Energy, Transport and Sustainability: Discovering Pathways to 2040

The relationship of transport networks, transport energy, and urban form

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Transport mode, transport energy, urban form

Abstract

This paper outlines the findings of a collection of research projects directed at the relationship of transport, energy, and urban form.

The dominant factor in shaping urban form at the city scale over the last 150 years has been the nature of the transport network; while the transport network appears to have been shaped by the nature of the energy available for transport.

By altering the spatial value across cities, the transport network directly influences both the size of cities and the location of activities within them. The decline of previously dominant modes of transport stems not just from user choice, but also from the way the car-based era has made it difficult for other modes to be effective. Nevertheless there are a number of examples of successful integration of transit networks within car-based cities from which we can draw lessons.

The search for a low carbon transport future needs to be more than just a search for a different form of energy to fuel the status quo. Rather, it should be how to base a viable transport network on the future energy available and how to manipulate this network so as to alter the urban form so as to greatly reduce carbon emissions.

Introduction

At present there is considerable discussion around urban form. Several cities, for example Wellington city, the Auckland region and Christchurch, have strategies for more compact forms, which are seen as means of adjusting to increased populations without expanding the reach of urban infrastructure, but particularly as a potential solution for transport issues. This discussion is not new, with the New Zealand government being criticised in the 1950s for developing large sprawling suburbs of state houses. At that time energy was plentiful and the issue was one of reducing the take of quality agricultural land, the general environment, and of having more heterogeneous living suburbs. Since the mid 1980s, the issues of addressing climate change have become more prominent, and to these issues since 2000 has been added the issue of peak oil and uncertainty in energy supply, which has in turn increased the prominence of transport in the debate.

There have been numerous studies into the relationship of urban form and transport, so much so that there are even a number of synthesis studies. Hughes[1] shows the usage of transport energy in relation to city area; Ewing and Cervero[2] show travel distance and travel frequency in connection with different types of suburbs; Litman[3] links the type of public transport (bus or rail) to its level of patronage.

In endeavouring to understand the wider relationship between urban form and transport, much of the literature does not help. Much focuses on a quite small scale such as a transit oriented development (TOD) or suburb. In addition, especially in New Zealand, our cities are so car oriented that we can see only minor variants within this dominant trend. For example, even those people without cars are twice as likely to travel as a passenger in another car than travel on public transport[4].

The approach taken in this paper is that in order to understand this wider relationship between urban form and transport we need to look back over several different eras when forms of transport other than cars, and forms of energy other than oil, were dominant. Further, in understanding this relationship of transport and urban form, we understand how our cities were put together and function and the extent that they are able to be transformed as we look towards coming eras with different energy form.

An alternative literature to most of the transport studies above, urban morphology, sets out much of the urban process and in understanding the transport-urban form relationship two sources are very useful. Vance[5] provides an explanation based around transport systems. Whitehand[6] gives an explanation based on cycles of building activity; in which residential, commercial, and government buildings and spaces are added cyclically, but at different points on the cycle, with spatial value being a dominant factor in their location.

This urban morphology approach is that our cities can be viewed as an accumulation of past activity, used, modified, and added to by the present inhabitants, then passed onto succeeding inhabitants. Because the cities are this accumulation, much of what may have developed for circumstances substantially different than now, still remains even though its original purpose has long since passed. In transport this is particularly relevant almost the entire street layout from walking and public transport eras remains.

Drawing both the transport and the building cycles strands together it can be seen that transport has a dominant role in the form of cities, with the transport network creating a set of spatial values across the landscape which affects the location of activities and influences the way in which components of cities such as residences, retail, and industry interact. In Vance's analysis, transport is not the driver of form, (the drivers being often economic, or demographic, or home ownership,) but transport regulates the way that the form of the city changes in response to the form-drivers.

Vance describes the major transport modes and their effect on form. Table 1 identifies the main types relevant to urban areas; comprising walking, horse drawn trams, electric trams, rapid transit, and car-based cities. Each mode has a distinct era in which it was dominant and a distinct associated urban form.

The range of each of mode is important for form, where range is a combination of speed and time that people allocate to travel. Range influences the form by first setting the ultimate size of the city. Secondly, when range is limited relative to what the city must contain, the form densifies and gains in height.

The first of the four eras is the walking era which persisted until approximately 1850 up to which time almost all cities of the world were essentially very overcrowded pedestrian precincts, little more than 1.6 kilometres in radius. Where steam-train transport existed, it generated a series of pedestrianised settlements spaced at about 5 kilometre centres linked by the train system. These cities were very crowded and, invariably, unhealthy. So it is notable that even with an extremely strong incentive to walk further, this 1.6 kilometre radius is the practical limit. When everybody walks, rather than just the fit section of the community walking, the average speed decreases and automatically so does the effective range[7].

The development of the horse-drawn omnibus (France, 1837), and the horse-drawn tram (United States, 1850), the second era, enabled the release of the overcrowded city into one of wider radius, about four to five kilometres, with consequent lower population density. Accompanying changes were from crowded rented multi-unit housing to owned detached cottages, with the wealthiest residents moving to the city perimeter and a wealth gradient back inwards to the old core. The horse-drawn modes of transport made a new more dispersed lifestyle possible while population growth continued the expansion of settlements, with the wealthy continuing to move outwards and the upwardly mobile following behind.

But four to five kilometres is the effective limit of horse-drawn transport. Ongoing population growth therefore resulted in consolidation infill and other densification processes, such as taller multi-level buildings. This consolidation phase was then relieved by the electric tram, with its effective travel range of about ten to twelve kilometres, which was in turn succeeded by wider ranging rapid mass transit systems and finally cars.

The following table shows each transport mode, its effective range, and the resultant potential city area.

Mode	Range of travel enabled	Settlement area enabled
Walking	1.6 to 2 kilometre	up to 15 square kilometre
Horse-drawn vehicle	4 to 5 kilometre	50 to 80 square kilometre
Electric tram	10 to 12 kilometre	300 to 450 square kilometre
Rapid transit	30 to 40 kilometre	2,500 to 5,000 square kilometre
Cars	About 60 kilometre	to 11,000 square kilometre

The "change in city size" via "change in transport technology" is significant in that, while each change allowed an expansion of the city, it also made the previous transport technology less effective. For example, with the change from walking to horse-drawn tram it became difficult to walk to all parts of a city now about five kilometres in radius. As the table above shows, a walker-only can access only about 5 percent of an electric tram-based settlement. Of course at the time, people would have walked and used the tram as all parts of the city were accessible by this combination. However the significance for now is if we hope for the process to be reversed and for car users to use only public transport systems. Very few of New Zealand current cities have a full public transport service that would allow for this change unless an individual was prepared to live in a very much reduced area of the city. Similarly cars have enabled large dispersed cities with form that makes it difficult for trams, or their modern equivalent, to be effective in the outer regions.

It is not just the change in settlement size that is significant. Changes in transport technology also cause the key components of the city to alter their relative locations.

Tram systems allowed for the outward expansion of the population into suburbs, and they also altered the nature of the commercial core. Some industry that was previously centrally located followed the population outwards, the commercial hub moved from near the wharves or railhead to where the tramlines converged, and the heavy foot traffic drawn stimulated the growth of department stores and similar mass retail at this point of convergence. Retail also grew in the suburbs where several separate tramlines converged and at the terminals of the tramlines.

Cars and trucks have not only allowed industry to move to the periphery of cities, and for people to live anywhere and work anywhere, but the commercial localities have also altered. Retail is now where cars, rather than pedestrians, can readily converge, moving to suburbs. Bulk retail (especially of furnishings, whiteware, hardware, and for gardening) have moved out of the Central Business District area to suburban settings or to regenerating industrial areas.

While it is the transport network that enables form, it is the processes around the creation of buildings, open spaces, and the relative mix of these two that cause urban form to be established and cities to grow.

Whitehand first traces the pace of urban development showing that within western cities, at least, it has never proceeded at an even pace but via a series of cycles of high building activity (of approximately ten to twenty years duration), then periods of low activity. Theories of causes are both at the international level of capital and migration flows between industrialised European countries and developing "New World" countries, and at the national or local level coupled to population growth and economic activity. Whitehand

cites Lewis' theory as his preferred theory; in Lewis' theory the cycles stem from the interaction of population growth (both natural and migratory increases) with credit availability which is synergised by one of more of other changes that boost real incomes. The resulting building boom tends to bridge the shorter term general economic fluctuations and continues until the credit crises, brought on by the strain of the building boom, together with slowing population growth causes excess building stock to develop which in turn hastens the slowdown with impacts across the economy causing reduced incomes and employment, and encouraging emigration.

However the impact of these building cycles on the urban landscape is accentuated by the different building rates for the different categories of: residential; commercial/industrial; Government and non-building land uses such as parks and golf courses. Residential building is the most cyclical; Government building, parks and sports fields have an almost consistent rate of establishment, with the commercial/industrial rate lying between these two. The result is a city built up of zones of a different composition for different eras.
Land value and land use is an inter-linked relationship with land value determining land use and land use determining land value. Whitehand's view is that this needs to be seen as a dynamic relationship over time rather than a static relationship if it is to explain urban processes and that fluctuations in land value correspond to fluctuations in building activity. It is this interaction of land value with building cycles that sets in place processes such as new suburbs at the periphery, infill in existing suburbs, rejuvenation of old areas, and the reuse or replacement of commercial buildings.

New Zealand experience

The New Zealand experience of transport systems mirrored that described by Vance with respect to the northeast American cities and the building cycles mirror the process outlined by Whitehand. Though the New Zealand towns in 1860 were much smaller than those of the time in northeast America, they were effectively pedestrian-only centres, in some cases linked by either small railways or water transport. Each of the transport technologies of America were quite quickly introduced into New Zealand with a delay of only about ten years following their first commercial appearance: Horse drawn trams in the early 1860s, an equivalent unsuccessful use of steam trams by the 1870s. Although the electric tram was invented in only 1882 by 1899 the first system was established in Dunedin, and by 1910, eleven settlements had electric tram systems with most established or under construction by 1905.

The impact of these systems on the urban form were quite deliberate, with the intent being to develop the adjacent land as residential suburbs, and to relieve the overcrowding inherent in a pedestrian-only city. The New Zealand city centres though less overcrowded than American and European counterparts were just as unhealthy, in part because basic infrastructure such as effective sanitation was not yet established.

The suburban growth occurred as expected and commercial areas developed at the termini and intersections of these tram lines, and the Central Business District at the central location of the tramlines. Because the lines radiated out from original settlement the developing Central Business Districts and associated warehouses and industry engulfed much of the original settlement with the residue deteriorating into slum housing, which served as a trigger for slum clearance policies from 1930 to 1950 resulting in

several inner city clusters of medium rise apartment complexes, such as Dixon Street flats and Berhampore in Wellington, and Shortland Street in Auckland.

The 1930s depression and the fuel restrictions of the early 1940s suppressed car uptake but the post-war period marked the transition from the public transport cities and towns to car-based cities. By then New Zealand was a one car per household, motorway construction as the major transport link in metropolitan cities had commenced, and suburban expansion was via subdivision-style where little regard was paid to the provision of public transport systems, and heavy vehicle transport, not rail, is the dominant means for freight.

The market reforms of the 1980s have reinforced the dominance of the car. Policies have lowered vehicle prices by about 30 percent for new cars and 50 percent for used vehicles. As a consequence expenditure on transport has fallen from about 17 percent to only 13 percent of household income. This is despite an ongoing uptake of cars so that now only 7 percent of households do not have access to at least one vehicle and 50 percent of households have two or more vehicles. This low cost of transport has facilitated lifestyles allowing travel over much of the city as well as in the adjacent region. Lifestyles spreading over two settlements are common; the weekday-settlement and the weekend-settlement at the beach, or lake edge, or mountains.

Transport energy

The transport eras sketched out by Vance also coincide with different transport energy. The first two, walking and horse-tram obviously have food as the energy source. But the horse-tram utilises the technology of rails for the more effective use of that energy, so that rather than a team of horses pulling a heavy coach along a crudely formed road, by using rails, two horses could easily pull a tram of about 30 passengers.

Up until about 1910-1920 the main transport fuel was coal. Its first use was in steam engines, but the slow acceleration and difficulty of stopping set a series of townships along a line spaced at about 5 kilometres as the typical form. Steam was found as an inappropriate energy source for urban transport, the steam trains being slow and cumbersome, they frightened animals, and there was the attendant smoke problem and potential fire hazard for the mainly wooden buildings. The electric tram was the result of seeking a better way to use coal as a transport fuel. Rather than attempt to generate steam within a vehicle, steam was generated in a power station, then used to generate electricity, then used via overhead wires to power electric trams which provided a rapid service to the suburbs. Without the need to rest or spell horses between trips, services could be frequent. For example, the Island Bay No. 1 route in 1910 had 105 services per day into town and a corresponding return number; a frequency that is only equalled nowadays on a few of the most heavily patronised routes in New Zealand cities.

Later in New Zealand, coal-based electricity was replaced by hydroelectric power and this change enabled the urban transport system to be resilient to two shocks during World War II; first the shortage of manpower to mine coal (many train services were curtailed), and the shortage of oil for motor vehicles, including buses. Electricity also allowed tram services to be greatly improved so that slow steam trains could be replaced by rapid transit, usually with stations at 1.6 kilometres for medium-speed systems, or 5 kilometres for very rapid transit systems.

Looking at the characteristics of petroleum fuels, it is easy to see why the resultant travel is as it is. Petroleum has a very high energy, delivers almost instant power, was perceived initially as pollution free compared to steam trains, is easily stored, is easily transported, with only a little care is safe, refuelling is simple and achieved within a few minutes, and it is easy to take additional fuel or borrow some if you run out, and especially for the first seventy years, it effectively welled out of the ground for almost free. All of these attributes allow for independent travel so that petroleum became not only an excellent fuel for urban transport but for the first time it allowed for easy travel outside cities into countryside and between cities. It appears from data and commentary dating back to at least 1928 and substantiated by transport studies in the 1960s and 1970s, that this social recreational travel was a major motivator for car uptake; cars which were subsequently then used for other travel. Data of the times show that car ownership was about the same in inner city suburbs with excellent public transport as it was in the outlying suburbs.

It appears that we are now entering another era of transport; one in which petroleum is to a large degree unacceptable, unaffordable, or unobtainable. It appears that the most logical replacement is electricity though whether it is used by fixed wire, by battery, by hydrogen, or in some other way is not yet apparent. What the past advises though is that rather than seek to find an alternate fuel to power the system that we have, we should look at the energy source, understand the best way to use it, and accept that the urban form will evolve around this new transport system.

Transforming cities

After fifty years of car/petroleum-based cities, we are clearly entering an era of change. The Government's goal is to reduce the greenhouse gas emissions from transport by 50 percent per capita by 2040. This will be extremely difficult given that fuel use has been increasing by 2 to 3 percent per year over the last 20 years even though we have now had in place strategies to reduce fuel use by 20 percent for about seven years.

This behaviour is seen as intractable behaviour with people needing more education to see the error of their ways and change and shed their love affair with their cars. The reality is that this behaviour is the rational logical outcome of the economic and policy settings of the last 70 years. Even our provincial cities have expanded well beyond the range which was historically found to be workable when that was the only mode available. Few parts of our cities have a public transport system that offers a sufficient frequency (about 60 services a day) that provides a public transport lifestyle that is roughly equivalent to that enjoyed by car-owners. Where they do exist these services are invariably in the older parts of the city laid out when public transport was the dominant form and are well patronised and probably operate without a subsidy.

Many argue that all we need is an alternate fuel for cars. This ignores the basic congestion problem (and emissions) problem that exists in our cities. Even if every "black" vehicle was replaced by a "green" vehicle, the congestion problem would remain. The traffic forecasters of the 1960s were accurate when they predicted the level of congestion that would occur when our cities reached their current populations unless we also addressed public transport. They were wrong only in the timing that it would take to reach that population.

Even if we could "traffic engineer" our way past this congestion problem, we would remain a high-energy economy and therefore become increasingly uncompetitive with those economies that do succeed in reducing towards having low-energy economies.

Another aspect of the new era is the relatively low population growth. Along with the rest of the world, the last 100 years has been utterly unique in that our population has doubled then doubled again. This will not happen again and forecasts for 2050 are for about a 20 percent increase followed by possible decline. The issue is more how we adapt what we have rather than controlling expansion.

If the Government's target for 2040 is to be achieved then given its enormity an early start is essential. Changing urban form is often quoted as the transport solution but other research is indicating a number of non-transport benefits of the existing urban form. From an energy perspective it appears that we need to transform transport within only modest changes in urban form.
It appears that the most available alternative transport energy, that is proven, is electricity, preferable from renewable sources. And, the best way to use this is in an electrified collective passenger transport system and in electrified railways for freight. There are numerous modern technologies for passenger transport already available.

Much of New Zealand's existing cities evolved around passenger transport systems so the urban form is amenable to improvement or reintroduction of passenger transport systems. However, there will be some problems. Much of the recent additional suburbs have a street pattern less favourable to walking and passenger transport, and some adaptation is necessary. There may be some parts of cities where passenger transport systems do not readily reach. There is also the need to consolidate destinations, rather than disperse them. However, history shows that future growth will evolve around the passenger transport network and over time reinforce its effectiveness.

From a transport perspective, we can divide New Zealand into four settlement types.

1. One large metropolitan area, Auckland (population 1.2 million). More than 75 percent of Auckland has been laid out in the car-dominated era and has a multiplicity of destinations, and so public transport will be difficult in many parts.

2. Two medium sized metropolitan areas, Wellington and Christchurch (total population 0.8 million). These settlements have "good public transport bones" but still have substantial areas with suburbs with street patterns unfavourable to passenger transport and a dispersal of the Central Business District into multiple destinations has occurred.

3. Twelve smaller cities of population each 50,000 to 120,000 (total population about 1.1 million). These cities are still quite compact and fit within a 6 to 8 kilometre radius. Most lives are still lived mainly within the city. This is a settlement size for which a simple public transport system can be effective.

4. Provincial towns, settlements, and rural areas, where the lifestyle still necessitates a high degree of independent travel.

Cervero[8] has identified twelve example cities around the world where public transport is a very significant part of the travel modes. His discussion of public transport types is very helpful in that he shows a match between the public transport type and the city type. Fixed systems such as rail-based rapid transit suit strongly centralised cities, but very small

flexible systems such as vans, taxis, and small buses suit highly dispersed-destination cities. However, from a greenhouse gases perspective it appears these small systems, even if successful, may reduce greenhouse gases only marginally. For New Zealand cities, achieving the Government's CO_2 target needs much more substantial gains than can be achieved via a medium-sized electrified system. Cervero's studies would suggest that such a system may not always fully work initially. However, if urban form modified over time, then the transport system should become successful. From the past experience we can see that urban form does evolve in response to changes in the transport system but it may take 20 to 30 years for this change to evolve.

The Vancouver metropolitan area helps illustrate. A light rapid rail system was built in 1985 and has been extended several times since. With 2.5 million people, Vancouver is more populated than Auckland, but similarly consists of four main cities and is a highly dispersed car-based settlement. Vancouver's rapid rail system is increasingly the core of its public transport system and now heavy densification is occurring at each station along the route.

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