. Paper presented at Newcastle University (July 1999).

Vaughan, R., 1987. Urban Spatial Traffic Patterns, Pion, London.