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**An Architectural Approach to Sustainable Transport Design: SkyCabs Elevated Small Group Automated Rapid Transit (ESGART)**

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**ABSTRACT**

Due to increased motorcar popularity, public transport use has declined such that congestion costs billions in wasted time, fuel, accidents, air and water pollution. Proposed passenger transport projects have been cancelled in major cities. This paper investigates reasons for this. As cities grow vertically and horizontally they form three-dimensional mazes requiring special analysis to find transport solutions that enhance the city. Results of population and traffic density analysis, origin and destination studies, time frames and travel patterns are presented. Congestion can be alleviated by transferring passenger transport onto elevated solutions like the presented SkyCabs system which straddles the gap between Group Rapid Transit (GRT) and Personal Rapid Transit (PRT). This two-way monobeam is detailed including ease of building through cities, low construction cost, facilitating directional understanding of a city. Architectural and engineering aspects of 8-seater cabs, cab frequency, stations and lines are described. This paper also explores the importance of connectivity on an example line in Auckland, connectivity treatment within a SkyCabs network and to other modes of transport. Quantitative and qualitative attributes are considered, with examples, and compared for GRT, PRT and SkyCabs. The result is a rapid transport system which is affordable and attractive enough to draw significant numbers of car users reducing congestion and CO<sub>2</sub> emissions.

Key words: elevated, two-way, rapid transit, congestion reduction, connectivity.

## INTRODUCTION

Due to increased motorcar popularity, public transport use has declined such that traffic congestion on our roads costs billions in wasted time, fuel, accidents, air and water pollution. (Laird et al. 2001). Passenger transport projects have been proposed and planned in many cities around the world yet several have been cancelled. Cities like London, New York, Seattle, Chennai, Sydney, Melbourne and Auckland have in the last five years, delayed or abandoned planned rail, light rail or monorail routes because of seemingly unjustifiable costs, or costs well beyond the budget.

### *Objectives*

In this paper city growth, public transport and traffic congestion are reviewed. A new passenger transport mode solution is presented to reduce congestion. This new mode is described in detail and compared to traditional forms of public transport. Qualitative and quantitative attributes are considered and connectivity is calculated to prepare the ground for the construction of a demonstration track as part of a pilot study.

## CITY GROWTH AND TRANSPORT

Urban expansion occurs in two ways. Easiest and lowest cost expansion is spreading into newly available areas further from the city center. Closer to the CBD expansion and development is more difficult and expensive. Vertical growth with ever taller buildings and higher occupancies in the CBD create a three-dimensional maze.

### *Global factors affecting travel demand and service provision*

Global factors affecting travel demand and service provision (TranSystems et al. 2006 in the US) summarised in the NZ context:

- 1 City/land development features and patterns like geographic, topographic, ecological, zoning and density considerations.
- 2 Population characteristics in zones, age distribution, activity related travel.
- 3 General and individual economic situation, household income, asset ownership.
- 4 Features of travel mode, mode choice due to attractiveness and convenience.
- 5 City/Government intervention via regulation / assistance via subsidies.

### *Transport Difficulties with Buses and Traditional and Light Rail in the City*

Providing passenger transport from the outer edges of the city with their own “hubs” but with very low population densities involves long trips by buses into the central areas along increasingly congested roads.

The use of exclusive bus lanes near the central city to overcome the disadvantage of multiple stops and slow trips, has to be regarded as a problem. While allowing faster bus trips, the exclusive bus lane takes a minimum 1800 to 2000 passengers/hr car users off the road. With 40 seater buses up to 50 full buses an hour, one every 1.2 minutes, are required just to equal the lost capacity. A bus with 80 passengers gives a frequency of 2.4 minutes. Both are in the congestion causing frequency. See Fig 1. page 7. (Nielsen et al. 2006). Buses alone on bus lanes do not seem to increase throughput of the roads.

Traditional rail services from the outer edges need exclusive rail corridors through the developed city. These rail lines must do one or more of the following:

- take over existing road space competing directly with cars and causing further congestion at intersections,

- take land currently developed with housing and commercial land to provide the exclusive way, (this still necessitates crossings at all roads at right angles)
- raise the rail line above roads, or
- build tunneling under ground with underground connections to the city above.

Rail lines are continually proposed to be placed directly along the simplest route severing communities on either side. Any use involving crossing the rail lines is restricted and accidents increase.

Light rail line costs are reduced by use of the roadway at the expense of previous use of the road. While light rail is described as being able to share space with cars and pedestrians, light rail like Dublin's line completed in 2007 has a record of multiple accidents. If light rail is to provide a service to attract car users as all new rail systems are expected to do, they need to be frequent and have a high operating speed. These two requirements cause a direct conflict with cars and pedestrians in any sharing of the road.

### ***Time Frames Travel Patterns and Proposed Rail Expenditure***

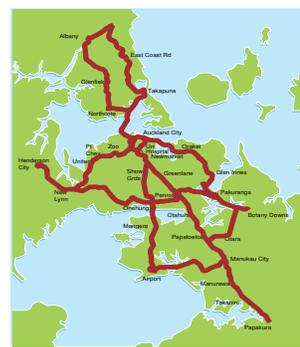
Auckland Transport Models (ATM) Project (1996) was undertaken by the then Auckland Regional Council (ARC), Transit New Zealand (TNZ) and the Auckland Territorial Local Authorities (TLA's). The Auckland Regional Transport (ART) Model uses data gathered along screen lines to establish trip generation by purpose and sector, vehicle ownership, trip distribution by purpose and AM Peak and Mid-Day trips, mode split among car driver, car passenger, public transport passenger, walk or cycle. Fuel use, CO<sub>2</sub> emissions, vehicle operating costs and accident costs are also covered. Travel time surveys are being carried out as part of the Regional Land Transport Strategy monitoring programme. Both studies are continually upgraded.

Congestion in cities normally shows up with the movement to the places of employment during 7am to 9am peak travel times at start of business and opening of schools and is at its worst usually in the CBD. Afternoon and evening peaks follow.

In Auckland the major morning peak traffic is heading to the CBD from approx eight directions. See Map 1. The existing rail, shown in red, covers only two directions the South and the West. As trains are full in peak hours, an expenditure of \$3.9 billion is currently proposed to increase trains from four per hour to six per hour or at 10 minute intervals. Using 600 passengers/train or 800 passengers/train this could allow an increase of 1200 to 1600 passengers/hr. Even allowing three directions, total of 3600 to 4800 passengers/hr extra into the city for the capital expenditure of \$3.9 billion or minimum \$812,500 investment per new passenger.



**MAP 1 Existing Rail Corridors  
REDUCING CONGESTION**



**MAP 2 Proposed SkyCabs Network**

There are two ways of achieving this and the two ways are best utilised together.

1. Using roads in a better manner than at present to facilitate peak traffic movement.
2. Improving passenger transport and its coverage so the car user finds a better solution that does not use the present congested roadways.

The question then arises as to how to provide this attractive passenger transport without destroying the existing transport that has initiated and supported the life of the city.

## **ARCHITECTURAL APPROACH**

Architects design many different types of buildings from small to monumental. From compact units for single or retired people, to homes to nurture a nuclear family, educational facilities to challenge and inspire the young, places of employment to house manufacture of products and completion of processes, office and commercial complexes to hopefully enduring mega structures to protect heritage in museums, dazzle viewers in art galleries, theatres, recreational facilities and sport stadiums. Expectations are that the project will be realised within budget and time while responding to and respecting the environment.

During the last two centuries, except for the motor car, new means of urban transport have been designed on the mega structure philosophy. Many of the traditional transport systems such as trains and monorails, need large stations and have large vehicles on the basis that it gets cheaper to run if passengers are allowed to accumulate at stations so fewer trains are operated.

In the 21<sup>st</sup> century the architect's approach to transport design has to be to design for the individual passenger. He/she needs a seat as soon as possible, a trip with as few stops as is reasonably possible and a trip that is as short as is reasonably possible.

### ***Where to Place the Transport Expansion***

The legally defined road and the space above it are dedicated to transport. The space above the road is generally available for services with elevated components like trolley buses, light rail and monorail. There are fairly well reported capital costs when we consider traditional rail and monorails. Bangkok's elevated rail with massive structures has been in financial difficulty three times. Indonesia tried several times to build a traditional monorail but the cost has thwarted them so far. Seattle planned for a 23km traditional monorail but found in 2005 that the US\$2.1 billion cost was too high and that the system would take over whole blocks of the city to turn a corner. (SMP 2003 – 5).

The space under the road has been generally dominated by services and is available at a cost involving digging and construction of tunnels, protection of adjoining buildings, alteration of major services and disruption to transport services while building. Few cities have found they can justify the funds for underground transport.

Analysis of the three-dimensional urban fabric shows that there is scope for an elevated transport system that has a relatively small structure, is able to carry considerable numbers of passengers at speeds better than the car, through a small restricted envelope that can fit happily in the three-dimensional street context.

Analysis of all modes of road traffic in the city shows that the greatest pressure from congestion is normally on arterial roads leading to and from the CBD or major centres. The vehicles on such an elevated transport system need to be small, able to collect passengers requiring similar destinations traveling along such a main route. (Bishop et al. 2001). These small vehicles would also need to be frequent to provide

useful capacity, require far fewer stops because of their lower number of passengers and their speed must be close to or better than cars.

Then the individual passenger's traveling requirements could be met.

## NEW TRANSPORT SYSTEMS

New systems have been developed over the last ten to twenty years to improve urban passenger transport and reduce congestion. Many are still in the concept stage.

### *Personal Rapid Transit (PRT)*

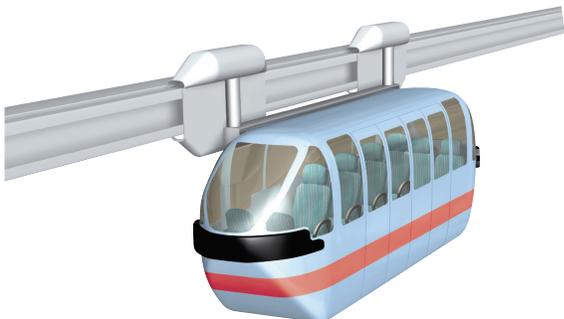
PRT focuses on totally personal trips for passengers. With the vast majority of passengers traveling alone, this necessitates many small vehicles. The smallness of the vehicle, low number of passengers 1-4 and short wheelbase restricting its speed, limit PRT in answering current urban needs. Hourly volume at three second intervals, ranging from 1200/hr single passengers to around 1700p/hr using a range of occupancy, is below the capacity of a motorway lane. The small wheelbase restricts speed to around 30-40k/hr, only slightly better than cars on a semi-congested motorway. However, elevated PRT can provide an additional transport option without the loss of existing road capacity on the ground, in the direction of the track. PRT has the advantage of not needing a timetable as long as there are sufficient vehicles available to answer the demand.

Austrans although a nine seater, is considered a PRT system by inventor Arthur Bishop. Taxi 2000, designed by Prof Ed Anderson, USA, and ULTra from Cardiff, UK are examples of PRT. Both use electric four seater vehicles and run on rubber tyres. All three require either two tracks or double width tracks to achieve travel in opposite directions. Austrans had a 500 meter demonstration track in Sydney. Taxi 2000 demonstration still operates on a dedicated guideway at 2.5 seconds frequency. ULTra completed an inter-terminal connection at Heathrow Airport in 2009.

An increasing number of cities are investigating elevated passenger transport. For the European Commission's (EC) Key Action "City of Tomorrow", short PRT systems were examined by the Evaluation and Demonstration of Innovative City Transport (EDICT) team in five urban environments: Huddinge in Sweden, Ciampino in Italy, Eindhoven and Almelo in the Netherlands and Cardiff in the UK. This three year study found high user acceptance and strong support from stakeholders but both the Cardiff and Eindhoven projects were hindered by political problems. (EC 2004).

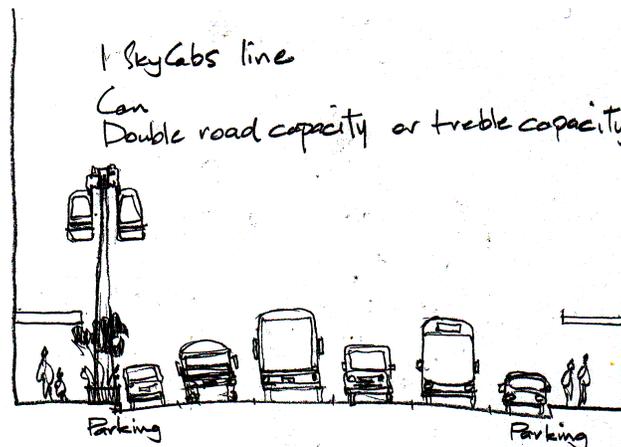
### *Small Group Rapid Transit*

The next largest passenger transport system is the New Zealand designed and patented SkyCabs ESGART (Elevated, Small Group, Automated, Rapid, Transit) system.



SkyCabs is an elevated two-way monobeam carrying light eight-seater cabs on each side of the beam, available on demand, providing fast, pollution-free, unimpeded travel above the footpath with panoramic views of the city. It is a collector system as distinct from PRT, with space for eight more standing passengers per cab. The longer vehicle length facilitates design speeds up to 80km/h and a 60km/hr average operating speed, considerably faster than PRT and light rail. SkyCabs is an automated electric system. Safety performances of established driverless systems have been reported to be excellent, better than manual systems. (Fabian 2004). SkyCabs uses similar high frequencies to PRT systems and provides vehicles smaller than the buses and trains of Group Rapid Transit systems and thus gains advantages over both systems.

### *Capacity*



A single two-way SkyCabs line with eight-seater cabs and frequency of up to six seconds between vehicles gives a capacity of 4800 passengers per hour. Therefore the single two-way line can match the capacity of a four lane motorway and, with the additional eight standing passengers, i.e. over 9000 pphr, that of an eight lane motorway.

### *Stations*

The key to SkyCabs' capacity and operating speed is the SkyCabs off-line station. This switched station allows cabs requiring to stop, to go off the main line into the station to one of four ports to unload or load passengers. The four ports with two separate access and rejoin tracks, enable a four port station to handle the full capacity of the line. This ensures the line is kept clear for through traffic. Two of the four ports can be used at night or in off peak times for parking of cabs. The elevation of the SkyCabs track allows unobstructed passage for the cabs but requires vertical connection with fast lifts for passengers from ground level.

There are very convenient positions for stations above or within car parking areas, shopping and commercial centres. Placing stations at or within existing centres provides an urban planning tool for increasing density by adding to single level centres. Stations on the second floor increase the pedestrian count and add further value.

### *Guideway*

Architecturally SkyCabs can blend into the street fabric with some changes in street lighting and some services in the footpath bypassed, straddled or rearranged. The lightness of the cabs requires about one tenth the concrete of traditional monorails, resulting in much lower capital cost. The guideway can turn street corners and is light enough to go on bridges. Guideway on North side of East-West roads allows for any

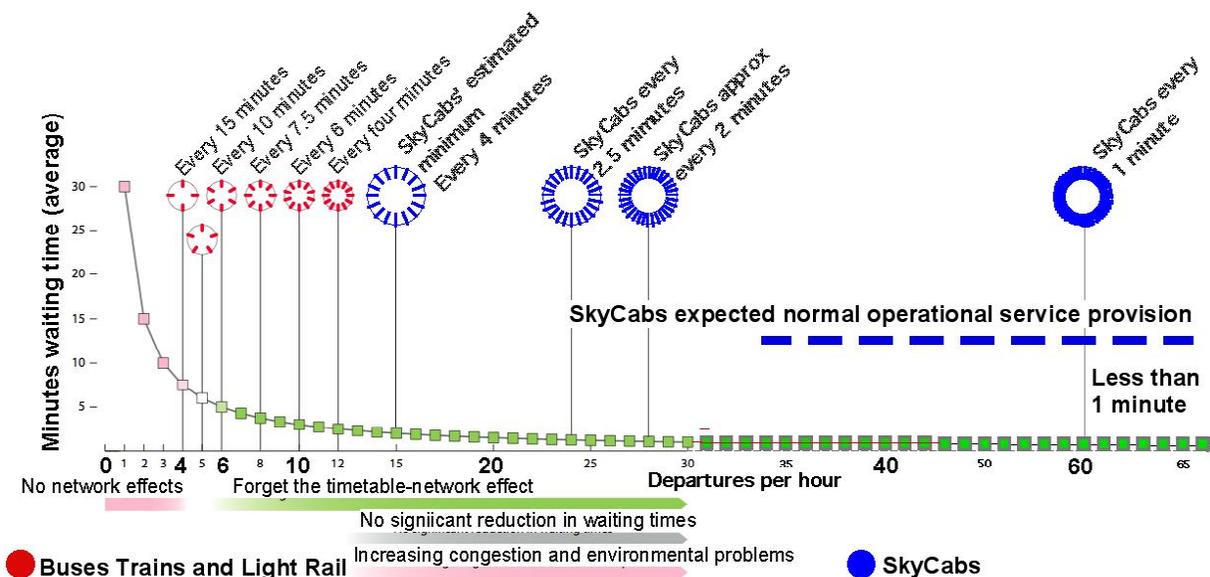
shadow from SkyCabs to be cast on the street. With North-South roads either side can be used as any shadow passes very quickly. For engineering the varying state of the ground can be catered for by adding additional depth to the drilled 'pole' foundation. A flat surface foundation may be used in some circumstances, but a 1.5 meter diameter pile could provide the usual limit of the required surface area every approximate 30 meters. Allowing 5-6 meter clearance under the cabs, the track itself would be 8-9 meters above the footpath. Consents will need to be sought and obtained for the guideway.

In some cities the visual impact of the guideway may be raised. Stakeholders living along a line may need to choose between quiet SkyCabs above the footpath out of sight and a bus lane either replacing parking outside their residence or carved off the front of their property, with noisy buses emitting CO<sub>2</sub> and small particulates closer to their living and sleeping areas. In the EC (2004) PRT study reduction in car traffic and hence in air pollutants were valued highly. Visual impact as a result of elevated track was raised only in Cardiff and in historic areas of Huddinge.

In the case of electrified heavy rail and light rail, the height of posts and the power lines that they carry may also be deemed visually intrusive and electrification of existing diesel lines may necessitate the costly raising of levels of existing over bridges.

### *Service frequency, wait times*

The SkyCabs system is a collector system with automated vehicles. Calculations show that while a waiting time of less than one minute would be normal in a city such as Auckland, four minutes would be the longest wait to allocate a vehicle with available capacity approaching the stop during very low demand times. Parked vehicles can be activated to ensure minimal waiting.



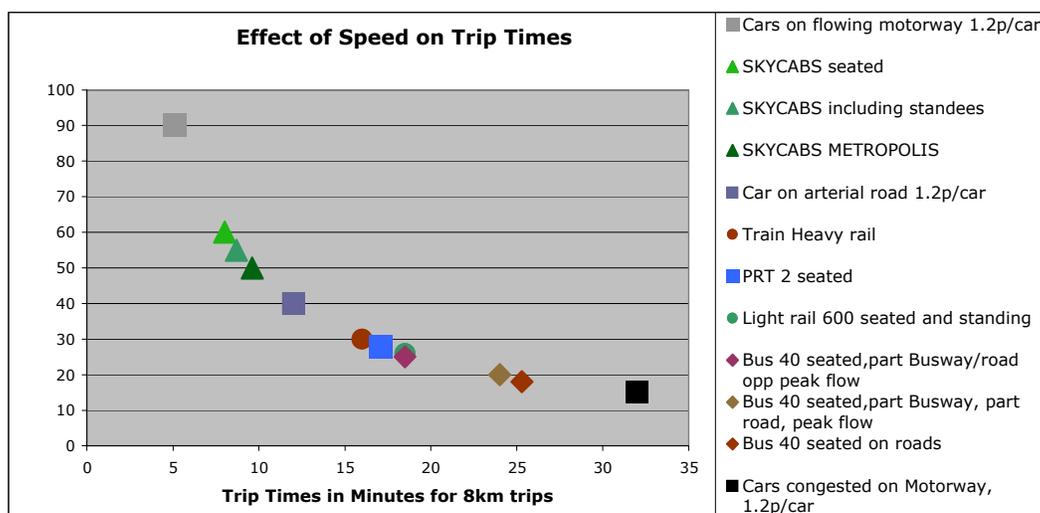
**Fig 1 Waiting Times versus Departures per Hour, with Congestion and Environmental Effects for Bus, Train, Light Rail (Nielsen, 2006) and SkyCabs**

Buses need timetables until six minute interval is reached. As headway decreases from four minutes, traffic congestion and environmental pollution increase. See Fig 1.

SkyCabs operate above the road space, so do not cause congestion even at less than one minute headway or a 30 second waiting time.

### *Operating Speed*

Monorails, rail and light rail cover the larger vehicle capacity systems. Large vehicles necessitate multiple stops. The Seattle monorail bid showed the fastest traditional monorail technically able to do the end to end trip in 45 minutes or at an operating speed of 30km/hr, a speed only slightly faster than cars. (SMP 2003 - 2005).



**Fig 2 Effect of different Mode Operating Speeds on Trip Time**

In Fig 2 bus and train times from MAXX, actual in July 2009 Auckland, light rail times from Phoenix Light Rail in 2009 and car and SkyCabs estimates for comparable 18 km journeys have been plotted against operating speed of the relevant mode.

After cars on a flowing motorway, SkyCabs offers the next fastest trip times followed by cars on flowing arterial roads, and heavy rail. PRT, light rail and buses are only slightly faster than cars on congested roads. These results are similar to mode comparisons presented by Lawson (2003).

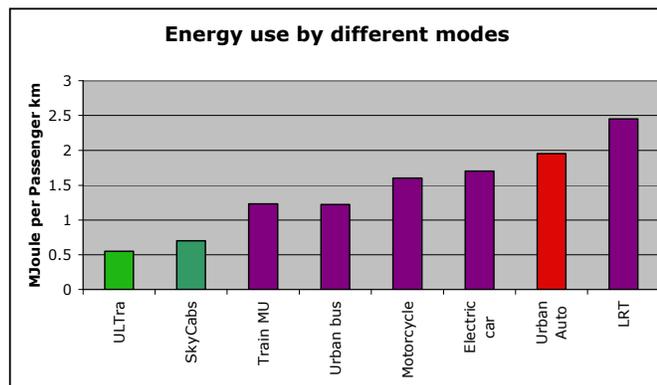
### *Inter mode integration*

Most SkyCabs stations can be positioned above or close to bus and rail stations. Beginning a journey with SkyCabs, the 'on demand' service means that the waiting for a cab starts when the passenger swipes their card and indicates destination or stop. If a bus or rail connection is required at the destination, the waiting time could be the maximum or the minimum frequency of the next mode. When the passenger wishes to continue a journey on SkyCabs, the transfer time is the one to one and a half minute walk from the first mode to the SkyCabs station plus the time for the cab to reach the passenger, a probable wait of 1 minute during busy hours and 1-3 minutes other times.

### *Energy use and environmental effects*

SkyCabs cabs are all electric, lightweight eight-seaters. PRT vehicles are generally electric and lightweight four-seaters. The EC (2004) study found that PRT use considerably less energy per passenger-km than cars or even conventional public transport. Even allowing for pollution caused by the production of the electricity required to run them there is a net saving in both energy and emissions compared with the modes which their passengers would otherwise use. Furthermore, the expected reduction in car traffic will lead to further reductions in CO<sub>2</sub> emissions. Electric vehicles are also generally quieter than the alternative modes. Also small vehicles can be run inside buildings thus reducing visual intrusion or habitat destruction. The main issue of concern

is when the system runs outside historic buildings or private residences. (EC Final Report 2004). Concerns may be mitigated by sensitive architectural design.



**Fig 3 Energy Use by different Modes from EC Final Report, 2004, plus SkyCabs**

The outcome expected of the 2007 New Zealand Energy Efficiency and Conservation Strategy is the installation of 15,000 – 20,000 solar water heating systems by the end of 2010, resulting in conservation of 0.13PJ energy and 0.02Mt CO<sub>2</sub> per annum in 2010. Currently 3400 systems are installed each year with numbers growing around 30 – 40% annually. So far 1.6% of homeowners in NZ have installed solar water heating systems. (EECA 2009). Future savings are therefore expected to increase.

The SkyCabs network on Map 2 would give 10 minute walking access to SkyCabs stations for 45% of Auckland's population. Ten percent of Auckland car trips attracted to SkyCabs would use the same energy as the 0.13PJ conserved each year, reduce congestion to tolerable school holiday levels and reduce pollution. The network would reach full capacity with seated passengers only when approximately 25% of current car trips are converted to SkyCabs use. Then another 0.19PJ are needed.

## WHAT DIFFERENCES COULD NEW TRANSPORT SYSTEMS/MODES MAKE IN AUCKLAND?

### *Current situation*

A two lane road with parking on each side changed to clearways at peak hours has a total capacity of two working lanes in the direction of peak time flow.

The present approach in Auckland is to change peak time clearway/daytime parking along the road to a bus lane. With peak time exclusive bus lanes the total capacity in the direction of peak time flow is one working lane plus bus lane capacity. This configuration can only be equal to the two working lanes when the bus lane use equals the car carrying capacity of the one road lane. In reality this takes many years to happen while the remainder of the increasing number of displaced cars are backed up along the remaining one road lane or its side streets.

### **Dominion Rd, Auckland**

This road has been converted into two lanes of general vehicles, one per direction, with a bus lane on each side. It is claimed that nearly half of the trips are public passenger transport trips along this route. This illustrates that this bus lane with buses at twelve per hour so far does not add to the throughput of passengers, its main reason for existence, but is only close to the capacity of a general vehicle lane.

### Onewa Rd, 1km Bus and HOV Lane, installed 1982, North Shore, Auckland

One of the two lanes connecting Onewa Rd to the motorway was specified as a T3 transit lane for high occupancy vehicles. The initial 45% of peak time commuters using car pooling and buses increased to 55%, but congestion reportedly doubled for the 45% remaining car users. By 2008 car pooling increased from 9% to 28% while bus use increased from 36% to 40%. The T3 lane accounts for only 27% of all vehicles using the two inbound lanes, giving an average of 2.7 people per vehicle across both lanes compared to overall average of 1.1 people per vehicle for car only travel in Auckland. (Macbeth et al. 2008). The short length of the T3 lane shunts buses and HOV vehicles to the front of the queue encouraging carpooling and thus achieving a degree of increase in throughput. There is restriction on the motorway after Onewa Rd and the congestion experienced still needs some solution to ease traffic in the car lane on Onewa Rd.

### New transport for future growth

What else could be done on these two routes to future proof for population growth and to increase capacity significantly and at what cost? PRT, light rail or a SkyCabs line could be installed at varying effects and costs per mode. See Table 1.

**Table 1 Mode Effect on Road and Mode Km Cost per Extra Traveler**

MODE	Type	Mode Capacity, Passengers/hour	Change in Road	Net Increase in Passengers/hour	Capital Cost NZ\$/km	Km Cost / extra passenger carried / hour
PRT	One Way Elevated	1,200 - 1,800	No decrease	1200 - 1800	\$14 million @ .67	\$7,780
LIGHT RAIL	Two Way On Ground	7,200 600p at 10mins	Lose two lanes	3200	\$64 million @ .67 \$43 million @ .79	\$20,000 \$13,440
SKYCABS	Two Way Elevated	9,600 seated 18,000 with standees	No decrease	9,600 18,000	\$16 million	\$1,670 \$890

PRT cost US\$9.4 million/km, adjusted from Ultra web site ([www.ultraprt.com](http://www.ultraprt.com)).

LIGHT RAIL average cost US\$43million/km. (Cox 2002). Phoenix Light Rail as built in 2008, US\$43.5million/km from [www.azcentral.com/news/articles/2008/12/09](http://www.azcentral.com/news/articles/2008/12/09)

City of Sydney Light Rail Extension A\$34.4million/km. (PWC 2006).

SkyCabs construction cost estimate of NZ\$16 million/km would convert to approximately US\$14 million/km overseas. Estimates by SkyCabs International Ltd.

Fiscally responsible choice of public transport modes must be governed by adding capacity to arterial roads to ensure congestion is significantly reduced.

### A WELL CONNECTED PATH

Besides SkyCabs being all electric, non polluting and very quiet with soft wheels, further attributes are required for car users to choose alternative public transport.

One possible definition (Ceder 2007) of a prudent, well-connected transit path is this: An advanced, attractive transit system that operates reliably and relatively rapidly, with smooth (ease of) synchronized transfers, part of the door-to-door passenger chain. Interpretation of each component of this definition as it relates to SkyCabs follows.

**Attractiveness:**

Clearly visible SkyCabs stations with convenient shops, protected from elements  
 Easy route selection with map directory and electronic display  
 Easy fare payment with smart card  
 Kind to the environment, emission free electric cabs  
 Comfortable airline quality seats in cab  
 Panoramic elevated views from SkyCabs windows along the route  
 Provision for wheelchair, pram and bicycles, on board entertainment in cabs

**Reliability:**

Short waiting time, on demand SkyCabs service, small variance in journey times as elevated route avoids intersections, traffic lights and general road congestion  
 Safe automated computerised controls, built in double redundancy where needed  
 Complies with ASCE Standards for automated people movers

**Rapidity:**

Easy access/egress to and from vehicle, door opening three meters wide  
 Fast travel at average 60km/hr operating speed, also express service available  
 Off line stations allow following traffic to bypass stationary cab

**Smoothness (ease):**

Approximate distance between off-line SkyCabs stations/stops is 750 meters  
 Fast lifts to transport platform, no time tables needed as service is on demand  
 Connects local communities otherwise bypassed or severed

**Synchronised:**

SkyCabs can integrate with all other modes of transport via elevated stops  
 SkyCabs cab allocation is computer controlled and demand responsive  
 On SkyCabs network one 1-4 minute transfer covers Greater Auckland suburbs

Key areas of dissatisfaction with public transport were found to be timing, frequency and destination. (Bachels et al. 1999). Also the need to transfer between routes generates a major cause of discomfort for transit users. Designing routes and schedules with a minimum amount of waiting time during a transfer may decrease the level of inconvenience. Many papers have been written from 1970s to today about a variety of ways to design synchronized transit services. Improving transit connectivity is one of the most vital tasks in transit-operations planning. (Ceder 2007).

***Connectivity measures***

Eight quantitative attributes which can be measured to evaluate the quality of connectivity and three subjective qualitative attributes which can be survey based are listed by Ceder (2007). The common denominator for all transit services are the following quality-of-connectivity attributes:

- $e_1$  = Average walking time (for a connection),
- $e_2$  = Variance of walking time,
- $e_3$  = Average waiting time (for a connection),
- $e_4$  = Variance of waiting time,
- $e_5$  = Average travel time (on a given transit mode and path),
- $e_6$  = Variance of travel time,
- $e_7$  = Average scheduled headway,
- $e_8$  = Variance of scheduled headway.

These eight attributes, which can be measured, will be termed *quantitative attributes*.

Other important attributes are not easily quantified and measured. Three of these:

- $e_9$  = Smoothness (ease)-of-transfer (on a given discrete scale).

$e_{10}$  = Availability of easy-to-observe and easy-to-use information channels (on a given discrete scale).

$e_{11}$  = Overall intra- and inter-agency connectivity satisfaction (on a given discrete scale).

These hard-to-quantify attributes will be termed *qualitative attributes*. Different perceptions of these by different passengers are captured in the average weighting of each attribute. The weight of each attribute is survey-based and/or based on the results of a mode (path)-choice model. Measuring transit connectivity involves various parameters and components. The following notations are introduced in “Public Transit Planning and Operation” by Ceder (2007).

### **Connectivity notations**

For a given time window (e.g., peak-hour, average week-day):

$O = \{O_i\}$	= set of origins $O_i$
$D = \{D_u\}$	= set of destinations $D_u$
$P_{Dk} = \{P\}$	= set of inter-route and inter-modal paths to $D_k$
$P_{Ok} = \{P_i\}$	= set of inter-route and inter-modal paths from $O_k$
$M_p = \{m\}$	= set of transit routes and modes included in path $p$
$E_t = \{e^t\}$	= set of quantitative attributes suitable for connectivity measures
$E_\ell = \{e^\ell\}$	= set of qualitative attributes suitable for connectivity measures
$e_{mp}^j$	= the value of attribute $e^j$ , $j = t, \ell$ , related to mode $m$ on path $p$
$\hat{\alpha}_e$	= weight/coefficient for each attribute $e^j$ , $j = t, \ell$
$c_p^j$	= quantitative and qualitative ( $j = t, \ell$ ) connectivity measure of path $p$
$F_p$	= average number of passengers using path $p$
$c_p(i,j)$	= capacity (flow of passengers) of arc $(i,j)$ between route and mode $i$ , and between route and mode $j$ ; each $i$ can also be an origin $O_i$ or destination $D_i$ ; $(i,j)$ is contained in path $p$ and is part of a network-flow model

Based on the above, ten equation-based notations are established. The first equation for the quantitative and qualitative connectivity will be used to compare two paths.

$$c_p^j = \sum_{m \in M_p} \sum_{e^j \in E_j} \alpha_e e_{mp}^j, \quad j = t, \ell \quad (1)$$

Note that the required weight/coefficient  $\hat{\alpha}_e$  in Equation (1) for measuring the level/quality/goodness of connectivity in Equations (1) – (10) can be estimated by the results of both passenger surveys and the path/mode-choice model. Destinations also can be evaluated for access-connectivity. Introducing average passenger numbers using the paths gives exposure-connectivity and paths can be evaluated for people-access-connectivity. Comparisons considering passenger flow can be made among paths and destinations. Weaknesses and bottlenecks can be found and corrected.

## **CONNECTIVITY OF SOME SKYCABS PATHS**

### ***Inter route and inter mode path comparison***

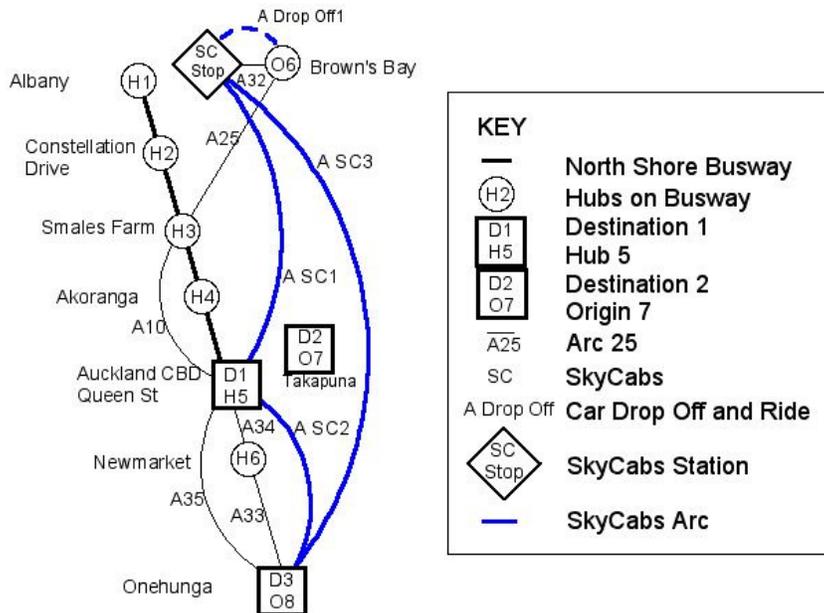
Two sets of origins and destinations have been chosen for comparison.

1. Origin O6: Browns Bay, North Shore    Destination D3: Onehunga, South Auckland
2. Origin O8: Onehunga, South Auckland    Destination D1: CBD, Auckland

**Table 2 Paths Selected for Bus and SkyCabs Comparison**

Path	Origin	Destination	Arcs	Path Description
P1	O 6	D 3	A25+A10+A35	Walk-wait-Public Bus-wait-Public Bus-wait-Public Bus-Onehunga
P2	O 6	D 3	A32+ASC1+ASC2	Walk-wait-Public Bus-wait-SkyCabs-wait-SkyCabs-Onehunga
P3	O 6	D 3	A32+ASC3	Walk-wait-Public Bus-wait-SkyCabsExpress-Onehunga
P4	O 6	D 3	ASC3	Drop off-wait-SkyCabsExpress-Onehunga
P5	O 8	D 1	A33+A34	Walk-wait-Public Bus-wait-Public Bus-Queen St
P6	O 8	D 1	A33+A34	Walk-wait-Public Bus-Queen St
P7	O 8	D 1	ASC2	Walk-wait-SkyCabs-Queen St

On Browns Bay to CBD paths nomenclature for origins, destinations, hubs and arcs follows that of Ceder et al. (2009). Path P1 in Table 2 and shown on Fig 4, includes the arcs A25 and A10 which had best connectivity to CBD during the morning 7 – 9 am peak in this bus study. Path P1 is used for comparison here to paths P2, P3 and P4.

**Fig 4 Schematic Selected Pathways, Browns Bay to Onehunga, Onehunga to CBD**

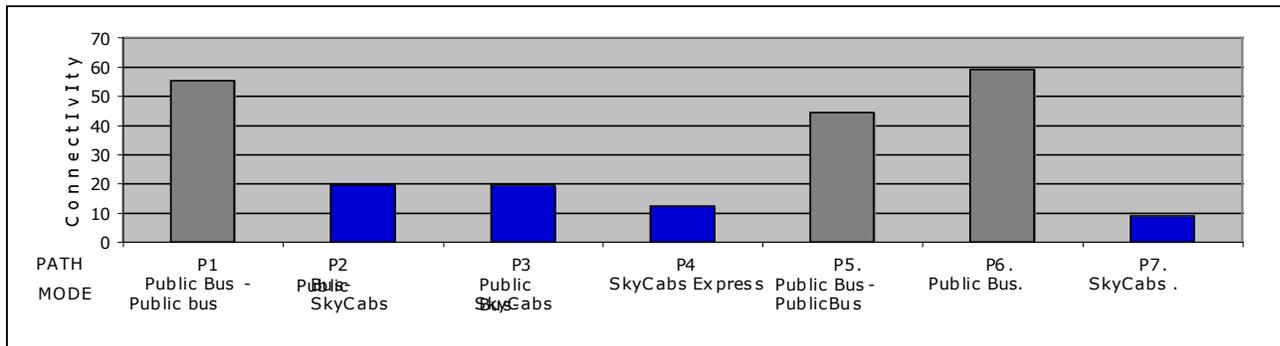
Some values of attributes were obtained from studies carried out at the Transport Research Centre, University of Auckland. Several other paths and associated travel times were obtained from MAXX web site. For the SkyCabs connections on paths and for the Onehunga – CBD paths P5, P6 and P7 additional nomenclature is used for origin, destination and arcs.

As no actual passenger survey was conducted for this comparison, the weighting coefficients of the attributes determined by Ceder et al. (2009) have been assumed.

**Table 3 Weighting Coefficients**

Weighting Coefficient	a1	a2	a3	a4	a5	a6	a7	a8	a9	a10	a11
Value	3.6	2.1	4	4.9	3.9	4.6	4	4.3	3.4	3.9	3.5

Qualitative attributes e9, e10 and e11 and their weightings have been excluded in calculating connectivity. The lower the connectivity value the better the connectivity for the path. Normalised values plotted on Fig 5 show substantially better connectivity for



**Fig 5 Normalised Connectivity of Busway, SkyCabs and Combined Mode Paths**

paths where an arc using bus travel has been replaced by SkyCabs travel. The best connectivity is shown on paths that are uni-modal SkyCabs paths. The superior connectivity of the paths involving SkyCabs shown above is due to faster unimpeded travel on an elevated guideway, shorter waiting times and headways due to on demand service where frequency is so high that timetables are not required.

## POLLUTION AND ECONOMIC EFFECTS OF CONGESTION

As cars take longer and drive at a slower pace engine inefficiencies increase dramatically. A car caught in traffic will operate at a 400% less efficiency compared to operating at 60-80km/hr. (Laird et al. 1999). Reduction of congestion that lead to reduced car travel times on city roads and motorways by 50%, would reduce pollution by well over 50% through improved engine performance. (Auckland Regional Council).

Auckland's local city councils together have a yearly budget of \$2.3 billion. (Royal Commission on Auckland Governance, 2009). Cost of congestion to Auckland city, industry and residents have been estimated by various bodies, including SkyCabs, at \$2 billion per annum. Auckland's growth per capita in real GDP grew by only 1.1% per annum over the five years to 2003 against a NZ average growth of 2.3% p.a. (New Zealand Round Table, 2006). If congestion and the \$2 billion congestion cost were removed and all time saved was used productively, the increase in Auckland's GDP would be 4.2% p.a., and New Zealand's GDP would increase by 1.2%.

New Zealand could be propelled towards the economic position it once had and Auckland Councils may not need 5-6% yearly increase in rates.

## CONCLUSION

Significant reduction of congestion can improve economic performance and reduce pollution, both vital areas of concern for cities around the world. The SkyCabs ESGART system could provide an attractive and affordable passenger transport solution to congestion problems. Initial connectivity comparison of the SkyCabs paths to comparable paths on the North Shore busway is very favourable, due to faster unimpeded travel on SkyCabs elevated guideway, shorter waiting times and headways. Further

studies should be carried out for a SkyCabs network (Map 2), internal connectivity, and for the connectivity of various SkyCabs routes to hubs/nodes of existing public passenger systems. A short \$5.5 million demonstration track needs to be funded and built to confirm the technology and the estimated low capital and operating costs. Evaluation of results by the Transport Research Centre, University of Auckland is included.

New bold thinking is needed to make our cities economically productive.

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