Zooma – A feasible pathway for Australia’s next infrastructure paradigm

Trevor Chorvat ^{a*}

Abstract: There are many paradigms that could shape this century’s infrastructure in Australia, and indeed the world. The suggested pathway – called Zooma – uses a fully automated passenger and freight system (Gazelle) leveraged by a consumer- and business-accessible built-in logistics system (the Super Postal Service). Gazelle uses light small vehicles moving inside an elevated track way. Contact-less propulsion, levitation and switching ensure reliable and efficient operation. Gazelle is self-sufficient in renewable energy. In contrast to linear arterial modes of transport, Gazelle uses a parallel distributed network transport paradigm to increase volume. Zooma’s real-time and predictive costing data facilitates a transport futures market which also helps to reduce congestion and optimises infrastructure utilisation. Zooma provides independent mobility and is a viable choice for people wanting a carbon free alternative to the car without having to forego the convenience of modern life.

Key words: Sustainable; Smart; Transformation; Transport Infrastructure; Renewable Energy; Congestion; Commuting; Transport market; Automation; Integration; Innovation; Land use planning

I. Introduction

Transport depends on one factor that influences the delivery of nearly all human needs – energy. Meeting basic human needs of growing populations in a cohesive social, healthy environmental and sustainable economic context continues to challenge governments around the world. Within this context, shifting energy and transport strategies at the margin have limits to delivering net benefits under prolonged population pressure. In the end, paradigm shifts – a fundamental shift in individual and society’s view of how things work in the world – have to be made in order to ensure desirable social, environmental and economic outcomes. Such shifts are an imperative to creative metropolitan land use planning strategies that lead to reduced conflict involved with urban consolidation and renewal.

New transport infrastructure is now recognised as a pathway to paradigm shifts in land-use planning philosophies. Nine key thematic paradigm shifts in energy and transport that are either currently underway or that could possibly be delivered in the future are presented below.

^a Independent Researcher, Wollongong, NSW, 2519, Australia,(tc@genling.com)

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1. Energy sources from non-renewable to renewable,
2. Fossil-fuel use from extensive to zero,
3. Mode track system capacity in heavy usage times spread from concentrated linear routing to distributed parallel routing,
4. Origin-destination access of shared transport for passenger and for freight from area-to-area to point-to-point,
5. Shared use of transport vehicles from limited to extensive,
6. Digital integration into transport from limited to deep,
7. Vehicle control from manual to automated,
8. Use of transport-dedicated people time from high to low, and
9. Land dedicated to transport use from high to low.

While converting cars to use electric sources of energy may go some way towards delivering renewable energy (theme 1) and fossil-free fuel (theme 2), electric vehicles are unable to deliver on system capacity limits (theme 3). As population pressures increase, more people time is devoted to transport and more resources are allocated to trimming travel time and costs because of congestion. In response, urban dwellers seek shared use of transport vehicles via taxis or public transport. However, these options are either expensive or deliver only area-based origin-to-destination capability (theme 4). Consequently, system networks (theme 3) never shift from concentrated linear routing to distributed parallel routing, which would deliver latent system capacity and reduce congestion in peak periods. Further, shared use of transport vehicles (theme 5) faces difficulty in shifting from limited to extensive. Electric cars (and their variants) will therefore not lead to a paradigm shift in transport. Driver-less cars seem promising. However, the increasingly critical themes of people-time and land-use are missed, and the efficiencies arising from distributed parallel routing are mostly foregone.

A true paradigm shift in transport will only occur when digital integration of transport becomes deep (theme 6) and when fully automated transport becomes available (theme 7). Certainly, GPS, smart devices, telematics systems, timing, alert systems and logistics included in courier and freight tracking systems are assisting existing transport modes to offer a range of new customer value propositions¹. However, these smart systems are hosted on existing transport modes with their attendant track system capacity and origin-to-destination capability characteristics. Driverless cars take the smart use of cars to their logical conclusion². However, the form of the car limits its automation capability and its use in the same space as pedestrians will remain a significant practical problem. Accordingly, only a new mode with the capability to deliver themes 1 to 7 will lead to a true paradigm shift in transport. Such a new mode would engender business innovation and transform customer and household engagement and resource usage³. With economic transformation, improvements in transport-dedicated people time (theme 8) by congestion reduction can be made to enhance city liveability. Further, reduction in land required for transport (theme 9) would provide for a robust metropolitan land use planning strategy platform⁴. The new transport mode is called Gazelle with a customer interface called the Super Postal Service. Together, these two elements form the Zooma paradigm.

The objective of this paper is to show that the proposed solution – Zooma – is a feasible paradigm-shift pathway and warrants funding to a stage where Zooma can be examined on its merits in any global city’s metropolitan urban transport and land use planning strategy. The key elements of the Zooma vision are introduced in the next section. The new automated transport mode called Gazelle is described in Section 3. The Super Postal Service that co-ordinates Gazelle’s new functionality and makes the new logistics functions accessible is outlined in Section 4. Section 5 explains how Zooma transforms transport so that it adds a new element to the converging technologies, creating an ITCT paradigm where Information Technology (IT), Communications (C) and Transport (T) are all integrated. Section 6 briefly describes how the Zooma paradigm addresses the Factor 8 challenge⁵. Section 7 examines whether Zooma is a feasible value proposition along technical, sensory, peak-period operations, pricing and economic dimensions. The final section provides summary and conclusions.

II. The Zooma Vision

The key elements of the Zooma paradigm are presented in Figure 1. Gazelle is a new transport mode; its goal is to provide fully automated transport. Customers use computing and telecommunications systems to interact with the Super Postal Service to send people, postal items and freight to desired locations in the Gazelle network. Customers interact in a similar way that they would with email software, except that physical objects are sent rather than text, pictures and file attachments. Since Gazelle effectively makes transport digital, the Super Postal Service is able to host with other business-to-business systems and transport futures markets. Deep integration of an automated transport mode and its spin-offs would lead to transformation in many economies and address much of the Factor 8 Challenge. More detail on the Zooma concept may be found in Chorvat and Bramma⁶.

Gazelle	Super Postal Service	Transformative Transport	Addressing the Factor 8 Challenge
<ul style="list-style-type: none"> • Fully automated mode • Plats (very light vehicles) • Air cushion levitation • Linear motor propulsion • Contactless switching • Self sufficient in renewable energy • One month energy storage • Elevated enclosed tracks • Access points every 60 metres • High volume • Medium load • Point to point • On demand • Dynamic, globally optimised routing • Fine mesh network 	<ul style="list-style-type: none"> • Allows customers to interact with Gazelle via email-type software • Smart phone SPS transport apps • Each Gazelle access point is a Micro-Post Office • Sends people as well as postal items & freight • Efficient small items transport • Auto-'carpooling' commuting • Dynamic pricing • Range of send options • Care & supervision 	<ul style="list-style-type: none"> • Paradigm shifts: from concentrated to distributed; from linear to mesh; from hierarchical to uniform; from private to public • Intensifies Just-In-Time logistics • Convergence of Transport into Information Technology & Communications: ITCT • Efficient transport market & pricing • True and full costing of transport • Allows business to reshape customer value propositions 	<ul style="list-style-type: none"> • Decouples economy from carbon production • New transport infrastructure capacity that augments existing infrastructure • Frees up land previously dedicated to transport • Returns city to people • Congestion gone • Air pollution gone • Scarce resources used most efficiently • Facilitates increased housing densities • Creative metropolitan transport and landuse planning strategies

Figure 1. Key features of Zooma.

III. Gazelle

The Gazelle transport mode aims to provide fully automated transport of people and goods within a city using a fine-grained mesh network. With this capability Gazelle could replace all cars, taxis, buses, light truck and palletised goods haulage within the city. However, Gazelle could not replace (non-palletised) heavy road transport. Gazelle articulates very well with other modes of transport. In particular, the train system would be able to leverage this articulation capability and gain efficiencies.

Gazelle uses an elevated and enclosed track to give it the security and exclusive right of way required for a safe fully automated system. The track enclosure has continuous windows along each side so that passengers can see out. The Gazelle track enclosure is 2.8 metres (9 feet) in diameter. Nominal track elevation would be 2.3 metres (7.5 feet), sufficient for uninhibited pedestrian and cyclist access under the track. Any road vehicle able to park undercover at a shopping mall or multi-storey car park can move or park under the Gazelle track.

The Gazelle track is single lane and one way. There are no intersections – only splits and merges. The tracks run down the centre of every street and minor road. Gazelle tracks also run down either side of heavy road transport corridors. That way, the current operations of important corridors are retained. It is possible for the direction of Gazelle track to be changed in response to general traffic flow.

Gazelle vehicles travel along the track and are called ‘plats’. Plats are payload platforms and take the form of flat bases. Plats can carry a variety of freight types, or if seats are installed, passengers. Plats are enclosed in a clear aerodynamic shroud in order to minimise drag, as well as allowing passengers to see outside. Plats and their payloads are propelled by a linear electric motor. The weight of the plat and payload is supported by an air cushion. Standard plat speed is 102 kilometres per hour (64 miles per hour).

Payload cross-sectional envelope is 2 metres high by 2 metres wide (6 foot by 6 foot). Payload length can extend to 6.5 metres (21 feet). Payload weight can vary from 760 kilograms to 1,500 kilograms (1670 - 3300 pounds) depending on length of plat. Plats are lightweight, so there is a high payload to weight ratio – an order of magnitude better than for cars.

Access points for the mode are ubiquitous and are positioned every 60 metres (200 feet) along the track, with 6.5 metre (21 feet) roll-on-roll-off access points every kilometre. Getting the payload to and from ground level is achieved by rapid lifts. Business truck loading bays are replaced by Gazelle auto-ports that can automatically dispatch or receive freight. Small, light, short-haul electric vehicles purpose-built for their accessibility and utility provide mobility for loads beyond the Gazelle track. Such light electric vehicles can be used for domestic trades purposes. The Gazelle track transports the electric vehicles over distance and provides recharging facilities for them, so they need only carry minimal battery weight and need only be designed to withstand crash tests for speeds at or below 40 kilometres per hour (25 miles per hour).

The roof of the Gazelle track is covered with photovoltaic panels, which provide the electrical energy to operate the entire system. Integrated electric storage units provide sufficient storage capacity for 25 days ‘sunless’ operation, with total recharge in 10 days (based on an example using Sydney, Australia, which has average daily operations supporting 23 million passenger trips and 50 million tonne-kilometres of freight per workday⁷). The track includes its own electricity distribution network. The electricity storage and distribution capability of Gazelle can serve as a ‘renewable energy infrastructure’ – facilitating the more widespread use of renewable energy sources.

The Gazelle network is controlled by computers. The speed and routing of every plat is controlled entirely through the track. There is no on-board power or control requirement. Globally optimised routing avoids congestion and flexibly re-routes plats around any track unavailability. While plats are driverless, they are not unsupervised. The Super Postal Service provides integrated payload supervision and care.

IV. Super Postal Service

Figure 2 displays the key components of the Super Postal Service. A postal service is an organisation that provides guaranteed levels of care and delivery of mail and parcels at an economical cost. The service takes responsibility for transporting your goods safely. You can send and forget, assured that your parcel or letter will arrive safely and timely at its destination. A super postal service extends this to provide for sending both people and freight. The idea is that you can ‘post’ yourself to work or you can ‘post’ your child to ballet lessons. In contrast, the current practice is to use a manual personal transport system composed of taxis or cars.

Figure 2. Key Features of the Super Postal Service.

Customers access Gazelle and the Super Postal Service via their smart mobile device, personal computer or internet-connected business systems. Essential to the Super Postal Service is its attribute of ‘being everywhere’ or its ubiquity. The Super Postal Service leverages the ubiquity of the Gazelle access points: post boxes in a range of sizes form a micro-post-office in the wall of one end of each access point. Such ubiquity locates a micro-post-office within 30

metres (100 feet) of all residential homes, and at the doorstep and loading bay of every business. The Super Postal Service is transparent – driven by the automation and control within Gazelle systems. A transport customer can see the status of all packages (goods or people) sent, received, and in-transit via their hand-held electronic device. The transport customer is notified when any of the packages change status. And so transport customers are always in the loop, fully informed at all times, in control of what happens to packages and where they go. Importantly, the Super Postal Service supplies a digital platform to enable economic transformation using a transport mode.

V. Transformative Transport

The cornerstone of current transport systems is the fixed and linear system within a grid or radial framework. Such systems foster congestion because users are forced to congregate on major thoroughfares. In these days of online navigation systems real-time information about delays on the current route are available, but of limited use as alternate routing options are difficult to reach since travel through back streets is – rightly – discouraged. In contrast, Zooma offers a distributed parallel transport network where real-time supply and demand information is used to route traffic across the network more evenly. With more efficient use of network capacity, travel times are reduced and more equitably spread among Zooma users.

Transformative transport comes about as Zooma integrates with systems used by households, businesses and government to deliver smart transport. Such integration will leverage off Gazelle's automation and the Super Postal Service's accessible functionality to co-ordinate the logistic functions. While Zooma initially adds to existing transport infrastructure capacity, as business practices change to integrate Gazelle and the Super Postal Service more fully into an economy, Zooma will replace existing transport modes and transform the transport market.

Fully automated transport would add value to transport. Computer systems that control the low level movement of goods and people can be designed to also provide high level, integrated functionality into business, or Business-to-Business Transport, and Just-in-Time Transport and Built-in Logistics. Using Zooma, transport services become very similar to a telecommunications utility in terms of forward bookings, level of service, dynamic pricing, billing and so on. For example, Zooma enables businesses to have on-demand transport in the form of plats (rather than a fleet of taxis or light taxi trucks). Manufacturers would no longer need to wait until sufficient produce is accumulated for a whole truckload before dispatching. Retailers are supplied goods sooner. A more direct producer-consumer relationship is fostered.

A well-functioning transport futures market would develop because a reference computer system has information about future network usage via the Super Postal Service. The Super Postal Service also provides easy access to the market for users. Moreover, the interaction of users supplying data on their people and product space requirements together with timing, sources and destinations establishes the framework on which user charges would be set consistently across an entire Zooma network, and provide incentive for Zooma users to make the most cost-efficient choices. A transport futures market avoids congestion before it happens, rationing overall use of the available capacity of the Zooma network in the most efficient way. Customers are rewarded for their advance notifications with cheaper transport.

Zooma transport infrastructure therefore has many channels through which economic transformation can occur in order to address the Factor 8 challenge.

VI. Addressing the Factor 8 challenge

“Given that infrastructure is not an ‘engineering artefact’ but an ‘agent of change’, is it possible to imagine infrastructure systems that can meet the needs of twice today’s population with half today’s resources while providing twice the liveability? (Factor 8)”⁸

The Zooma paradigm delivers positive associations for supporting **double the population** through lower energy use, lower transport costs, lower supply-chain and end-point food wastage, reduced competition by bio-fuels and fossil-fuel extraction (such as Coal Seam Gas) on agricultural land and water resources and reduced physical footprint on landscape by the transport system (less disruptive to habitat and agriculture). Competition for land within cities from the transport and logistics services would be significantly reduced. Energy security would be enhanced.

Zooma assists in **halving the resource footprint** by supercharging the utility and effectiveness of co-operative consumption. Zooma facilitates a market for recycling, repurposing and re-use by making resource movement easier and cheaper from someone who doesn’t want it to someone who does. Zooma is long-lived, ethically-used, ethically-sourced infrastructure with a life span of over 50 years. Zooma would assist in driving transport fossil fuel usage to zero and preserving limited fossil fuel resources for the more valuable and more sustainable petrochemicals industry.

The Zooma paradigm enables positive connections for **doubling the liveability** in cities via several channels including elimination of congestion and pollution, green space enhancement, health and safety improvement, transport accident minimisation and active lifestyle facilitation. Zooma could improve mental health by reducing commuter issues, road rage, road accidents, public transport overcrowding, sirens at night, road noise and stress for pedestrians and cyclists. Connecting isolated elderly and disabled people improves their quality of life and general health and wellbeing.

VII. A Feasible Pathway

This section presents a pre-feasibility evaluation of Zooma along technical, sensory, peak-period operations, pricing and economic dimensions.

A. Technical Feasibility

Energy calculations for the Gazelle design have shown potential for a technically feasible solution. Table 1 shows energy use by Gazelle in terms of watt hours (Wh) under four different plat possibilities: 4-seater passenger (full) commute, 6-seater passenger commute (full and empty) and 2-pallet freight plat. Low energy use stems from the low weight of the vehicle (plat), and thus a very high payload-to-weight ratio, as well as from its very aerodynamic shape. The

low vehicle weight and low drag of the vehicle body result from simplifying the propulsion, control, energy and levitation mechanisms and vesting significant aspects of these in the fixed track. This approach also yields significant benefits to reliability and near-zero maintenance requirements, both critical to a full automation outcome.

Table 1. Gazelle Energy Use for Typical Payloads.

Item	Unit	4-Seater Commute Plat	6-Seater Commute Plat	2-Pallet Freight Plat	Empty 6-Seater Commute Plat
Trip and Payload Details					
Trip Length	km	11	11	36	11
Net weight	kg	360	540	740	0
Gross weight	kg	560	780	900	220
Payload ratio	ratio	1.8	2.3	4.6	0
Trip Energy by Component					
Raise lift	Wh	5	7	8	2
Accelerate	Wh	89	121	143	35
Decelerate	Wh	-30	-41	-49	-12
Open air drag	Wh	178	221	676	154
Piston effect drag	Wh	85	153	389	37
Compression	Wh	428	581	2310	168
Trip Total	Wh	754	1041	3476	384
Distance Averaged Energy					
Energy per km	Wh/km	69	95	97	35
Energy per passenger km	Wh/passenger km	17	16	-	6
Energy per tonne km	Wh/tonne km	-	-	130	-

Key elements of the calculations include the following:

- Propulsion is provided by a coreless linear synchronous motor utilising high-performance permanent magnets.
- Levitation is provided by a novel air compressor design. The compressor needs to be proven before feasibility of the Gazelle system can be assured. The energy figures for compression are derived from characteristics of a Computational Fluid Dynamics (CFD) design of a closely related compressor type.

Gazelle design costing references an off-the-shelf linear motor. However, redesign is required to increase its velocity from 10 metres (30 feet) per second to 30 metres (100 feet) per second. Solar panels are standard off-the-shelf units.

The Gazelle design makes use of high performance flywheel energy storage and ultra-capacitors to ensure continuity of energy supply to maintain uninterrupted transport function.

These high performance elements are still under development. However, the ultra-capacitors are expected to be on the market by the time Gazelle is piloted. The Fradella high efficiency flywheel is in prototype development at University of California, Berkeley⁹. The basic ultra-capacitors are off-the-shelf items and used currently in transport (for example, Maxwell BMOD0063 P125 04). The preferred high performance EESstor ultra-capacitors are in pre-commercial development¹⁰.

An enclosed track (or tube) instantly creates an issue with trapped air impeding vehicle movement inside the tube, the so-called 'piston effect'. A vehicle in a tube is turned into a ram, pushing air down the length of the tube. Energy is wasted and vehicle progress is retarded. Any tube diameter widening to reduce the piston effect has to be counter balanced against tube diameter narrowing possibilities that facilitate construction cost reduction and visual amenity improvement.

The energy calculations present the drag of the vehicle as if the vehicle is travelling in open air. The drag attributable to blockage within an enclosed tube is then added. Two-dimensional solid blockage factor corrections, and wake blockage corrections, are made to arrive at the Piston-effect drag figure. Importantly, the plat shroud is teardrop shaped, without any protuberances or disturbances such as external mirrors, aerals, radiator cooling ports, wheels and wheel arches, windscreen wipers or recesses. Accordingly, the plat shroud is an aerodynamically clean symmetrical streamlined (teardrop) shape that has a very low co-efficient for drag. The very low drag co-efficient is critical to minimising the piston-effect.

Table 2 shows that Gazelle has competitive energy efficiencies with its key rivals in the transport market, particularly in passenger transport. In the passenger segment, Gazelle exhibits energy use in the range of 16 to 29 watt hours (Wh) per passenger kilometre while indicative energy use for rival modes as a group range from 60 to 317 Wh per passenger kilometre. In the freight segment, Gazelle is calculated to use 130 Wh per tonne kilometres compared with a range of 67 to 139 Wh per tonne kilometre for key existing modes. Further research and development is required to verify full technical feasibility: specifically, detailed engineering design, full-scale wind-tunnel testing and prototyping. However, the underlying design approach of Gazelle has shown resiliency in the face of challenge.

Table 2. Comparative Energy Use for Typical Payloads for Alternative Modes.

Mode	Units	Current	Future
Passenger			
Zooma (direct)	Wh/passenger km	-	16
Zooma (return+stops)	Wh/passenger km	-	29
Urban rail	Wh/passenger km	139	92
Rail - high speed	Wh/passenger km	153	83
City bus	Wh/passenger km	317	-
Light Rail	Wh/passenger km	224	-
Automobile, 2006 (1.57 passengers)	Wh/passenger km	211	-
Plug-in Prius (2 passengers)	Wh/passenger km	74	-
Boeing 787 Dreamliner (90% load, long trip)	Wh/passenger km	97	-
MagneMotion M3 (direct)	Wh/passenger km	-	60
Freight			
Zooma	Wh/tonne km	-	130
Urban rail	Wh/tonne km	139	83
Rail - suburban	Wh/tonne km	97	67

Source: Glazebrook¹¹. Thornton¹².

B. Sensory Feasibility

Yantis¹³ suggests sensory analysis as a quality assurance technique for new products like Gazelle. This section provides a qualitatively-based comparison of the physical attributes of Gazelle to those of its key competing mode, the road transport system, along visual, sound, smell, collective and mental attention dimensions.

i. Road Transport

The road transport mode is a system consisting of roads (a layer of gravel and bitumen or concrete on the surface of the earth) down the middle of every street. In this case, a 'street' is a line of houses facing another line of houses, with a public space between the lines that allows for physical access to houses. The mode's vehicles – cars and trucks – travel (move) on the roads. The vehicles are parked on the side of the roads, inside private garages or in public or commercial car parks when not in use. There are many road signs, traffic lights and traffic and safety devices like roundabouts, guide posts, reflectors and road markings (visible and audible). There are overpasses, underpasses, elevated roadways, freeways, fences and walls, sound walls, tollways, toll booths, bus ways and bus stations. There are considerable cuttings through the landscape and volume-equal embankments. There are bridges and tunnels. There are multi-storey car parks, and large scale ground-level car parks. There are also accident scenes. There are exhaust fumes, particulates and smog. There is road noise, screeching tyres, car engines, horns and sirens. The road transport mode is primarily powered by liquid fossil fuels and the fuel distribution system itself forms part of the road transport system such as petrol stations, fuel depots, oil refineries, oil pipelines, oil tankers, oil production facilities, oil exploration facilities

and oil spills. Moves to electric cars would acquire all the visual elements of the 'hydroelectric chain', or the 'coal-fired electricity generation chain'. People need to keep an eye out or an ear out for cars at all times: our sensory systems are designed to track movement. Mentally attending to moving cars is a useful survival skill as they can kill or maim you or your loved ones.

All of these are visual, aural, olfactory, touch or mental attention elements. Many elements are large and block the visual scene behind them, either permanently or temporarily. A number of elements are intentionally designed to be highly visible and attention-drawing (for example, signage, guide elements and reflectors, traffic lights, tail lights and indicators). Many elements are lit at night. There is street lighting (primarily for personal safety) and road lighting. All moving vehicles have headlights on at night. In fact, there is considerable light pollution arising from the road transport system. This light is readily visible from space at night.

ii. Gazelle

The Gazelle mode is a system consisting of elevated tracks down the middle of every street. The elevated tracks are 2.8 metres (9 feet) in diameter, and have ground clearance of 2.3 metres (7.5 feet). The track is supported by pylons and access points, which incorporate rapid lifts and serve as Micro-Post Offices (MPOs). These features are the primary visual elements of the system. By placing the track in the centre of the street, the angular impact is at its least because the smallest angle to the sky is used, and is equal for homes on either side of the street. The elevation of the track allows people to see the ground storey of the dwellings on the other side of the street, but typically not their rooves or first storey. People can move safely into the street and underneath the track to get a greater uninterrupted vertical angle of vision.

The mode's vehicles (plats) move inside the tracks. No mental attention is required for the vehicles: most of the movement is above eye-level and hidden by the track, and in any case, there is no possible way for the vehicles to run you down in the street as cars can do. Gazelle runs silently and produces no gaseous emission of any sort. The vehicles are parked within the track or in an access point when not in use. Light Electric Vehicles (LEVs) are an integral part of the system. These LEVs are carried within the track, but then may venture into the street space. These LEVs are smaller and very much lighter than road vehicles and are speed-limited to 40 kilometres per hour. Amenities such as hand trucks and flat-bed trolleys are stowed within the associated street furniture next to the access points. There are bridges and tunnels; however, these structures are of a smaller scale and lighter than for road transport – only needing to support a maximum of 300 kilograms per metre (200 pounds per foot) above track weight. The solar panels on the roof of the Gazelle track may just be visible from the ground, sourcing all the energy required for the system. So there are no other visual elements such as that needed for the fossil fuel chain, the hydroelectric chain, or the coal-fired electricity generation chain.

'All', and there appears only a few, of these are visual, aural, olfactory, touch or mental attention elements. The track, pylons and access points are large and block the visual scene behind them, permanently. However, if both side walls of the access points are transparent, then visual blockage would be reduced. The limited number of LEVs are small, and block the visual scene behind them temporarily. The only elements intentionally designed to be highly visible and attention-drawing are the post-office box doors. These are small and visible temporarily at the time the transport user is locating their box. Some elements are lit at night in a subdued way.

There are no headlights on Gazelle vehicles, only LED cabin lighting. There will be minimal light pollution arising from Gazelle. Gazelle's track system would not be visible from space. Street lighting can be redesigned to be lit from underneath the Gazelle track with highly efficient LED lighting that emits even lighting.

iii. Conclusion

Road transport infrastructure imposes on people's senses in a number of ways. Zooma infrastructure imposes on people's senses primarily through the visual impact of the elevated track. However, a critical difference between the road transport system and Zooma needs to be taken into account: the energy manufacturing and distribution system — Gazelle is far more compact. The sound and smell attributes of the Gazelle system will be an improvement compared with the road transport system given Gazelle's use of non-contact air-cushion levitation and non-contact electro-magnetic propulsion rather than internal combustion engines and 'rubber-on-road' traction. The total sensory experience and the 'internal sense' — mental attention — of Gazelle compared with the road transport system is a complex issue, however, Gazelle's total grade separation between pedestrians and vehicles should certainly ease the mental burden. When the automobile emerged to replace animal-drafted vehicles in the late nineteenth century: hard-nosed transport benefits, not sensory impacts, were the primary driver of the automobile's success. Non-functional sensory impacts are transitional issues.

C. Peak-Period Operational Feasibility

Zooma was designed to conquer the mounting road traffic congestion issue evident in all large and growing urban areas, from medium-sized global cities to the world's largest urban agglomerations¹⁴. In the example below, Sydney, Australia (a medium-sized global city) is used to assess what capacity volume is added via a Zooma network to give guidance on the feasibility of congestion reduction. The Zooma network size for Sydney is estimated to be 21,000 kilometres (13,000 miles) of track, based on the length of the street and road network.

For Sydney, calculations show that Zooma's volume capacity is 4.6 million passenger trips per hour in peak periods, assuming predominant traffic flow in one general direction. This calculation uses 252,000 plats, and assumes a 50/50 split between 4-passenger plats and 6-passenger plats, or an average 5 persons per plat. Capacity growth on the same track network can be attained by using a greater number of plats, up to some characteristic limit. For example, by doubling the number of plats to 500,000 (at an additional cost of A\$2.5 billion) Zooma's volume capacity rises to 9.1 million passenger trips per hour in peak periods. The nature of trips that are generally made would mean that 4-passenger plats would be employed closer to the city in the inner and middle rings, whilst the 6-passenger plats would be more suitable for longer distance commutes with trip origins and destinations for locations within the outer ring.

The Zooma deployment example for Sydney has been designed to cope with the passenger and freight capacities expected in the year 2050. That is, no further investment is required to cope with increasing trip volumes between 2020 and 2050. Further, assuming a population for Sydney in 2020 of about 5.3 million¹⁵, a Zooma volume of 4.6 million passengers per hour in peak periods deals with all worker and education commuters in a timely manner. This assertion considers provisions for picking up and dropping off all passengers to obtain fully occupied plats, as well as the return of the empty plat for the next cycle of commuters. The average speed

of plats is 80 kilometres per hour, including all pick-ups and drop-offs. This average plat speed yields a 33 per cent trip time improvement over the non-congested (or off-peak) average speed of 52 kilometres per hour on Sydney's roads¹⁶. This plat speed also represents a very significant improvement over Sydney's congested AM average speed of 34 kilometres per hour, or the congested PM average speed of 40 kilometres per hour for the road mode as cited in Glazebrook¹⁷. Energy efficient trips up to 130 kilometres per hour are possible so commuter trips from the suburb of Campbelltown in Sydney's outer ring to the CBD could take as little as 20 minutes.

Drop-off/pick-up queuing, and potential congestion, is resolved by using the optimised routing capabilities of the network to route through-traffic around any stopping-traffic. On high-volume routes, advantage is taken of the parallel distributed streets to rotate a local-access-only route between the streets, with the other streets being through-traffic. The ratio of local-access-only routes and through-traffic routes can be dynamically determined depending on traffic volume. High-volume streets displaying inward and outward peak behaviour can be fitted with bi-directional Gazelle tracks. In this way, additional inward or outward routes can be deployed depending on the principal traffic flow.

Drop-offs and pick-ups are quick and easy. Passengers have direct and quick access to seating or to the exit. The plat does not block the track during stops. Other plat traffic continues overhead unimpeded. Routing and passenger selection aim to pick up one couple per plat to help reduce the number of pick-ups and drop-offs. Commuter drop-offs may 'pool' passenger disembarkation points (in line with the passenger's specific service conditions) to help keep drop-offs to a minimum, and help to reduce congestion during peak hours in the Central Business District (CBD).

High-volume access points would be utilised for high throughput locations such as entertainment or sports venues, or in the CBD. With many distributed Zooma access points, congested congregation as tends to occur at train stations or bus stops in CBDs is very substantially reduced. Passengers are also delivered much closer to their place of work compared with bus interchanges and train stations.

Further, an underground Zooma network in CBD precincts is achievable due to the relatively small diameter of the Gazelle track combined with the elimination of the need to remove motor vehicle exhaust fumes. Such an underground network would serve high-volume access points located within CBD building's basement car parks. Suitable depth can be determined to avoid subterranean utilities. With many high-volume access points available in the CBD (and under the CBD), there is plenty of scope to avoid congested drop-off points. And if capacity is in short supply, then the Transport Futures Market utilises pricing to spread the otherwise congested traffic according to an economically efficient regime.

In summary, Zooma is able to utilise a combination of mechanisms, including speed, globally optimised routing and passenger selection, to provide a high peak-volume carrier with plenty of capacity. And instead of 'hitting a wall' during peak periods as road transport does, Zooma is able to use market-based mechanisms to spread traffic load in a globally co-ordinated way so that congestion is avoided. Zooma's operational feasibility in peak periods is assured.

D. Pricing Feasibility

Transport pricing can be a complex issue because of the multiplicity of sustainability objectives, the institutional separation of infrastructure from operations, pricing from tax components of charges and transport modes from each other¹⁸. In road transport, the shift to user charges such as tolls has allowed greater cost recovery for roads. Satellite positioning and wireless data transfer technologies have also allowed these tolls to closely reflect the time and place of use of vehicles. Variable tolling is increasingly being utilised to manage traffic demand¹⁹, essentially inducing people to travel less or to seek alternative transport means during peak periods. Tolls and other taxation instruments reflecting environmental performance are also progressively being utilised to accelerate deployment of cleaner fleets. However, Zooma removes or internalises these social and environmental costs inherent in existing transport modes. Further, Zooma has full system capability for efficient pricing schedules.

Gazelle's energy efficiency combined with Zooma's automation translates into mode pricing that is very competitive against existing transport modes. Full operational cost recovery, plus full asset cost recovery where principal is paid off within 30 years is assumed in the Zooma pricing. Zooma has a significant infrastructure cost structure and very few variable costs. Other costs such as consumables, cleaning and labour at the service centres do not vary greatly with system use. Accordingly, the more passenger or freight kilometres utilised, the greater the fixed costs are amortised. Gazelle's variable costs are very low due to its low energy requirement, near-zero maintenance operation, automation and renewable solar energy source based on fixed assets. Human supervision would increase with more trips, although such supervision would be leveraged by computer-vision supervision.

In this paper, pricing estimates are established using a case study city of Sydney, Australia. To allow fair comparison of the cost of different transport modes to transport users in Sydney, Glazebrook¹⁷ categorises transport costs into three groups: externality and subsidy, other private costs and variable user costs. Table 3 defines what costs are included in each of three groupings. For cars, the biggest private cost is fuel at A\$0.12 per passenger-kilometre (based on A\$1.40 per litre in 2006, a similar level in 2013) while the largest external cost is congestion at A\$0.20 per passenger-kilometre. For buses and rail, public funding, congestion and greenhouse emissions are the biggest contributors to their Externality and Subsidy component. For Gazelle, there are no externalities, although two pricing scenarios are considered: without a subsidy and with a subsidy equal to 100 per cent of Zooma's annual interest cost. Fares are the only variable user cost in the case of trains, buses and Gazelle, and no other private costs are incurred by users of these three modes.

Table 3. Costs Inclusion by Mode.

Item	Cars	Trains/Buses	Gazelle No Subsidy	Gazelle With Interest Subsidy
Externality & Subsidy Costs				
	Pollution	Pollution	-	
	Noise	Noise		
	Congestion	Contribution to congestion		Government subsidy to operator for interest
	Accident costs above insurance	Accident costs		payments over 30 years
	'Free' or subsidised parking			
	General revenue payments to motor registry (RTA/RMS)	Government subsidies to operators		
	Local government rates used on roads			
Other Private Costs				
	Registration	-	-	-
	Insurance			
	Depreciation			
	Maintenance			
Variable User Costs				
	Petrol	Fares by users	Fares by users	Fares by users
	Tolls			
	Paid parking			

Table 4 compares cost estimates for three different existing transport modes for Sydney, as compiled by Glazebrook¹⁷, and compares these to Gazelle's two pricing scenarios. Since Glazebrook's costings are expressed on a per passenger kilometre basis, Gazelle pricing shown in the table is based on a Zooma passenger revenue share at 60 per cent; commercial and freight account for the remaining revenue.

**Table 4. Costs by Selected Mode in Sydney (A\$ per passenger-kilometre).
2005-06 data for cars, trains & buses. Pricing estimates for Gazelle.**

Item	Gazelle		Cars	Trains	Buses
	<i>No Subsidy</i>	<i>With Interest Subsidy</i>			
Externality and Subsidy	-	0.08	0.38	0.37	0.38
Other Private Costs	-	-	0.34	-	-
Variable User Cost	0.20	0.09	0.14	0.11	0.19
Total	0.20	0.17	0.86	0.48	0.57

Table 4 shows that Gazelle's fare price would be 20 cents per passenger kilometre without subsidy and on a fully funded basis. By comparison, Sydney transport users pay 14 cents for cars (48 cents when other private costs are included), 11 cents for trains and 19 cents for buses. On the basis of price alone, Zooma would possibly achieve limited modal shift despite the removal of the many externalities accruing to other modes. The application of full carbon pricing on fossil fuels would be appropriate with Gazelle offering a viable transport alternative for both social and economic reasons. However, the impact on fuel cost per kilometre would be small, and would likely to be significantly ameliorated in the future through improvements in the fuel efficiency of newer cars. However, Zooma does have substantial non-price benefits such as convenience and reduced trip times — not to mention ethical use, with zero-carbon operation.

The cost structure of Zooma may be split into its operating and financing components. Gazelle's true operational cost structure would be charged to transport users if Zooma's interest payments are subsidised (for 30 years in the Sydney example). As shown in Table 4, Gazelle's fare price would be only 9 cents per passenger kilometre with an 8 cents interest subsidy on a per passenger-kilometre basis. At a fare level of 9 cents, modal shift to Gazelle would be considerable given the speed, safety and coverage of the Zooma network. Further, any interest subsidy borne by governments with increased use of the Gazelle mode would be reduced to the degree that subsidisation of other modes lessens, lower road costs and bus service provision expenses accrue and tax revenues grow from higher productivity and economic activity.

Clearly, Gazelle is feasible on a pricing basis given the assumptions outlined in this paper. However, can governments justify providing an interest subsidy (for 30 years in this example) to Zooma so Gazelle can be supplied at pricing rates that reflect its underlying cost structure? This value proposition is assessed in the next section on economic feasibility.

E. Economic Feasibility

Australia's infrastructure priorities are assessed using the Benefit-Cost Analysis framework. Benefit-Cost Analysis allows the systematic comparison of different types and different time profiles of costs and benefits. The focus of the Benefit-Cost Analysis is on the difference between benefits and costs of a scenario compared with the baseline. A Benefit-Cost Analysis is difficult to produce for a new transport mode without a prototype, particularly using the best practice principles as outlined in the Infrastructure Australia document²⁰. However, two factors reduce the scope of the benefits and costs that need to be assessed: first, Zooma's operating costs are very small relative to Gazelle's infrastructure costs, and second, Zooma's cost structure for pricing is assessed to be very low compared to other modes under the interest subsidy scenario. If these costing calculations are reflective of Zooma's eventual cost structure, then the Benefit-Cost Analysis exercise becomes more about how much market share Zooma would be able to achieve, and how quickly any market gains would occur. Another key uncertainty is how governments and societies would respond to the many possible socio-economic transition impacts of a Zooma deployment.

Key methodology assumptions are as follows. First, a discount rate of 7 per cent (real) per year is used to discount future benefits to the current day. Second, all costs and benefits reflect 2013 dollar values. Finally, the Zooma scenario commences in 2020 for illustration purposes.

Consequently, the discounting time horizon chosen is the thirty-year period between 2020 and 2050.

i. The Base Case

The case study city chosen to apply Zooma to is Sydney, Australia. Sydney's current population is around 4.6 million people with a road network estimated at around 21,000 kilometres (13,000 miles) in length. The Base Case scenario assumes the extension of existing trends for population, passenger trips and pallet freight and has been derived from Bureau of Transport Statistics forecasts^{21,22,23}.

ii. The Zooma Scenario

A five-year Sydney infrastructure roll-out plan occurs: completing the South-West by 2021, the South and East by 2022, Central to West regions by 2023, the North West by 2024 and the North and North East by 2025; an average daily roll-out plan of 11.5 kilometres (7,000 miles) of track. Annual average infrastructure spend over the 30 years is estimated at around A\$4.2 billion given system set up costs at just under A\$7.5 million per kilometre (A\$12 million per mile). However, total expenditure is 'front-loaded' into the first 5 years.

Zooma's mode share is set at 80 per cent in the passenger travel market and 70 per cent of the truck pallet freight market (pallet freight accounts for 70% of the total truck freight). Migration from existing modes to Zooma is surmised to be rapid given Zooma's time savings, cost relativities, ubiquity and automation advantages. Importantly, city-based trips are replaced in the modelling while motor vehicles are made redundant only on a turnover basis.

Under Zooma, urban consolidation would intensify and city footprint expansion would be limited; similar to the 'Inner Ring-Middle Ring' alternative growth scenario for Sydney as outlined in Centre of International Economics report²⁴. Hence, the network size is assumed to remain at 21,000 kilometres into the future. Sydney's population density expands from around 400 persons per square kilometre to around 600 persons per square kilometre in this scenario, a population density that remains much lower than in most global city agglomerations²⁵.

iii. Benefits

Table 5 summarises the key elements of the methodology used to estimate the economic benefits arising from a Zooma deployment in Sydney. The benefits definition used is narrow. The scope of the transport market is limited to passenger and pallet freight only. The majority of benefits are generally derived from the first-round economic impacts of Zooma replacing the bulk of city-based road transport trips, thus nullifying the bulk of road transport's subsequent direct costs and external costs. Any justification for the benefits attributed to Gazelle comes down to an argument for overwhelming modal shift within the city from road transport to Zooma.

The second-round impacts and wider economic benefits from a Zooma deployment would be significant but are, by and large, not accounted for. First, any induced demand impacts because of reduced trip times, lowered trip costs and increased accessibility created by Gazelle are ignored. Second, the deep integration of automated and digital transport across an economy would lead to very substantial cost savings, and are unaccounted for. Third, any space saving that

might arise from redundancy of land dedicated to road use, on-street and off-street car parking and fossil fuel distribution to be employed in alternate land uses is not modelled. Finally, agglomeration economies arising from better land use planning possibilities as outlined by SGS Economics & Planning²⁶ are not measured.

Table 5. Methodology for Measuring Benefits for a Zooma Deployment, Sydney, Australia.

Scope of Benefit	Modelling Approach and Sources
Fuel Savings	
<i>Scope of fuel savings is limited to petrol and diesel; Liquefied Petroleum Gas use is not modelled. Petrol fuel use excludes Sydney weekend and holiday car travel.</i>	Fuel use per capita is held constant. Base Case fossil fuel use is escalated with population only. Petrol and diesel prices are assumed to rise over the 30 year period. For example, petrol price rises from A\$1.69 per litre in 2020 to A\$2.90 per litre in 2050. A similar rise is assumed for diesel. Fuel use & fuel price projections source: Bureau of Infrastructure, Transport and Regional Economics ²⁷ .
Other Transport Mode & Industry Savings	
<i>Paid parking</i>	Estimates for paid parking in the Sydney CBD by 2020 is A\$1 billion, Sydney Airport A\$0.4 billion, plus parking fees in the remainder of Sydney; totalling A\$2 billion. These values expand with population. Paid parking value source: Lentini ²⁸ .
<i>Deferred car industry subsidy payments & tariffs</i>	Car industry subsidy payments and tariffs value of A\$1.6 billion in 2011 for Australia is claimed. Measure is calibrated to grow in line with the Sydney population size in the projection years. Zooma deployment in Sydney is likely to result in a transitioning of manufacturing from cars to robotics and automation, plus bulk production of track & plats. Car subsidy value source: Productivity Commission as reported in Bosworth ²⁹ .
<i>Deferred road network investments & maintenance</i>	Sydney Metropolitan Transport Plan indicates A\$21.9 billion over 10 years. Initial estimate value of about A\$2.2 billion expands with projected population. Source: Engineers Australia ³⁰ .
<i>Deferred taxi fares</i>	Taxi trip value of A\$1.5 billion is assumed to be displaced by Gazelle. Deferred taxi fare value expands with population. Benefit source: Select Committee on the NSW Taxi Industry ³¹ .
<i>Deferred bus fares</i>	Bus trip value of A\$1 billion is assumed to be displaced by Gazelle. Deferred bus fare value expands with population. Benefit source: IBISWorld ³² .
<i>Extreme weather-related - e.g. inundated road & public transport delays</i>	Daily congestion figure is upscaled three times for each bad weather day. Initial estimate value of A\$0.2 billion in expands with projected population. Source: Sydney Morning Herald ³³ .
<i>Displaced road tolls</i>	Transurban tolls, Harbour bridge and tunnel tolls and eTags projected to 2020. Initial estimate value of about A\$1 billion expands with projected population. Source: Transurban ³⁴ and Roads and Traffic Authority ³⁵ .
Congestion Savings	2010 industry estimate scaled to 2020. Widely-reported initial estimate value of about A\$7.8 billion expands with projected population. Congestion source: ACIL Tasman ³⁶ .

Reduced Non-Congested Trip Time Savings

Using 'Congestion Savings' as estimate for cost of time - proportional time-saving below the 'no congestion' trip time. Median trip timed on 4-seater plat, 100% occupancy, 1 couple and 2 singles. Initial estimate value of A\$7.4 billion expands with projected population. Congestion source: ACIL Tasman³⁶.

Productivity Gains

Sydney Orbital Ring Road productivity estimated at A\$1.8 billion. Productivity estimate for a Sydney fine-mesh network is extrapolated to be A\$5 billion. Initial estimate value expands with population. Orbital Ring Road productivity estimate source: Ernst & Young³⁷.

Health-Related Savings

Air pollution

Upper-end health impact estimate of vehicle emissions in Sydney by Amoako, Ockwell, & Lodh³⁸ of A\$4.7 billion is initially used, and then grows with projected population.

Accident-related

Initial cost of road crashes estimate of A\$2.2 billion expands with population. Accident Cost Source: NRMA³⁹.

No-Buy-Car Savings

Average cost of a new car assumed at A\$20,000, held constant in real terms. Fleet turnover rate is assumed to be 7 per cent per year. Zooma's market share is 80 per cent so 8 out of 10 cars of the 7 per cent are replaced. Motor vehicle numbers source: Bureau of Transport Statistics⁴⁰.

Carbon Offset

Benefit is modelled as petrol and diesel fuel use savings in volume terms expressed in terms of carbon emission equivalents times the carbon price. Carbon price is assumed at A\$33 per tonne-e in 2020 rising to A\$90 per tonne-e by 2050. Emission equivalents source: Bureau of Resources and Energy Economics⁴¹.

Other Benefits

*More physically active environment
- e.g. reduce obesity & diabetes*

Initial cost estimate of A\$0.2 billion expands with population. Benefit estimate source: Matan, Trubka, Newman & Vardoulakis⁴².

*Noise pollution - including impact
on sleep disturbance*

Initial cost estimate of A\$0.5 billion expands with population. Benefit estimate source: Matan, Trubka, Newman & Vardoulakis⁴².

Sale of excess electricity

Initial sale estimate of A\$0.25 billion, held constant. Assumes excess Gazelle electricity sold to National Electricity Market at wholesale prices at a NEM average price of A\$25/MWh. Price source: Office of the Tasmanian Economic Regulator⁴³.

Waste collection

Initial cost estimate of A\$0.3 billion expands with population. Benefit estimate source: Morris & Cameron⁴⁴.

Post parcel

Initial cost estimate of A\$0.5 billion expands with population. Benefit estimate source: Chappell⁴⁵.

iv. Costs

Table 6 presents initial costings to supply Sydney with Gazelle and SPS infrastructure. These costings are based on recommended retail prices for the major items. Clearly, a wide range of assumptions lie behind the costings in the Benefit-Cost Analysis. For example, for solar panels, the non-mirror all-solar configuration is used. For supervision of the network in operating costs, supervision costings are based on 21,000 shift-based employees who supply round-the-clock supervision semi-proportionally to demand. Table 6 shows that the total infrastructure spend is estimated at around A\$152 billion given system set up costs at just under A\$7.5 million per

kilometre. In comparison, the road construction cost of the Melbourne East West Link project for 6 lanes was around A\$10.7 million per lane-kilometre⁴⁶.

Table 6. Gazelle Infrastructure Costs for a 21,000 kilometres city network, Sydney.

Item	<i>A\$ billion</i>
Solar panels	15
Flywheels	12
Ultra-capacitors	16
Linear Motor	21
Electricity distribution (cables)	7
Track Structure	19
Track Enclosure	17
Switches/Merges	2
Electrical power switching & control	9
Air Compressors	2
Access Points	20
Plats (vehicles)	3
Service Centres	1
Air Quality Points	4
Computer centres	4
Total Network Cost (A\$billion)	152
<i>Average Cost per kilometre (A\$million)</i>	<i>7.5</i>

v. Net Benefits Assessment

The Zooma paradigm applied to Sydney from 2020 onwards leads to net benefits of around A\$511 billion or may realise economic benefits that could be 5 times the infrastructure costs that are front-loaded into the first 5 years. Table 7 presents a summary of the benefits and costs that are included in the Benefit-Cost Analysis. These results are based on fare pricing that fully covers operating costs (not interest expenses) and allows for full infrastructure cost recovery within 30 years. Additional calculations show that any interest payment subsidy by governments would be covered 12 times by the measure of economic benefits in undiscounted terms.

While the benefit and cost measures in this paper attempt to as much as is possible err on the side of conservatism, a proper risk analysis of the Zooma concept as suggested for mega-projects by Flyvbjerg, Bruzelius and Rothengatter⁴⁷ would need to be made.

Table 7. Cost-Benefit Analysis for Sydney, Australia.

<i>Discounted Benefit-Cost Ratio</i>	4.9	<i>Discount Rate</i>							7%
<i>Net Present Value (A\$bil, 2013)</i>	489.2								
	<i>2020-2050</i>	<i>2020</i>	<i>2021</i>	<i>2022</i>	<i>2023</i>	<i>2024</i>	<i>2025</i>	<i>2026-2050</i>	
<u>Costs (\$bil, 2013 \$ terms)</u>	Cumulative								Average
Infrastructure Costs	152	32	31	30	30	29	-	-	
Operating Costs (fares full cost recovery)		-	0.2	0.4	0.7	0.9	1.1	1.1	
<u>Benefits (\$bil, \$ 2013 terms)</u>									
Fuel Savings	435	-	2	3	5	7	8	9	
Other Transport Mode & Industry Savings	337	-	2	4	6	8	11	11	
Congestion Savings	265	-	2	3	5	7	8	8	
Reduced Non-Congested Trip Time Savings	250	-	1	3	5	6	8	8	
Productivity Gains	170	-	1	2	3	4	5	5	
Health-Related Savings	160	-	1	2	3	4	5	5	
No-Buy-Car Savings	157	-	1	2	3	4	5	5	
Carbon Offset	37	-	0	0	0	1	1	1	
Other Benefits	58	-	0	1	1	1	2	2	
Total	1,869	-	10	20	31	42	53	55	

One key uncertainty is Zooma's mode share and one could argue that existing modes could employ new technologies that could result in a far lower Zooma mode share than assumed in the Benefit-Cost Analysis. The benefit measure in Table 7 could simply be reduced by 50 per cent to reflect a halving of the assumed Zooma mode share to 40 per cent in the passenger travel market and 35 per cent in the truck freight market. In this scenario, there would be cost savings compared with the base Zooma scenario. But these potential cost savings are ignored and costs are unadjusted in this low mode share Zooma scenario. The present value of net benefits in the low mode share Zooma scenario are measured at around A\$190 billion or 2 ½ times the full cost of operations and deployment. Gazelle fares on a per passenger kilometre basis could be increased to 15 cents to ensure full infrastructure cost recovery within 30 years. This Zooma's fare of 15 cents per passenger kilometre remains well within the range of feasibility given the 11 to 19 cents pricing range for trains, buses and cars. Any interest payment subsidy by governments would also be covered 5 ¾ times by the measure of economic benefits in undiscounted terms.

Best-practice infrastructure cost estimation also suggests applying a P90 value (that an estimate of project cost should be based on a 90 percent probability that the cost will not be exceeded) should be employed⁴⁸. On the other hand, best-practice measurement of economic benefits for use in Table 7 would also include full scoping of transport markets, behavioural interaction modelling between modes, induced demand impact modelling and the full assessment of the wider economic benefits. The wider economic benefits would be substantial, stemming from the integration of an automated and digital transport mode into the economy, any land

saving that would occur across the road transport and carbon fuel chain (Glazebrook¹⁷ measures the economic value of real estate devoted to car parking in Sydney in 2005 to be in the order of A\$76 billion alone), and the possibility of significant agglomeration economies arising from improved land use and transport planning strategies based around Zooma.

VIII. Summary and Conclusions

The Zooma infrastructure paradigm applies a fully automated passenger and freight system called Gazelle that is leveraged by a consumer and business-accessible built-in logistics system called the Super Postal Service. Gazelle uses light small vehicles moving inside an elevated track way along every street. In this way, Zooma provides independent mobility and presents people with a carbon-free alternative to the car without having to forego the convenience of modern life. Gazelle could replace all cars, taxis, buses, light truck and palletised goods haulage within a city. However, Gazelle could not replace (non-palletised) heavy road transport. Gazelle articulates very well with other modes of transport, particularly rail.

Zooma transport infrastructure represents a feasible pathway for global cities seeking a paradigm shift in their transport and land use planning strategy. Gazelle offers the opportunity to conquer the mounting road traffic congestion issue evident in medium sized global cities through to the world's largest urban agglomerations. Reduced conflict involved with urban consolidation and renewal can occur because transport costs can be reduced, trip times are easily shortened, and land dedicated for transport and carbon-fuel manufacturing and distribution is diminished. Since Gazelle effectively makes transport digital, the Super Postal Service is able to host with other business-to-business systems and develop transport futures markets. Deep integration of a digitally-based automated transport mode into the household, business and government sectors would deliver significant economic transformation in many global-city economies.

On the evidence presented for Sydney Australia, Zooma is able to utilise a combination of mechanisms, including speed and globally-optimised routing, to provide a high-peak volume carrier with plenty of capacity, and lead to peak hour trip-time reductions by two-thirds. Unlike road transport peak periods at peak periods, Zooma exhibits graceful degradation under volume pressure by the use of market-based mechanisms to spread traffic load over time in a globally co-ordinated way and economically efficient manner. Gazelle is assessed to be very price competitive against incumbent modes. Gazelle's fare – based on its underlying cost structure – would be 9 cents per passenger-kilometre compared with 14 cents for cars, 11 cents for trains and 19 cents for buses. Besides being cheaper, Gazelle's contact-less propulsion, levitation and switching ensures reliable, long-lasting and efficient operation. The Zooma paradigm applied to Sydney from 2020 onwards leads to net benefits of around A\$500 billion or economic benefits that are 5 times the cost of the infrastructure. A preliminary risk analysis shows that there are still substantial net benefits to Sydney even if Zooma's mode share is reduced to half that assumed in the base Zooma scenario. Further, the benefit measure applied is conservative, and does not include the wider economic benefits of transport automation, digital integration and enhanced metropolitan planning possibilities.

The Zooma concept warrants further development so the concept can be examined on its merits in any global city's metropolitan urban transport and land use planning strategy. More

research is required to advance the proposed concept through to proof of concept of the levitation mechanism, and to design and engineering of propulsion and switching mechanisms, in order to build a prototype and refine costing estimates. Once a Gazelle prototype has been demonstrated, a multidisciplinary, international project-based approach would best address the further challenges in deploying such a revolutionary system into society.

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