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Comparison of Zero Emission Transport Methods for Hong Kong SAR

Electric Trolleybuses, Modern Trams, Light Rail

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2. public
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Abstract

The purpose of this project was to explore three modes of zero emission public transportation - electric trolley buses, modern trams, and light rail – for Hong Kong Special Administrative Region (HKSAR). We performed a side-by-side comparison of the performance aspects and costs associated with these systems, gave insights on how they could be implemented into HKSAR, and identified possible social impacts associated with this implementation. These goals were obtained through case studies, archival research, and interviews of transportation professionals.

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Executive Summary

As one of the most densely populated cities in the world, with nearly seven million citizens, Hong Kong faces a severe pollution problem. Over ninety percent of Hong Kong's population uses public transportation as the primary transport method. A major source of pollution is vehicle emissions at street level, much of it from public transportation vehicles. Diesel buses and other vehicles emit pollutants into the air, endangering the health of both the citizens and the environment. Therefore, a zero street level emission transport system is necessary for sustainable transportation in Hong Kong.

This project looked at three alternative modes of transportation that have been recently proposed: electric trolleybuses (ETBs), modern trams (MTs), and light rail (LR). The goals were to do a side-by-side comparison of the three technologies, to discuss the possibility of their implementation in Hong Kong, and to consider the potential social impact of these systems.

The methods that we used in carrying out this project included archival research, case studies, and interviews. Technical data were obtained from previous studies of several cities and from interviews with transport engineers and professionals. Two recent studies that we evaluated were the side-by-side comparison in Rome carried out by Veca and Villanti, professors of engineering at University "La Sapienza" of Rome, and by the Electric Tbus Group, an advocacy group for the re-introduction of ETBs in Greater London.

These reports were supplemented with data on the double-decked ETB obtained from Citybus, a company in Hong Kong that submitted an ETB proposal to the Government as a zero local emission transport method. While the above technical data

provided a framework for discussing the costs that would be incurred during implementation of a new system, we also used case studies from other cities comparable to Hong Kong to uncover other relevant technical data. The cities chosen were San Francisco, Vancouver, Singapore, Bordeaux, Greater London, Zurich, and Amsterdam. They were chosen because of their similar landscape or environmental concerns.

In addition to case studies and archival research, we interviewed company and governmental officials as well as experts on both technical and social aspects of zero emission transportation. We spoke with Dr. William Barron, a professor at the University of Hong Kong, Simon Ng, a research associate at the University of Hong Kong, Professor Hung Wing-Tat from Hong Kong Polytechnic University, and Ms. Alice Au Yeung, principal transport officer from the Bus and Rail Branch of the Transport Department, for their views on the current and possible future plans for Hong Kong's transportation systems. We interviewed the chief engineer at Citybus, John Blay, to obtain performance and cost data as well as insight about Citybus' pilot ETB installation on Hong Kong Island.

From our interviews with the Transport Department and Professor Hung, we have found that there are no governmental policies regarding the implementation of zero emission transport, only suggestions for the transport companies to explore these options. The government has asked for proposals for installing zero local emission transport in the old Kai Tak Airport site. Citybus has also submitted plans for their double-decked ETBs to be used at this site and to replace some of their diesel buses on various routes on Hong Kong Island.

	ETB	MT	LR
comparative noise level	Loud conversation	electric typewriter	noisy office
segregation from traffic	integrated with road traffic	integrated with road traffic	completely segregated from traffic
distance between stops	short	short	long
power supply	overhead electric wires	overhead electric wires or electric third-rail	overhead electric wires or electric third-rail
route covered	fixed path, but can deviate up to 4m from wires	fixed path	fixed path
capacity	Low	medium	high
Terrain capabilities	All terrain	flat terrain only	flat terrain only

Table I Performance Aspects of ETBs, MTs, and LR

Table I summarizes some performance aspects of ETBs, MTs, and LR. Most of the ETB vehicle data were obtained from Citybus based upon the double-decked ETB test vehicle, and the other data were gathered through case studies, comparative studies, and interviews. According to the table, ETBs are more flexible than MTs and LR because they can deviate up to 4 meters from the overhead wires to bypass construction or other obstacles. An LR is the least flexible because it must be completely segregated from traffic. Another major datum that we found from our methods is that an ETB can climb the largest gradient, making it the only vehicle out of the three that can operate on a large variety of terrain.

The data represented in Table I provide general performance comparisons among the three alternative zero emission transport systems: ETBs, MTs, and LR. In overall performance aspects, all systems can be customized to fit the needs of particular areas of implementation.

The Electric Tbus Group's East London Transit Scheme and Veca and Villanti's comparison of ETBs and MTs provided comparisons for cost considerations. These studies showed that the capital cost for an MT system is higher than the capital cost for an ETB system, as listed in Table II below. This difference in capital costs comes from the expense for building the tracks. Although the ETB system uses a fleet that is twice the size as that of an MT system, the capital costs of an MT fleet are 50 percent greater than the costs necessary to buy the fleet of vehicles for the ETB system. The London analysis showed that the operational and maintenance costs of the MTs are half of the operational and maintenance costs of ETBs. However, the Rome study showed an opposite trend in the operational and maintenance costs for MTs and ETBs. According to that study, the operational cost of MTs was 18-81% higher than that of the ETBs, and the maintenance cost for an MT is more than the maintenance cost for an ETB. These discrepancies, summarized in Table II, suggest that costs are dependent on the particular implementation circumstances.

	Rome		Greater London	
	ETB	MT	ETB	MT
capital costs	Low	high	Low	high
operational costs	Low	High	High	low
maintenance costs	Low	High	High	low

Table II Costs Considerations Adapted from the Rome and London Comparative Studies

The major goal of any new system will be to reduce the level of noise pollution and vehicular emissions that are affecting the health of Hong Kong's citizens and environment. Safety issues relating to the overhead powering system is also a concern as are possible concerns about its visual intrusiveness. A new system should not only reduce traffic congestion, but also allow convenient transfers from one transportation mode to another. Since pedestrianisation is crucial in Hong Kong, a new tramway can create more space for pedestrians for easier transfer as well as creating areas that would be required for the convenience of the elderly and disabled. The government may need to subsidise these low pollution systems in some way in order to keep the fares low, and it should educate the public about alternative transportation methods that are available to better the health of the citizens. The public must be able to understand the systems and the changes that they may bring about in order for them to be successful.

In conclusion, we recommend more research into these alternative zero emission transport methods. A Hong Kong specific technological study must be performed in order to determine which new system is most appropriate and the adaptations that would be necessary. This study must also include a cost-benefit analysis per route. A feasibility study for the social issues discussed earlier must also be included in future investigations before further recommendations can be specifically made to determine which type of transportation system is most suitable for Hong Kong.

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List of Figures and Tables

List of Definitions, Conversions, and Acronyms Used

Acronyms:

AC - Alternating Current

DB - Diesel Buses

dBA - Decibels

DC - Direct Current

ETB - Electric Trolley Bus

HKD - Hong Kong Dollar

MHKD - Million Hong Kong Dollars

MT - Modern Tram

LR - Light Rail

Definitions:

Articulated Vehicle: A vehicle having a hinge or pivot connection between sections to allow negotiation of sharp turns.

Diesel Bus: Manually steered, rubber-tired transit vehicle that is propelled by an internal combustion engine which uses diesel fuel.

Electric Trolley Bus: Manually steered, rubber-tired transit vehicles that are propelled by an electric motor powered from overhead wires.

Modern Tram: An electric transit vehicle guided by rails and powered from an overhead wire and is fully integrated with vehicular and pedestrian traffic.

Light Rail: An electric mass transit vehicle, guided by rails that is completely segregated from vehicular and pedestrian traffic, and has a higher capacity and speed than a modern tram.

Conversions:

1 USD = 7.7 HKD

1 Euro = 8.4 HKD

1 Canadian Dollar = 5.14 HKD

1 Singapore Dollar = 4.48 HKD

1 British Pound = 12.28 HKD

Chapter One Introduction

One of the fundamental requirements of a successful city is a strong public transportation system. Public transportation is important to the day-to-day operation of the city and the livelihood of its citizens. People need accessibility to community services, employment opportunities, and recreational facilities. This is especially true in Hong Kong because over ninety percent of the population use public transportation (Rooks and Deckjan, 2001). In striving to become "Asia's World City" and to achieve the paradigm of sustainable development, a relevant goal for a transportation policy in Hong Kong is one of zero street level emissions. The latter goal provided the rationale for our project, which is to perform a side-by-side comparison of electric trolleybuses (ETBs), modern trams (MTs), and light rail (LR). These data will then be analysed for possible implementation of the systems throughout parts of Hong Kong SAR.

Urban transportation continually changes to reflect the future needs of its users and of society. Varying economic, social, and environmental conditions of a city are usually the motives behind the changes. Levinston and Weant (1982) state that environmental protection and the conservation of petroleum fuels usually take precedence over the traditional economic benefits of change. Environmental concerns are prompting Hong Kong officials to re-evaluate the public transportation system, even if the environmentally favourable solutions may not be economically attractive.

Pollutants emitted from buses and other vehicles are among the major causes of the pollution index rising to unsafe levels, endangering the environment and the health of people throughout Hong Kong. It has been reported that two thousand people die annually due to air pollution, and forty percent of children suffer respiratory problems

(Associated Press, 2002). Residents of Hong Kong are calling for the government to consider new, environmentally sound transportation methods (Barron, 1999).

Although Hong Kong's network of underground railways, trains, ferries, and buses is well developed, investigation has just begun on zero emission ETBs to replace diesel buses (DBs). ETBs are a promising alternative method of public transportation that increases fuel and transportation efficiency while also decreasing the contribution of pollution at street level. An organization that is looking into the feasibility of replacing the DBs with a zero emission transport method is our sponsor, Civic Exchange.

Civic Exchange is an organization that strives to promote municipal education as well as undertaking research on economic, social and political issues in Hong Kong. In the effort to explore new zero emission transportation methods that will eventually replace DBs, they have suggested MTs and LR, in addition to ETBs, as possible solutions. Civic Exchange has asked us to undertake the groundwork for this recommendation by formulating a side-by-side comparison of ETBs, MTs, and LR. This database of information can then be used by them to advise the government as to the most appropriate method of zero emissions transportation.

Citybus and Civic Exchange completed studies into the replacement of DBs with ETBs and concluded that this change is necessary (Citybus Ltd., 2001; Barron, 2002). Citybus converted a DB to an ETB and installed a pilot track on Hong Kong Island that, according to them, shows ETBs to be a promising alternative to DBs. Citybus also concluded that, in uphill tests, ETBs are superior to MTs. However, they failed to address how well ETBs compare to MTs on flat surfaces. In fact, Hong Kong could alleviate many of its air and noise pollution problems and its reliance on imported diesel fuel by implementing any or all of the three vehicles - ETBs, MTs, and LR - that rely primarily on electricity.

One major attribute that differentiates the three types of transportation with respect to their implementation in Hong Kong is their performance on different terrain. Hong Kong's varied topography and landscape, along with its high density of people in areas such as Kowloon and parts of Hong Kong Island, has made an overhaul of the current transportation system a severe economic, social, and engineering problem. The total cost of a new transportation scheme may well exceed the perceived benefits of employing such a system (Barron, 2002).

In order to obtain the necessary information for our research, case studies of other cities' public transportation systems were carried out. Amsterdam, Bordeaux, Singapore, Zurich, and London were examined for their MTs and light rail systems while Vancouver and San Francisco were used for case studies of ETBs. From studying various transportation methods in different situations, we extracted and analysed a variety of technical information.

The outcome of this project was to provide a database of information that can be used by Civic Exchange for advising the government on the most appropriate solution for the replacement of DBs. Citybus had outlined the benefits of ETBs, but there had been little investigation into whether MTs can be combined with ETBs as a replacement system. Our study attempts to provide the missing information needed to determine whether it is feasible to adopt MTs, ETBs, and/or LR throughout Hong Kong SAR.

Chapter Two Background

In this chapter, we discuss the nature of public transportation in Hong Kong and present case studies of ETBs, MTs, and LR in selected cities.

2.1 Public Transportation in Hong Kong

In many cities, one of the main purposes of public transportation is to ease the problems with pollution and congestion due to the use of automobiles. The types of public transportation that are used to achieve this objective mainly include buses and some form of rail transit. Since most residents of Hong Kong do not own cars, public transportation is crucial to the day to day operation of the city, and the livelihood of its residents. At a minimum, these people need to be able to access community services, employment opportunities, and recreational facilities. In addition, transportation systems must be able to meet the needs of the elderly, disabled, and the poor.

Due to the considerable cost associated with owning a car in Hong Kong, it makes sense that about ninety percent of Hong Kong's residents and tourists travel by means of its public transportation system (Rooks and Deckjan, 2001). Over seven million people live in Hong Kong, and there are over eleven million passenger journeys made daily on the public transport system (Government of Hong Kong Special Administrative Region (HKSAR), 2001). The Hong Kong government suggests that "a public transport system that is well coordinated, convenient, and efficient" is crucial for the high demand of usage in this densely populated area (p. 17).

The public transportation system in Hong Kong includes franchised bus and ferry services, trams, rail, light buses, and taxis. Buses are the most frequently used public transportation method with an average 4.24 million daily passenger trips (Government of HKSAR, 2001). The railway system, in particular the Mass Transit Railway (MTR) and the Kowloon-Canton Railway (KCR), provides 2.1 million daily passenger journeys (Government of HKSAR, 2001). The MTR mainly runs through areas of Kowloon and Hong Kong Island, whereas KCR passes through the New Territories to the boundary with Mainland China. These railways, along with the light rail system between Tuen Mun, Yuen Long and Tin Shui Wai, help to alleviate the dense traffic situation in Hong Kong because they are completely segregated from other traffic. There is also a small double-decked tram on a thirteen-kilometre track operated by Hong Kong Tramways Ltd. on Hong Kong Island.

Although the rail system currently in place in Hong Kong is adequate, the overall transportation system has one major flaw, pollution. William Barron summarises the problem with Hong Kong's current transportation system as follows: "Hong Kong's pollution and noise are at their worst on the street in congested urban areas. In a city where everyone, except the very rich, are pedestrians everyday, it is shocking that the Transport Department has allowed Hong Kong to deteriorate into such a hostile place for pedestrians" (Barron, 1999).

Another problem with the structure of public transportation in Hong Kong is the manner in which it is funded. In almost every city in the world, the government subsidizes the public transportation system. This is not the case in Hong Kong; public transportation systems are privately run, and therefore try to return a profit. Since the government subsidizes the fuel tax that helps to pay for the infrastructure of road transport like buses, buses are a relative inexpensive method of transportation. However, given the negative aspects of pollution, new, less polluting methods such as light rail or electric trolley buses need to be considered (Barron, 1999).

2.2 Public Transportation Methods

Table 2-1 qualitatively compares four types of public transportation: diesel buses, electric trolleybuses, modern trams, and light rail. Each subsequent section will give a general overview the respective system.

	DB	ETB	MT	LR
	ETB	MT	LR	
comparative noise level	loud conversation	electric typewriter	noisy office	comparative noise level
segregation from traffic	integrated with road traffic	integrated with road traffic	completely segregated from traffic	segregation from traffic
distance between stops	short	Short	long	distance between stops
power supply	overhead electric wires	overhead electric wires or electric third-rail	overhead electric wires or electric third-rail	power supply
capital cost	very low	Low	medium	high
capacity	low	Low	medium	high
terrain capabilities	All terrain	all terrain	flat terrain only	flat terrain only

Table 2-1 Comparative Aspects of DB, ETB, MT, and LR

2.2.1 Diesel Buses

Levinston and Weant (1982) report that buses have been the mainstay of public transportation in American cities for several decades, accounting for seventy percent of the eight billion annual transit trips and half of all transit miles travelled. Buses are a cost efficient way to transport people in cities with a high population density, where their use is the greatest.

Buses have several other advantages, the two main ones being in the great flexibility and low capital cost. Since they follow the road network already in place, the only capital cost incurred is the purchase of the buses. This comparatively small capital cost creates an extensive and flexible network that can serve many people. Although buses are usually regarded as a flexible means of transportation, an efficient public transportation system will need to have a combination of buses and other modes to keep passenger usage and avoid losing customers to automobiles. A technical paper at the UITP 2000 Assembly in Melbourne stated that between 1986 and 1996, twenty two bus-only cities lost an average of 5.6% of passenger use (Kenworthy, 2001).

The major disadvantage of buses is their dependence on fossil fuels. When diesel fuel is burned in an internal combustion engine, harmful exhaust is emitted. The Vancouver Transit Authority reports that many upgrades to the diesel engine and the fuel that it uses have allowed DBs to meet the emission requirements imposed on them (Greater Vancouver Transit Authority (GVTA), 2001). Even with these lower emission requirements and the use of low sulphur fuels, DBs still release carbon dioxide, a greenhouse gas, nitrogen oxides, and particulates into the air. Since this exhaust is emitted at the street level, it contributes more to the pollution of inhaled air than other sources (Transportation Research Board, 1982). In addition to emitting pollutants, internal combustion engines are less than half as efficient as electric motors.

Besides environmental factors, the upkeep costs associated with DBs are also a disadvantage. Although the initial cost of combustion engines is cheaper than non-traditional engines, such as electric engines, diesels require significant amounts of maintenance to run at their peak performance. The cost of maintaining a fleet of motor coaches is approximately thirty percent more than the maintenance required for a fleet of ETBs (Transportation Research Board, 1982).

2.2.2 Electric Trolleybuses

A transportation method similar to DBs, but more environmentally friendly, is electric trolleybuses, also known as trolley coaches. ETBs are manually steered, rubber-tired transit vehicles propelled by an electric motor that draws its power from overhead wires.

The major advantages of ETBs over automobiles and buses are their quiet operation and lack of exhaust at street level. Even if coal, the most polluting fuel, is used to generate the electricity that powers the ETB, the total pollutants generated per kilometre travelled are negligible compared to the 18.8 grams of pollutants per kilometre travelled for a DB (Barron, 2002).

On level ground, ETBs and DBs perform similary, but ETBs can accelerate quickly and are more efficient in hilly terrain (Transportation Research Board, 1982). DBs produce the most noise and pollution while accelerating uphill, whereas ETBs do not create any surface pollution and negligible noise. On average ETBs produce fewer than 70 decibels, about the same noise level as a loud conversation, which is a minute amount for a transportation method (GVTA, 2001). In addition, when technologies such as dynamic and regenerative braking are used, there is no physical friction with the vehicle during braking, which further reduces noise (Wong, 1999).

The energy requirement for the ETB to climb up a hill is substantial. To add to its energy efficiency, technologies such as regenerative braking and a flywheel system are used. Both systems transfer the power that is lost while braking to a battery, which then can provide the extra energy needed while climbing up hills (Tarrant, 2002).

Since ETBs have rubber tires and do not involve rails, there is a lower capital cost when compared with MTs and LR, although the construction of an ETB system requires a substantial cost for the overhead power supply. The cost for the ETB vehicle itself is also higher than a DB. Depending on the system, one way to lower this cost is retrofitting the current DB with electric motors, which has been done on the current pilot ETB in Hong Kong (Tarrant, 2002). Seattle also retrofitted its DBs when converting its ETBs, but found this method to be very expensive, almost the same cost as buying a completely new fleet (GVTA, 2001). According to John Blay the chief engineer, Citybus says that they will purchase new ETBs to save on capital cost (personal communication, January 15, 2003).

Although there is a higher capital cost than with DBs, an ETB system will last longer. The Transportation Research Board theorizes that ETBs can last up to thirty years while DBs have a maximum lifespan of fourteen years (John Blay, personal communication, January 15, 2003). Although the ETBs might not seem economically feasible, environmental factors sometimes are more heavily weighted and can justify the use of ETBs (Transportation Research Board, 1982).

One disadvantage to an ETB system is that it will be competing with automobiles and other road vehicles because it is a form of street transportation. Even though an ETB can venture four metres from the overhead wires to move around obstacles, other problems exist (Transportation Research Board, 1982). New technology such as guided bus systems totally separates the bus from other traffic, which adds to the efficiency. Guided buses are an intermediary system between conventional buses and trams, running as a tram where necessary and as a bus where the road space is sufficient. Carmen Hass-

Klau, a professor at the University of Wuppertal, Germany, feels that this type of separation is best achieved with a light rail system rather than a segregated bus line (Tramways & Urban Transit, 2002).

ETBs' main disadvantage is the overhead power supply, and as with light rail systems, ETBs are limited to a fixed route because of their overhead wires. The main energy inefficiency of ETBs is the loss of electricity through overhead wiring. In addition, overhead wires can create a visual and safety intrusion in the surrounding area, and the capacity of an ETB is less than a rail car because ETBs cannot be linked to increase the number of passengers (Levinston and Weant, 1982). Even with these disadvantages, Translink suggests that, "Trolleybuses are favoured by customers for their cleanliness, quietness, and even ride" (GVTA, 2001). They hypothesize that greater capacity can be achieved through the use of articulated buses, which are larger and therefore can hold more passengers.

A local bus company, Citybus, has taken the initiative to install a pilot ETB track on Hong Kong Island. Citybus' study of this trial line has outlined the benefits of ETBs in Hong Kong. This ETB is one of the most technologically advanced in the world, being the first ever double-decked and air conditioned ETB. According to Citybus engineer John Blay, "The trolleybus also shows superior performance. Even when fully loaded, the trolleybus accelerated more quickly, and was better at hill climbing than an equivalent diesel bus" (Citybus Ltd., 2002).

2.2.3 Modern Trams

Another environmentally friendly alternative to DBs is modern trams. Barron refers to trams as modern trams in order to differentiate between the antiquated tramway installed on Hong Kong Island and the new modern tramway that could eventually replace some of the DB lines (personal communication, November 11, 2002). There is a lot of confusion about the various words that describe a train that operates at street level. While "tram" and "streetcar" are synonymous, it is harder to differentiate between light rail and tramways.

Light Rail is usually segregated from other traffic and users get on and off at stations rather than at the kerbside, while trams can operate in the street. Most street rail systems can be seen as a combination of both light rail and tramways (Light Rail Transit Association [LRTA], 2002). For the purpose of our project, we will define a modern tram as a transit vehicle guided by rails that is powered through an overhead wire or a third rail and is fully integrated with vehicular and pedestrian traffic while light rail is a system that is completely segregated from vehicular and pedestrian traffic.

Similar to ETBs, trams do not produce emissions at street level, and therefore have less of an environmental impact than DBs. Trams run on electricity and can receive their energy from either a third rail or from an overhead wire. For safety reasons, an overhead wire is usually used where pedestrians will cross the tracks (LRTA, 2002).

In the past, an overhead catenary system was the only technology available to tramways, creating the same visual intrusion as ETBs. In Bordeaux, France a new technology called APS (Alimentation Par le Sol, loosely translated from French as "power from the ground") is being used to remove the intrusive overhead wire. It uses eight-meter electrified third rail sections with a three-meter neutral buffer in between. When the train passes over two of the electrified sections, a circuit is completed, powering the train. When the train is not over the third rail, the safety problem for pedestrians is greatly reduced (Tramways & Urban Transit, 2002). This new technology adds a favourable powering system for modern trams in urban settings with many pedestrians. Furthermore, tramcars can be linked together, allowing trams to carry more passengers than either ETBs or DBs.

Although the advantages of trams are evident, there are also problems with current tramways. The problems are mainly due to bad planning since the tramways are not segregated from other vehicles (Tramways & Urban Transit, 2002). This segregation is not always possible given the infrastructure of the city where they are to be applied. Other problems are caused by slow speed, short headways, and the necessity of operating in a highly pedestrianized street. Since space is at a premium in Hong Kong, Citybus claims that this is one of the main reasons why they support an ETB system (Tarrant, 2002).

2.3 Public Transportation in Other Cities

The following subsections describe the information obtained for the cities used in the case studies of ETBs, MTs, and LR. These subsections include the transportation systems in San Francisco, Vancouver, Zurich, London, Singapore, Amsterdam, and Bordeaux. These cities were used to gather technical information and then to compare to Hong Kong.

2.3.1 Muni ETBs in San Francisco

Public transit services started in 1851 in San Francisco and were mainly operated by privately owned companies. Publicly owned transportation was non-existent until the city charter of 1900, which called for the public ownership of all public utilities in the city. On December 28, 1912, the Municipal Railway (Muni) started servicing the public using cable cars. Near the end of World War II, Muni converted the system's primitive streetcar lines and cable cars to ETBs. The ETBs offered more torque and as a result, were much faster climbing uphill than diesel-powered vehicles (Arnold, 1974). Arnold concluded that ETBs were ideal for the hills of San Francisco.

Operating the ETBs in San Francisco involves high average costs, although the system itself financially benefited from low maintenance costs and high average fares. Despite those positive characteristics, the ETBs still needed government subsidization due to the fact that fares only contributed thirty-three percent of the total cost. Arnold and Sanborn both suggested that the transportation system would also need funding for future changes and improvements to the system to accommodate a growing population, as well as other possible undetermined factors that could arise. To provide for possible future extensions and improvements, a city charter was devised. In 1974, HKD 63.6 million was set aside for any foreseeable needs of the ETB system (Arnold, 1974). The money set aside for these improvements will allow the service to adapt to city's population and travel needs as they arise and change.

Currently, Muni is the seventh largest public transit system in the United States; approximately seven hundred thousand passengers use the system on an average weekday. Despite the heavy use of automobiles in the United States, the number of passengers who use Muni has been consistent throughout its history and relatively high compared to that in other cities. Its fleet consists of one thousand vehicles comprised of ETBs, DBs and cable cars (San Francisco Municipal Railway, 2002).

The company came under scrutiny when the San Francisco Department of the Environment criticized the emission of pollutants by Muni's DBs (Epstein, 2001). On April 25, 2000, the Environmental Commission of San Francisco voted unanimously to urge Muni to stop buying DBs. Since then, Muni has decided to promote air quality and committed itself to finding the best solution to deal with the pollution from their buses. The company has to decide whether natural gas-fuelled buses or hybrid-electric buses perform best on San Francisco's hills and streets.

2.3.2 TransLink in Vancouver

There are several major means of public transportation serving over two million people of Vancouver (Statistics Canada, 2002). In large urban city areas such as Vancouver, there needs to be a transit system to reduce vehicular congestion in high-density areas and to provide affordable transportation to its residents. Besides the light rail system (SkyTrain), the disabled service HandyDART, and the bus systems, Vancouver also converted its tramways to an ETB system in 1948 because of the high fuel cost and the high population density.

A 1996 essay written by Ian Fisher, a student at the University of British Columbia, explains in detail the advantages and disadvantages of ETBs compared to DBs (Fisher, 1996). As he pointed out, there are numerous reasons for the survival of the ETB system in Vancouver despite the decreased usage of ETBs in the 1960s. Some of these factors include timing, public ownership, economies of scale, and the topography of the city. Rising oil prices and growing environmental awareness in the 1970s encouraged the use of ETBs over diesel vehicles due to the lower electricity costs which resulted in lower operating and maintenance costs. The varying landscape on the routes favoured ETBs, which are able to run on sloping streets.

2.3.3 Light Rail in Zurich

Railways are the most common form of transportation in Zurich spanning 4,406 km and virtually all are electrified (CIA, 2002). The systems serve nearly seventy percent of the population (Husler, 2002). Zurich decided to use light rail instead of electric trolley buses in part because of the regulations that the government puts on the latter.

> The regulations concerning electrical installations on railways, stipulate a minimum contact wire height on 4.8 meters. This clearance is to be maintained at the highest temperature, at the highest track position and taking due account of contact wire oscillations and catenary construction tolerances, as well as of the geometrical effects of peaks and troughs (GEC Alsthom, 1989, p. 102).

Since there are so many regulations concerning wired electrification, a different way of obtaining power was needed. Unlike the ETB system which is dependent on the wires, the light rail system can use a third rail. The Swiss government recommended light rail because, "it [the rail] does not have any moving parts and is not damaged by short circuits" (GEC Alsthom, 1989 p. 103). Today, the system is still popular due to its speed, efficiency, reliability, and vast coverage. The postbus, a diesel engine bus, is used to complement the light rail when the latter does not serve a particular area. The postbus serves as a feeder system to the light rail for citizens who live far from light rail stops (CIA, 2002).

2.3.4 Greater London

Greater London's comprehensive public transportation system is of interest because its population, street layout, and topography are comparable to Hong Kong. In particular, Central London can be compared to the densely populated areas such as Hong Kong Island and Kowloon whereas suburban London is comparable to the rest of HKSAR. Greater London has many means of public transportation ranging from conventional buses to trams. Some problems with public transportation are the street level pollution and the massive amounts of traffic congestion (Transportation for London and Department of Transport (TFL), 2002). The London Transit Authority (LTA) is continually looking for ways to address these problems.

In order to overcome problems of pollution and congestion, London has looked into expanding its existing underground railway rather than building new roads "The major reports suggest that the most straightforward way of relieving congestion on central London's rail system is to upgrade the capacity of the existing system" (Chartered Institute of Transport, 1991, p. 12). According to London's Transport, modernizing the current underground railway is the most efficient solution for their problem.

Despite the convenience of Greater London's transportation systems, thirty percent of the population use their own vehicles. The Association of London Government and the Greater London Authority, in a joint initiative to improve London's air quality, recommended a low emission zone (TFL, 2002). In Croydon, an area south of London, trams are the main source of transportation, and therefore the air pollution is noticeably lower than that of metropolitan London.

A recent survey was conducted to determine the effects of extending the Tramlink, the main tramway, into Croydon, using a pre- and post-Tramlink surveys. It was conducted by TfL and the Department of Transport "to assess the impact of Tramlink compared to a situation where it had not been built" (TFL, 2002). The study showed that sixty nine percent of those that used Tramlink had previously used the bus and sixteen percent had used their personal automobiles. It also showed how street traffic flow and city parking increased and measured the effects of Tramlink on its patrons. The increase in traffic flow and city parking showed that fewer people were using their own cars, thereby minimizing congestion. The tram system was meant to complement the bus system, not to compete with it.

2.3.5 SMRT in Singapore

Singapore has bus, railway, and taxi systems to serve its densely populated areas. The objectives of the Singapore Government regarding transportation are to integrate land use and transport planning, to expand the road network, to manage vehicle ownership and usage, and to improve the public transport system (MITA, 2002). The light rail system in Singapore is the Singapore Mass Rapid Transit (SMRT). Incorporated in August, 1987, it is an extensive rail network that provides efficient and a low pollution transport for a large number of passengers. The main reason the SMRT system works better than either the bus or the taxi systems is that it carries a higher capacity at a faster rate, comparable to the Mass Transit Railway (MTR) and the Kowloon-Canton Railway (KCR) systems in Hong Kong. On average, the SMRT makes approximately one million daily passenger trips (SMRT, 2002).

To promote the use of public transportation in Singapore, customer satisfaction and environmental friendliness are both taken into consideration. Mr. Lim Swee Say, the Minister for the Environment in Singapore, stated that vehicular emission accounts for 50 percent of fine particles in the air. Although only 18 percent of Singapore's vehicle population is composed of diesel vehicles, they are responsible for almost all of the fine particles in the air. Because of Singapore's emission standards, it is promoting the use of cleaner sources of energy (National Energy Efficiency Committee, 2002).

Besides the pollution problem, the Singapore Government also looked at the economic aspects of expanding the transport system. The Deputy Prime Minister, Lee Hsien Loong, suggested in a speech that although developing the SMRT system was profitable and beneficial to the Singapore citizens, excessive expansion of the system would be a waste of resources and money if there was no demand (National Archives, 1996). The capital, operation, and maintenance costs would be higher for an extensive system. Since unused tracks and trains depreciated day by day, the government might choose to raise taxes, shut down parts of the SMRT line, or to raise fares to break even.

2.3.6 Combinos in Amsterdam

Over 1.3 million people inhabit Amsterdam, the capital of the Netherlands (Schwandl, 2003). In the heavily populated metropolitan area, the public has access to an extensive transportation system consisting of the metro and rapid trains, buses, and trams. The seventeen tramlines of Amsterdam are the primary means of travelling around the city. They are running mainly on the surface, with only 3.5 km of the tram system running underground. Similar to what is found in Hong Kong, streets in Amsterdam are narrow and parking spots are scarce. Thus, public transportation, walking, and bicycling are widely used.

The streets that have the tramlines have track areas that are not exclusively used by the trams, but are offset by a small curb from other vehicular traffic (Pirmann, 2002). Although trams have the right-of-way, DBs and taxis can use the tram route as well. Some streets have tracks in the centre, which allows two-way traffic. This arrangement eases the traffic congestion by allowing automobiles to use the tracks when trams do not use them, adding an additional lane.

Currently, plans for upgrading and improving the existing tram system are constantly being considered. Gemeente Vervoer Bedrijf (GVB), the municipal transport company controlled by the Amsterdam City Council, placed an order with Siemens to replace its antiquated fleet of trams with the Siemens Combino, a new type of modern tram which includes features such as increased seating capacity, low floors for the elderly and disabled, wide double doors, and visual appeal (Net Resources International Limited, 2002). The improved capacity of these new trams will mean fewer trams are needed for the same level of service.

The new Combinos will be used on sixteen older tram routes (Net Resources International Limited, 2002). In addition, new routes will be specifically designed and opened for them in areas lacking a pre-existing public transportation system. One such line is planned to go from central Amsterdam and will run ten km to Ijburg, which is the focus of the city's largest new housing development. Known as the "supertram" route, this line will introduce the first Combinos in artificial islands recently reclaimed by Amsterdam. The Combinos are expected to be fully integrated by late 2003.

2.3.7 Bordeaux's New Tramway

One of the newest MT systems in the world is that in Bordeaux, France. As with Hong Kong, due to increasing air and noise pollution, automobile usage, and space constraints a new public transportation method was needed there. Many different transportation types were considered including subways, buses, and trams. The website for the new tram states that government officials of Bordeaux and its greater area chose a tram system over buses and other means of public transport because of the success of trams in other French cities (Publicis Soleil Réalisation, 2000).

The system will be built in such a way as to provide a sustainable transportation solution by being designed for future upgrades. It will consist of three lines, serving a current population of approximately 660,000, which is similar in size to new cities in the New Territories and other new development areas in Hong Kong. In addition to adoption of the new tram system, the current bus system will be restructured to complement instead of compete with the new trams.

Although the cost of the system is large, it will be built in two phases with a total projected cost of HKD 8.5 billion. The construction will be done in two phases, reducing the burden of construction and other capital costs. The capital cost could also have been reduced by choosing a standard type of tram instead of a custom designed one with low-floor access, air conditioning, and a "modern" design. Hass-Klau suggests that choosing a standard tram instead of a custom one is one of the easiest ways to reduce the capital cost of a new tram system (Tramways and Urban Transit, 2002).

Thanks to extensive planning, the Bordeaux system was designed to have ninety four percent of all residences, stores, and government offices within three hundred meters of a tram stop. Bordeaux transportation officials hypothesize that due to the fixed nature of the trams there will be an economic boom along the lines and a decrease of crime due to the increase in the number of people there (Jong, 2002).

Adding to the benefits of the new tram system will be a reduction in the current automobile roadway, resulting in more than fifty percent of the space occupied by the trams also accessible for use by pedestrians and cyclists. Increased space for pedestrians is largely due to the new APS system that powers the tram from beneath. The "third rail" APS system was created to remove the visual intrusion of the overhead catenary and will be the first system to use it extensively. To further increase the efficiency of the tram, the right of way will be given to all the trams at all intersections (Publicis Soleil Réalisation, 2000).

In order to create a new MT system for Hong Kong, many of the thorough planning procedures utilized for this system should be considered. The Bordeaux situation is similar to that of Hong Kong in that there is investigation into a new transportation system to help alleviate noise and air pollution problems, and that system will need to be interfaced with vast amounts of pedestrians. The use of modern technology such as the APS powering system and expert planning will help with the goal of reducing emissions and could make MTs a distinctive possibility for sections of Hong Kong.

2.4 Comparative Studies

We found two case studies that directly compared ETBs, MTs, and LR were found. "Comparison between trolley-bus and tram vehicles: performances and consequent environmental impact" is a study presented at the sixth conference for Urban Transport and the Environment for the 21st Century. It was authored by two professors of engineering from the University "La Sapienza" of Rome in Italy. According to Veca and Villanti (2001), an attractive alternative zero transportation method to the trams currently used in Rome is articulated ETBs. They performed a comparison of ETBs and MTs to evaluate which system is more cost effective, reduces waiting time, and provides less noise and fewer visual impacts. In order to accurately compare both systems, they based their comparisons on the construction of a new system on an existing route.

Veca and Villanti used computer simulation and complex mathematical models to determine energy consumption and transport costs. Transport costs were calculated in several ways: Ct1, cost per km run by a vehicle; Ct2, cost per km run per passenger (standing or seated); and Ct3, cost per km run by all vehicles at the same time on the line during peak hours. Although Ct2 is a direct index of the expense per passenger, only Ct1 and Ct3 will be discussed in depth in Chapter Four because they provide a better comparison between the transport methods. Ct1 comes from summing all costs associated with wages, energy supply, maintenance, and general expenses. Ct3 is formulated by multiplying Ct1 by the number of vehicles on the line during peak hours. This result provides a more accurate comparison between ETBs and MTs because it takes capacity differences into account when comparing the two systems on the same passenger flow (Veca and Villanti 2001).

Complementing the Rome study, the Electric Tbus Group (2001) has completed a study on implementing an electric trolley bus route in East London. The Electric Tbus Group is an advocacy group consisting of engineers, academics, and business people aimed at promoting the re-introduction of ETBs in London. East London Transit Scheme presented by Tbus compared DBs, diesel bus ways, tramways and electric trolley ways over a specific distance (6.55 kilometres) with respect to cost and energy effectiveness. The first phase of the study was based on a planned route that would cover the distance between Ilford and Barking Reach, London, traversing mainly flat terrain. This route was chosen because it has high level of patronage, the possibility of segregation from other vehicular traffic, and convenient interchanges with other transportation modes important for a successful ETB or MT system. Quantitative methods were used for the comparison.

Although both of these studies provide an excellent comparison between ETBs and MTs, they represent very different systems and, therefore have their limitations. Since the studies were performed based on the comparison on a particular route or routes in their respective cities, their direct applicability to Hong Kong is questionable. As seen by the studies discussed in Chapter Four, different trends are seen for operational and capital costs, which lead us to believe that these costs are dependent on the city. In addition, Tbus is an advocacy group for ETBs that raises concerns of objectivity with its findings.

Chapter Three Methodology

In this chapter, we discuss the goals of the project and the methods that were used to meet those goals.

3.1 Goals

The goal of this study was to provide a database of information on MTs, ETBs, and LR that can be used by Civic Exchange for advising the government on the most appropriate solution for the replacement of DBs. To begin to determine which transportation method could best eventually replace DBs, an economic and engineering comparative study was performed.

In addition to the technical comparison, the social issues arising from a proposed future zero emission transportation system were addressed. Recommendations were made to determine the possible areas of implementation in Hong Kong. We discussed whether one system or a combination of systems can help to alleviate the excessive amounts of air and noise pollution associated with the current system. In addition, investigation was done on what further intrusions would be a result of these systems such as intrusive overhead wires and additional noise.

3.2 Methods

For each transportation system - ETBs, MTs, and LR - we gathered qualitative and quantitative data pertaining to cost and performance characteristics (as shown in the data matrix in Appendix C). The information we gathered consisted of average distance between stations, speed comparisons, passenger capacity, infrastructure costs, maintenance costs, energy consumption, environmental effects, terrain capabilities and space constraints. In turn, this information allowed us to compare the relevant economic and engineering parameters.

The case studies pertained to the transportation systems in San Francisco, Vancouver, Amsterdam, Bordeaux, Greater London, Zurich, and Singapore. These cities were chosen in part because their population, landscape, and/or street layout are similar to those in Hong Kong. San Francisco and Vancouver were chosen for case studies because of their ETB systems. The LR and/or MT systems of Greater London, Amsterdam, Bordeaux, Zurich, and Singapore were investigated because of the cities' choice of these types of public transportation. The qualitative and quantitative data we gathered were summarized and placed into tables and figures.

To supplement the information obtained through case studies, technical reports that directly compared ETBs and MTs were used. The reports were titled "Comparison between trolley-bus and tram vehicles: performances and consequent environmental impact," by G. M. Veca and L. Villanti, engineering professors at the University "La Sapienza" in Rome, Italy, and "The East London Transit Scheme Phase 1," written by an advocacy group consisting of engineers, academics, and business people aimed at promoting the re-induction of ETBs in London. Due to the fact that public transportation systems are custom built to best fit the city, these reports allowed us to extract data that included direct comparison between the systems that would not be possible through case studies. In addition, these studies utilized methods such as computer modelling and complex mathematical models that were not available to us.

In addition to forming our own evaluation of Hong Kong's transportation needs, we obtained the views of various Hong Kong authorities. We interviewed John Blay

(Chief Engineer of Citybus), Hung Wing-Tat (Professor in Civil and Structural Engineering of Hong Kong Polytechnic University), Simon Ng (Research Associate at the Centre of Urban Planning and Environmental Management at the University of Hong Kong), and Alice Au Yeung (Principal Transport Officer of the Bus and Rail Branch of the Transport Department). We also attempted to contact officials from HK Tramways Limited, but they declined our request for an interview. (The synopses of the John Blay and Alice Au Yeung interviews are found in Appendix F and G, respectively.)

Through these interviews we obtained valuable information pertaining to technical specifications of various systems, future plans for a new system, and the individual's personal views of sustainable transport in Hong Kong. Before the responses from the interviews were analysed, we organised them quantitatively and qualitatively. Using the qualitative and quantitative data, we compared the interviewees' statements with the information gathered through case studies. These compiled data were then adapted to show appropriate ranges and general trends among the different systems.

In addition to the technical information provided at these interviews, general insights into social issues regarding these systems were also addressed. Since it was impractical for us to conduct a full-scale social investigation, the views of our officials were taken into account for our social analysis of the systems. For example, Alice Au-Yeung outlined the detailed procedure that the Transport Department uses to determine the public's view of a new system, which includes surveys, presentations and feedback at district meetings and regional meetings. An investigation such as this would need to be carried out in the future.

Chapter Four Data Analysis

In this chapter, we present a side-by-side comparison of electric trolleybuses (ETBs), modern trams (MTs), and light rail (LR). Two categories that provide an accurate evaluation of these different zero emission transport methods are performance aspects and cost considerations. To obtain the quantitative and qualitative data provided in the following sections, case studies and archival research were performed.

Due to the customized nature of each system, unless otherwise stated, the data that are presented in the following sections represent an average quantity or range of values to show a trend when the different systems are compared. In addition, the quantities quoted for ETBs represent double-decked vehicles, technology that only exists in pilot form at the Citybus' depot. This configuration is needed for Hong Kong, given the narrow streets and the road congestion, which makes single-decked DBs or ETBs impractical. The quantities for MTs and LR represent single-decked articulated vehicles, which can achieve the higher capacity. The sources used for the tables are located in Appendix D.

4.1 Performance

There were five primary performance categories considered for our comparison: power details, lifespan, noise, speed and acceleration, and vehicle size and capacity. For each characteristic, we looked at other cities that use ETBs, MTs, and LR. Case studies of San Francisco and Vancouver's flourishing ETB systems were combined with the information collected from the double-decked Citybus ETB. The LR and/or MT systems of Greater London, Bordeaux, Zurich, Amsterdam, and Singapore were also investigated.

4.1.1 Power Details

While both MTs and LR primarily use an overhead catenary system, the details of this power system, particularly the voltage supplied and kilowatt-hour consumed per vehicle kilometre (kWh/v km), differ. For an ETB, the overhead catenary consists of two wires, one positively and the other negatively charged. Unlike ETBs, MTs and LR can utilize the rail of the train to complete the circuit, so only one positively charged overhead wire is needed. If appropriate, a third rail could be used to power the LR, operating at the same voltage as the overhead wires.

	electric trolley bus (ETB)	modern tram (MT)	light rail (LR)
power supply - (rail or overhead)	overhead	overhead	third rail or overhead
overhead voltage (V AC or DC)	600-750	600-800	600-800
rail voltage (V DC)	N/A	N/A	600-800
energy consumption (kWh/v km[1])	up to 2.5	up to 3	up to 5
efficiency of motor (%)	70-90	80-90	80-90
maximum gradient (%)	15	7	5

Table 4-1 Power Details Adapted from Citybus, SMRT, and Bombardier Studies

[1] kilowatt hour per vehicle kilometre

According to John Blay (personal communication, 2003), the chief engineer at Citybus, the voltage supplied to the average ETB system is less then that of MTs and LR, which is consistent with the data we gathered. As shown in Table 4-1, the energy consumption of a LR is double in comparison to an ETB even though a LR has a higher motor efficiency. MTs consume more energy in comparison to ETBs as well.

One advantage ETBs have over MTs and LR is more flexibility with regards to the overhead powering system. In addition to being able to move up to 4 m from the centre of the lane, they can also be equipped with a diesel powered electric generator.

These features allow ETBs to move around obstacles such as construction, accidents, or broken-down vehicles blocking their path.

The previously mentioned energy consumption of LR and MTs are an average based on a primarily flat network from studies by Bombardier Transportation (2003), the Federal Transit Administration (2002), and SMRT (2002). Information provided by the Federal Transit Administration shows that one advantage of an ETB is its ability to climb slopes with a higher gradient than MTs and LR. Although most MT systems have a maximum slope gradient of 7%, some models can climb up to 10%. However, during hill climbing, energy consumption increases approximately 30% for ETBs (John Blay, personal communication, 2003), resulting in similar energy consumption as for a flat MT system.

Depending on the layout and the topography of the area, different aspects of the systems must be considered. For flat terrain, a MT or LR system is more appropriate if there is land available for the construction of rails. However, if the route requires the vehicles to climb a large slope, then ETB should be a more acceptable alternative.

4.1.2 Lifespan

By determining the lifespan of a vehicle and its infrastructure, it becomes possible to determine the projected costs of the systems and the time frames for upgrades over their expected lifetime. Table 4-2 lists the lifespan of the vehicles, overhead wires, and, if applicable, the third rail.

	ETB	MT	LR
lifespan of vehicle (years)	up to 30	up to 50	up to 50
lifespan of overhead wires (years)	up to 30	up to 30	up to 30
lifespan of third rail (years)	N/A	N/A	up to 40

Table 4-2 Lifespan of ETBs and Greater London's MT and LR

Studies by Bombardier Transportation (2003) demonstrate that MT and LR vehicles have a longer lifespan than their rails and wires. A feasibility study for ETBs in Hong Kong suggested that the maximum lifespan of an ETB vehicle is the same as its overhead wires (HKSAR Government, 2001), but a MT or a LR vehicle under normal operation can last longer than their overhead wires. In comparison, a DB only lasts about fourteen years. Next, we compared the lifespan of the infrastructure associated with each system.

For all three systems, the overhead wires have a similar lifespan, but the third rail of a LR lasts longer. In this respect, systems that use overhead wires are comparable. Since LR can use a third rail, which also has a longer lifespan, its infrastructure has the most potential to last the longest out of the three systems. Thus, if operated smoothly and efficiently, a LR system has the longest lifespan when compared to the other two systems.

The lifespan of both the vehicles and the power systems directly affect capital, maintenance and operational costs. If the lifespan of a system is long, the impact of its capital cost would be lowered, because the total cost would be amortised over its lifetime. Similarly, the capital cost incurred when additional vehicles replace old ones would not occur as often. This topic will be discussed in greater depth in Section 4.2.

4.1.3 Noise Level

An important impact on the environment is noise pollution, which is measured in decibels (dBA). Since the noise levels are registered within a city, they vary slightly depending on each system's layout and geographic location (GVTA, 2001). In addition, because parts of Hong Kong are located in a valley with many high rise buildings, the noise levels for systems in these areas would be noticeably higher as a result of sound reflecting off the buildings and generating an echo.

	ETB	MT	LR
average operating noise (dBA[1])	< 70	up to 70	up to 75

Table 4-3 Noise Level Adapted from Citybus and Frost (2002)

Referring to Table 4-3, studies have shown that ETBs operate at with the lowest noise level, with LR having the loudest noise output. However, although MTs and LR are generally louder than ETBs, the frequency of resonance emitted from the vehicles determines how it sounds to the human ear. Veca and Villanti (2001) compared the performances of ETBs and MTs and suggested that new technology, such as anti-vibrating permanent ways on floating foundations, greatly reduces the average frequency emitted by a MT or LR even though the noise level remains the same.

4.1.4 Speed and Acceleration

ETBs and MTs have similar operating distances between stations with LR station distance significantly larger: 350 m, 400 m, and 0.5 to 1 km, respectively. Table 4-4 shows that the lower operating speed for ETBs is the result of the average station distance. These speeds factor in time spent at the station; when there are more stops per km, they reduce the operating speed of ETBs and MTs. In addition LR can achieve higher speeds between stops due to the longer distances.

	ETB	MT	LR
average distance between stations (m)	< 350	< 400	500 - 1000
average operating speed (km/hr)	18.0 - 21.4	20 – 25	> 40
maximum speed (km/hr)	70	80	100

Table 4-4 Speed Adapted from Kiebling (2001) and Public Transportation (1995)

In a study by the United States Public Transportation Department and tests in Vancouver, a conclusion was made that the average operating speed for the majority of ETB systems was 21.4 km/hr (Public Transportation, 1995). This average operating speed varies substantially due to congestion from other traffic, loading and unloading time, and the design of the overall system, especially if it is segregated from vehicular traffic. In cities such as San Francisco, where congestion is a major problem, average operating speed is only 18.4 km/hr.

With MTs and LR, there is less congestion as a result of the permanent ways somewhat separated from traffic. Both vehicles operate at speeds ranging between 20 and 40 km/hr (Kiebling et al, 2001). These ranges are used as an engineering standard in Europe for the construction of tram and LR systems, such as those in Berlin and Frankfurt.

As shown in Table 4-4, a LR has the highest maximum speed in comparison to the other two systems. For intercity travel, it may be ideal to use LR because of its speed. Consequently, depending on the layout of the city, the lower maximum speeds for ETBs and MTs are more suited for internal transport in suburban and urban areas.

	ETB	MT	LR
acceleration rate (m/s^2)	1.33	1.2	1.25

Table 4-5 Acceleration Rate Adapted from Tbus Study (2001) and Kiepe Elektrik (2002)

The acceleration rate is relevant to this comparison because it determines how quickly a vehicle would return to its original speed after it makes a stop. In his interview, John Blay mentioned that the acceleration rate of an ETB was superior to diesel buses, especially when climbing up hills and when fully loaded (personal communication, 2003). As seen in Table 4-5, when ETBs are compared to MTs and LR, all three types of vehicles have a very comparable average rate of acceleration.

The values for ETBs, MTs, and LR were obtained from studies for Greater London and from Kiepe Elektrik (2002), a worldwide traction equipment distributor for trams and LR. Although ETBs accelerate the fastest, none of the systems have much of an advantage over one another. Since the acceleration is similar among the three vehicles, it does not significantly affect the average operating speed of each vehicle.

4.1.5 Vehicle Size and Capacity

An important performance characteristic relating to how well the system can combine with the other road-based transportation is the vehicles' dimensions, which determines the space needed for possible implementation. This parameter is especially important for narrow and congested roads, as in Hong Kong.

	ETB	MT	LR
vehicle height (m)	up to 4.6	up to 3.35	up to 2.29
vehicle width (m)	up to 2.55	up to 2.65	up to 2.65
vehicle weight (metric tonnes)	up to 13	up to 36	up to 35

Table 4-6 Vehicle Size averaged from the transport systems of Berlin, Cologne, Frankfurt, Greater London, Hong Kong, San Francisco, CA, San Jose, CA and Singapore

We encountered difficulty when we tried to compare the heights of each vehicle, which are shown in Table 4-6. Since modern double-decked trams and LR do not exist, it was hard to compare their heights with the ETBs that would be necessary for Hong Kong. Similarly, the lengths of MTs and LR were not determined and compared since they varied too greatly because each vehicle was different depending on the respective system and its rolling stock. The maximum widths of the three systems were all within 0.10 m. We obtained the vehicle dimensions using the transport systems in the following cities:

Berlin, Frankfurt, Greater London, Hong Kong, Cologne, San Francisco, San Jose, and Singapore. It was easy to notice that the height, width and length were all slightly different because each vehicle was modified depending on the requirements of each city.

The only size characteristic that stood out was the weight of each vehicle. Of the three, MTs are the heaviest at thirty six metric tons, while LR is about one metric ton lighter per car. Compared to ETBs, the weight of MTs and LR are almost three times heavier. As a result, depending on the placement and location of the system, it may be crucial to strengthen the roadbed (Vestnik, 2002). For instance, a water-saturated roadbed is unsuitable for any vehicles, whether they use rails or rubber tires. The weight of the vehicles and an unstable roadbed may lead to a collapse.

	ETB	MT	LR
standing capacity (# of passengers)	35 – 45	90 – 110	100 - 120
seating capacity (# of passengers)	75 – 85	50 – 70	60 - 80
overall capacity (# of passengers)	up to 130	up to 180	up to 200

Table 4-7 Capacity Adapted from Citybus, SMRT, and Bombardier Transportation

After determining the size characteristics for each vehicle, we determined the capacity of each in relation to its size. The capacities of MTs and LR are greater than that of ETBs. Although the average capacity of MTs and LR are greater than ETBs, the actual capacity in each case is entirely dependent on the vehicle model chosen. This capacity difference is due to MTs and LR having large areas to hold standing passengers, while almost all passengers on ETBs have seats. European standards give 6 passengers/m^2 as a comfortable standing capacity, although capacities as high as 8 passengers/m^2 can be attained (Bombardier, 2003).

In addition to choosing different models of ETB, MT, and LR vehicles, another way to increase capacity is through articulation (GVTA, 2001). This option is most commonly chosen with trams and LR, but is seeing more use on ETBs. However, articulated buses may not be feasible in Hong Kong due to the narrow streets, tight corners, and the short length of existing depots.

4.2 Cost Considerations

As previously mentioned, public transportation methods are custom-built so they best fit the city for which they are designed. Although performance aspects can be accurately compared using case studies, comparing costs among different cities presents more of a quandary. To help alleviate the difficulty of comparing entirely different quantities, technical studies that compared ETBs and MTs were adapted for our project.

4.2.1 ETB and MT Comparisons: Rome and Greater London

Veca and Villanti (2001) performed a comparison of ETBs and MTs to evaluate which system is more cost-effective, reduces waiting time at stops, and produces less noise and visual intrusions. In order to accurately compare both systems, their analysis was based on the construction of a tramway or articulated ETB system on the existing tram routes. They assumed a passenger flow of 1000-6000 passengers per hour per direction transported on articulated trams of two or three cars (260 passengers) or two-car articulated ETBs (155 passengers). The ETBs had the ability to use a diesel electric generator in addition to getting the electricity from the overhead catenary system. The tram's tracks used in the study were anti-vibrating permanent ways with floating foundations.

In addition, an energy consumption simulation program and a transport costs calculus model were used to approximate these figures. Costs include personnel, traction materials, rolling stock, infrastructures and plant maintenance, and amortization. They were calculated for overall capital cost per vehicle-km (Ct1), per passenger-km (Ct2), and cost per km run by all vehicles at the same time on the line during peak hours (Ct3).

In addition to the Rome study, the Electric Tbus Group (2001) has completed a study on implementing an ETB route in East London. The East London Transit Scheme (Tbus) was aimed at comparing DBs, diesel bus ways, tramways, and electric trolley ways over a specific distance and the cost effectiveness of each system. This study also had a projected profit analysis for the systems. The proposed track for the new systems was from Ilford to Barking Reach, a suburban area that spans approximately seven kilometres.

The study assumed that eight MTs and fourteen ETBs will be used on the track to offer the same ideal passenger flow. The ETBs and MTs that the study selected are articulated vehicles that can be purchased from companies in Europe. The costs involved, but were not limited to the following: purchase of vehicles, maintenance, operational and capital costs, and energy consumption. More information on these studies is given in Section 2.5.

There are possible limitations to these studies. They are city specific so the trends in the data shown would not necessarily be observed in Hong Kong. In addition, the Tbus group is a private advocacy group promoting ETBs, which can raise questions of objectivity.

4.2.2 Capital Costs

Capital costs are made up of, but not limited to, the infrastructure elements described in Table 4-8. They were adapted from Veca and Villanti (2001) by converting from Euros to HKD as well as adding in comparative cost figures.

element	ETB	MT	comparative cost
depot (MHKD[1]/vehicle)	.48	1.82	3.8 x ETB
overhead catenary system (MHKD/km)	8.59	6.66	1.3 x MT
substations (MHKD/km)	6.07	6.07	Same
permanent ways (MHKD/linear rail km)	0	6.70	N/A
vehicle cost (MHKD/vehicle)	5.46	15.17	2.78 x ETB
sum of all elements w/out vehicles (MHKD/km)	15.14	21.26	1.4 x ETB
sum of all elements w/out permanent ways and vehicles (MHKD/km)	15.14	14.55	1.04 x MT

Table 4-8 Elements Forming Capital Costs Adapted from Veca and Villanti (2001)

[1] million Hong Kong dollars

This infrastructure includes the overhead power system, depot, and permanent ways. For their study, substations were placed every 10-11 kilometres, a distance which would be different depending on the city. As can be seen in column four, the overhead catenary system is more expensive for ETBs. This is because of the double wires required (Section 4.1.1). In addition, the rail network for the tram costs almost HKD 20,000 per kilometre, a price that is nonexistent for ETBs, given that the roads are provided by the government. If the government were to pay for the infrastructure the tram would travel on, as they do for the buses, the overall capital cost of the two systems would be almost the same, as can be seen in the last row of Table 4-8.

Table 4-9 shows the range of overall capital cost (columns two and three) and per kilometre (columns five and six) that would be incurred by the city of Rome if it were to construct an entirely new ETB system or tramway on the existing tram routes. The cost per kilometre was calculated by dividing the total capital cost by the route length (5.45 kilometres). The detail of these routes is shown in Appendix E.

line[1]	ETB capital cost (MHKD)	MT capital cost (MHKD)	comparative cost	ETB capital cost (MHKD/km)	MT capital cost (MHKD/km)
8	7752	38347	4.95x ETB	1422	7036
30b	8501	50050	5.89x ETB	NA	NA
14	4661	27217	5.84x ETB	NA	NA
19	8485	54125	6.38x ETB	NA	NA
225	3087	19383	6.28x ETB	NA	NA
516	3983	23432	5.88x ETB	NA	NA

Table 4-9 Rome Comparative Capital Cost Adapted from Veca and Villanti (2001)

[1] Existing tram route in Rome

As shown in the third column of Table 4-9, the capital cost of constructing a tramway is five to six times that of building an ETB system. This is primarily due to the additional costs associated with the tram tracks. In addition, the difference in capital cost between ETBs and MTs is dependent on the topography and geography of the line itself. Thus, depending on the particular route, it may be just as attractive to build a tramway as it is to build an ETB system. Another reason for the dissimilar comparative capital costs between lines could be due to the type of suspension used to with the overhead wires. In an open area poles would need to be used, increasing the price, while in areas with buildings close to the road, the wires could be attached to the sides of the buildings, reducing the cost.

Additionally, the permanent way quoted in this study was anti-vibrating permanent ways with floating foundations. This type of track is more expensive than the traditional track. If a traditional track was used instead, their costs would be closer, but a less attractive option due to the higher frequency of the emitted noise pollution. Although these new tracks are more expensive, they are easier to lay and require less maintenance than traditional ones (Veca and Villanti, 2001).

	DBs	ETBs	MTs
1 new vehicle (MHKD)	1.84	4.3	12.3
fleet to operate route (MHKD)	66.3	60.2	98.2
electric powering system (MHKD/km)	N/A	18.4	61.4
total cost of infrastructure (MHKD)	50.7	53.9	98.1
total capital costs (MHKD)	117.0	114.1	196.3

Table 4-10 Greater London Comparative Capital Costs Adapted from Tbus (2001)

The capital cost is the most expensive portion of a new transportation system. In Table 4-10, the prices shown for each vehicle are standard prices and vehicle types from companies found in Europe. Although the capital investment for the entire fleet is higher for MTs, the number of vehicles for a particular system would vary on the size of the system. For the Tbus study, the MTs total fleet was proposed to have eight vehicles, while the ETBs had fourteen.

The total cost of infrastructure is a figure that entails, but is not limited to, overhead wiring, platforms and track construction. The study assumes that both the ETB and MT systems will have platforms. This is an extra cost for both systems but more so for the MTs. Since most MTs are closer to the kerb than ETBs, additional construction of ramps and other access equipment for the elderly and disabled does not need to be accounted in the total infrastructure cost. Finally, Tbus agrees with Veca and Villanti that the total capital costs for MTs are nearly double when compared to ETBs.

4.2.3 Operational Costs

There are many different ways to compare transport costs for a zero emission transportation system. Veca and Villanti (2001) used three different formulations for transport costs: Ct1, cost per vehicle kilometre; Ct2 cost per passenger; and Ct3, cost per km for all vehicles operating simultaneously on the same line during peak hours. To calculate the values of Ct1, Ct2, and Ct3 they used a calculus model, not described in the study, and a computer simulated energy consumption program applied to the current Roman tramway network. These transport costs include all operational and maintenance costs that the transport department of Rome would have to pay to operate the systems.

	Line 8			Line 30b		
	ETB Operational Cost (HKD)	Tram Operational Cost (HKD)	Comparative Operational Cost	ETB Operational Cost (HKD)	Tram Operational Cost (HKD)	Comparative Operational Cost
Ct1[1]	35	70	2.01x ETB	44	86	1.96x ETB
Ct2[2]	0.22	0.27	1.23 x ETB	0.28	0.48	1.71 x ETB
Ct3[3]	1005	1182	1.18x ETB	835	1378	1.65x ETB
	Line 19			Line 225		
	ETB Operational Cost (HKD)	Tram Operational Cost (HKD)	Comparative Operational Cost	ETB Operational Cost (HKD)	Tram Operational Cost (HKD)	Comparative Operational Cost
Ct1[1]	44	94	2.14x ETB	38	71	1.87x ETB
Ct2[2]	0.29	0.52	1.79 x ETB	0.24	0.39	1.63 x ETB
Ct3[3]	775	1406	1.81x ETB	342	570	1.67x ETB

Ct1[1]	HKD per km run by a vehicle
Ct2[2]	HKD per km run by an offered place
Ct3[3]	HKD per km run by all vehicles at the same time on the line during peak hours

Table 4-11 Rome Comparative Operational Costs Adapted from Veca and Villanti (2001)

As shown in Table 4-11 the variation between the different transport costs decreases in the order Ct1 to Ct3. Ct3 gives a more accurate comparison because it equalizes the passenger flow since ETBs have a smaller capacity than trams. Veca and Villanti's study shows that the general trend for the transport costs of ETBs and MTs is that ETBs are 18-81% more expensive to operate than MTs. The ETBs have a higher crew wage expense simply because the system requires more vehicles to offer the same level of service. It is in this regard that ETBs are more expensive to operate.

The difference in transport costs could be related with maintenance and amortization, which are included in these transport costs. The trams cost more to maintain even though there are more ETB vehicles. In addition, expenses associated with amortization would be higher for trams because of the higher capital costs. Although Veca and Villanti conclude that the transport costs including operational and maintenance are more expensive for MTs for Rome, the transport costs in other cities could show a different trend, as will be demonstrated with the Tbus analysis.

	DBs	ETBs	MTs
fuel consumption (km/L)	2.5	N/A	N/A
electricity consumption (kWh/km)	N/A	3	5
wage of crew (MHKD/year)	23.7	23.2	12.6
total operational (MHKD per year)	25.3	24.6	13.7

Table 4-12 Greater London Comparative Operational Running Costs Adapted from Tbus (2001)

In Table 4-12, the large difference between MTs and the other systems for total operational costs is obvious. Despite MTs' electricity consumption being nearly twice as much as ETBs, MTs average HKD 10,000,000 less to operate in comparison to DBs and ETBs according to the Tbus study. We did a calculation to determine an estimated cost for the electricity required to run these systems each year in Hong Kong. The ETBs and MTs cost HKD 4,000,000 and HKD 3,800,000, respectively, to power for one year. The following formula shows how those numbers were computed:

route length (km/yr) X energy consumption (kWh/km) per vehicle X energy cost (HKD/kWh) X number of vehicles in fleet = Energy cost per fleet per year

Route length is dependent on the system and is the same for both the ETBs and MTs, chosen at 105,485 kilometres per year. That is the calculated distance a tram on the current tram track in Hong Kong would travel in one year, assuming it takes a tram one hour to travel the track, and operates for seventeen hours a day. The energy consumed by each system in kilowatt hours per kilometre is given in Table 4-12, with the price of electricity in Hong Kong taken as 80 and 90 cents per kilowatt hour. The final assumption was to use the same number of fleet vehicles as proposed in the Tbus study. Once all the information was computed, it becomes evident that MTs are HKD 200,000 cheaper per year to operate.

4.2.4 Maintenance Costs

Maintenance costs are totally dependent on the length and number of vehicles in the system. The maintenance cost per route kilometre is a figure that represents the cost for the life of the system, shown in Table 4-13.

	DBs	ETBs	MTs
maintenance cost (HKD/km)	N/A	36,840	122,800
fleet maintenance (MHKD/yr)	14.3	8.46	3.27
total operational and maintenance (MHKD/year)	39.6	33.6	18

Table 4-13 Greater London Comparative Maintenance and Operational Costs Adapted from Tbus (2001)

As Table 4-13 shows, the tramway maintenance cost is three times that for ETBs. However, the higher expense is because the government provides maintenance to the roads that the ETBs operate on but the tram company is responsible for the maintenance of the tracks and other tram specific components. This is also the case in Hong Kong with the existing tram, and it is safe to assume that this practice would continue if a new tram were to be built. Overall, according to Tbus, the annual operational and maintenance costs calculated for MTs are almost half that of ETBs, the opposite relationship of that shown in the Rome study.

4.2.5 Cost Analysis

One of the most important considerations when comparing the zero emission transportation methods is cost. The largest cost incurred in creating a new system is the capital cost. Both the Tbus and Rome comparative studies show that the capital cost is much greater for MTs than ETBs due to the permanent ways. The infrastructure for buses, primarily the roads, is paid for by the government whereas the permanent way for trams would need to be paid for by the company. If the government were to subsidize the infrastructure for trams, as they do for buses, the capital cost of ETBs and MTs would be more comparable.

Areas where the two comparative studies differed were in operational and maintenance costs because of the varying energy price and crew wages in each city. Due to the smaller maximum capacity of ETBs, more vehicles are required to provide the same passenger flow as MTs, requiring more crew and thereby adding to their operational expenses. The total operational cost of powering the system will be dependent on the efficiency of the motors and the price of electricity. Depending on the cost of electricity and the average labour cost in a particular city, the difference between the operational costs of ETB and MT system will change. Operational and maintenance costs are more for ETBs in Greater London, while in Rome, ETBs are cheaper to operate and to maintain. Depending on how these costs work out in Hong Kong, either system has the potential to be preferable.

One additional financial consideration is the amount of money that the public will contribute to the new system, which depends on the fare. Both an ETB system and a tramway will have higher capital costs than a diesel bus system; therefore, the ETB or MT company will need to charge a higher fare in order to make up for the increased capital cost. In order to keep the fare comparable and avoid direct competition between the systems, governmental subsidisation or regulation will be required.

The Tbus study shows that if both systems have revenue of HKD 62.7 million, then after total operational and maintenance costs are subtracted, the MT system will have a surplus of HKD 44.7 million, 71% of the annual revenue, while the ETBs will only realise HKD 29.1 million, 46.4% of the annual revenue. This annual surplus can then be applied to pay back the capital cost shown in Table 4-10. It will take a MT system 4.39 years to pay for the capital investment before it returns a profit, while it will take an ETB system 3.92 years. Although these figures show that ETBs will return the capital investment faster than MTs, when projected over a longer time frame MTs will be more profitable. In systems that have higher maintenance and operational costs, it may take longer for a MT system to return a profit, and thus, pay for its capital cost earlier.

4.3 Implementation in Hong Kong

After the technical comparison made, attention needs to be paid to where these systems can fit into Hong Kong. It appears practical for one or a combination of systems to be installed in sections of Hong Kong. Either ETBs or MTs could be constructed in any section if money and time were not an option. Since this is not the case, there are certain areas where one system makes more sense than the other.

HKSAR is divided customarily into three primary regions: Kowloon, Hong Kong Island, and the New Territories. However, based on our findings, we determined that it was more accurate to classify specific parts of the HKSAR into three types of development regions: high-density urban areas such as Nathan Road and areas of Northern Hong Kong Island; new development areas such as the old Kai Tak Airport; and suburban areas such as most of the New Territories. This classification is more useful than the geographical areas because each geographical region may contain all three types of development.

MTs are more feasible in areas where the majority of land is flat and have enough space that would allow for some segregation from traffic. Because these regions with extra space are scarce throughout Hong Kong SAR, MTs would only be suitable in areas that are still developing or are to be developed such as the old Kai Tak Airport or new suburban towns.

ETBs are more flexible than MTs and can be implemented in almost any section of Hong Kong because they can deviate from the overhead wires by shifting lanes, or if necessary, lowering their boom and running on a diesel powered electric generator. However, a problem with constructing the necessary overhead powering system in these highly developed areas such as Nathan Road is the overhead signs. It would take extra time and money to remove all of these obstructions, but is not a large obstacle to overcome.

A LR system would not be an effective internal transportation method. LR is better used for inter-suburban transport, similar to the MTR, KCR, and North-West New Territories LR systems. In Amsterdam, a LR Combino system was constructed to connect new housing development areas with the centre of Amsterdam. This idea could be applied to connect new housing developments in the New Territories with the more densely populated regions of Hong Kong.

4.4 Social Perspective

In addition to the previous comparison discussed in Sections 4.1 and 4.2, the social issues regarding a proposed future zero emission transportation system and how they relate to Hong Kong are important. Although any of these systems will have an overall positive social impact by lowering pollution, one system might be more beneficial than another. These social issues should be paid close attention to during the planning stages.

Despite the possibility of having some negative social impacts such as extra interchanges and visual intrusion, these systems will achieve their goal of alleviating much of the noise and air pollution associated with the current extensive diesel bus network. The current DBs contribute to the high spatial intensity of air and street level noise pollution, while zero emission transport methods reduce these problems.

A negative impact associated with the electricity used by these transport methods is the way it is supplied to the vehicles. This overhead catenary system contains wiring that has been found to be visually intrusive. There are mixed reports on how the public views the power system. Compared to the advertisement signs and other overhead objects, the effect of overhead wires can be minimized though careful planning. Extra attention should be paid to how these overhead wires would affect the safety of people near them. These wires could hinder fire fighting efforts and harm people if they were to become detached from the poles and other supports. These negative aspects can be avoided by careful planning of the electric substations to include electricity terminating devices.

Another important issue that has to be addressed is how the pedestrians will interface with the system. Because pedestrian comfort is a significant issue in Hong Kong, both systems have the possibility of not only pleasing them through improving the air that they breathe, but also creating more space away from other vehicular traffic.

With careful planning, as was done in Bordeaux and outlined in the Tbus study, this segregation can create more space for pedestrians.

Once a system is chosen, there will definitely be disruptions due to its construction. Difficulty in construction would be greater for a MT and LR system in comparison to ETBs. The roadbed may need to be strengthened and roads must be dug up for the rails. The construction would cause substantial amounts of traffic congestion and construction pollutants for the nearby residents.

Even after a system is completely implemented, an important issue to the users of public transportation is interchanges with other transport systems. Ease of interchange is important to the users in order to make the fastest and most convenient trip, especially for the elderly and disabled. Since it is possible for a system consisting of both ETBs and MTs to operate simultaneously, a problem with this scenario would be interchanging between the two systems and the current ones. Taking these problems into consideration, it might be more efficient to construct a single system for internal transport in an area. However, avoiding additional interchanges might not be possible. Education of the public would need to be conducted in order to minimize negative public reaction.

In addition to ease of interchanges, users of public transportation want to wait the shortest amount of time possible at stops. Compared to MTs and LR, twice as many ETB vehicles are needed in order to attain the same capacity level. Although fewer vehicles on the road would lead to lower congestion levels, this advantage is not always seen by the users. In the eyes of passengers, more vehicles would mean less waiting time at stops. When the vehicles are running on a regular schedule, most passengers would prefer more vehicles instead of high capacity vehicles, even if less congestion would result in faster running times.

Educating the public on the importance of zero emission transport is necessary to bring about the changes and future success associated with each system. Since these technologies would be new for most people, their education and the explanation of the safety issues and the reasons why there are changes within the system are important.

Furthermore, careful attention should be paid to governmental subsidisation. Although historically the Hong Kong Government does not directly subsidise public transportation, its cross subsidization does help companies operating more expensive systems, such as the MTR, to succeed. In addition, provisions such as the fuel tax and high car registration fees help to pay for the road infrastructure used by the buses. In order for new zero emissions systems to be effective and not lose patronage; they would have to operate at the same fare as, or in areas without DBs.

This fare level could only be achieved with help from the government. It would need to provide subsidisation to the company or pass legislation allowing only zero emission transportation in certain areas. The MTR Corporation is already doing this by asking for subsidisation for their proposed "Southern Loop" (Alice Au Yeung, personal communication, January 28, 2003).

Since different systems have varying lifespan, the government may also want to investigate extending franchises to offset large capital costs, especially for MTs. The problem with extending a franchise is that the company may start to neglect its responsibilities. In addition, new regulations, such as accessibility features for the elderly and disabled, cannot be imposed until the franchise is renewed. Once these social issues are examined and addressed, they can be combined with the technical data to decide on a future system that most favourably impacts Hong Kong.

Chapter Five Conclusions and Recommendations

In comparing three zero emissions transportation methods – electric trolley buses (ETBs), modern trams (MTs), and light rail (LR) - we evaluated each system in respect to its performance and cost characteristics. For performance aspects, there are no decisive characteristics among the systems that make one system more favourable over another, with the exception of ETBs' superior hill climbing abilities and the option of running free of the overhead wires for short distances. However, if a new system were planned on flat areas, the advantage would be nullified. In addition, depending on the layout of a new system, each performance aspect could be adjusted and modified to complement the area of implementation. Therefore, in terms of overall performance, all three systems are comparable and should continue to be investigated as possible zero emissions transportation systems for Hong Kong.

Greater differences among the systems can be seen during cost comparisons. The capital cost of MTs and LR exceeds those of an ETB system due to the cost of the permanent way. When operational and maintenance costs are taken into consideration, there is not a distinct difference. The conflicting studies showed that these costs are dependent on energy consumption and crew wages, which depend heavily on the city where the system operates. If the operational costs for MTs are less expensive than those for ETBs, the higher capital cost might be able to be offset. The amount of governmental subsidization of the tram system can also make MTs a more affordable option. These factors indicate why MT systems flourish in some cities while ETB systems prosper in others.

A Hong Kong specific technological study similar to those conducted for Rome and Greater London needs to be conducted. The study's performance characteristics should reflect those that would be used for certain routes in Hong Kong. In addition to the technical and cost comparisons, future studies should examine which method would be best accepted by the public and how it could be constructed to achieve the best public opinion. These studies would include social issues such as the intrusiveness of the overhead wires, pedestrianisation, additional noise pollution, ease of interchanges with other systems, and safety concerns. Once these social issues are examined and addressed, they can be combined with the technical data to decide on a future system that will most favourably impact Hong Kong.

For our recommendations, we classified HKSAR into three types of development: high-density urban areas such as Nathan Road and areas of Northern Hong Kong Island, new development areas such as the old Kai Tak Airport, and suburban areas such as the New Territories.

In high-density urban areas, ETBs seem to be the only feasible option for zero emission transportation, due to the large congestion of buildings and traffic. In order for MTs to operate most efficiently, some sort of segregation from other vehicular traffic should be obtained, which would not be possible in these areas.

In new development areas, both ETBs and MTs would be possible. Since space is not yet a concern and segregation could be planned into the layout of the city to allow for the most efficient passenger transport. When compared to urban areas, lower traffic congestion and population density in suburban areas would allow for the construction of either system. However, strict attention should be paid to which system would offer the least disruption associated with the overhead wires, construction, and noise since these cities are already partly developed. Given that ETBs are more suitable for urban areas, they might be appropriate in suburban areas as well. The linkage of similar electric power supply systems makes it possible to connect the vehicles systems together and interchange the vehicles and equipment associated with each.

Due to its speed, the number of stops, and the amount of segregation needed, a LR system would not be feasible as an internal transportation method in any of the three defined development areas. LR is better used as an inter-suburban transportation method between new development areas and other more developed areas of Hong Kong, much like the MTR, KCR, and North-Western New Territories LR systems that already exist. The government outlines their strategy for rail expansion in a report titled "Railway Development Strategy 2000". This strategy is beneficial and should continue to be explored.

Finally, education of the public on zero emission transportation needs to occur as soon as possible. This education would include information on the details of the systems, temporary disruptions due to construction, permanent disruptions like overhead wires and additional interchanges with the current transport methods. Overall, changes need to be made clear to the public to prepare them for the possibility of an entirely new sustainable transportation method in order to gain their full support.

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Appendix A: Civic Exchange

Our sponsor for this project is Civic Exchange (CE). CE is a Hong Kong based public policy "think tank" that was established in October 2000. It was set up for two major reasons, the first being to promote and educate the community through conducted research and publicity on economic, environmental and social issues. CE does this objectively and with balanced information. The second main reason was to actually have a way to undertake research that could, depending on the problem at hand, be quite a difficult task. Consider the transportation problem, and it is clear that a great deal of data collection and analysis will be needed for the nation's leaders to make an educated decision on what should be done to best address the growing anxiety associated with the current difficulty.

Every organization needs a basic concept. CE's basic concept is to create an open-minded organization that can reap intellectual ideas to help solve an existing problem. CE uses the idea of cooperative structure rather than traditional enterprise. In cooperative structure, the motive for enterprise is to meet social needs, rather than to turn those needs into profit. This is one way that CE is used for Interactive Qualifying Projects (IQP). From day one, CE wanted to use common sense and intuition to pool many ideas about a given topic, in hopes that this research could be used for social change.

As we already know, CE participates in a student intern program. The program offered through WPI and Wellesley College sends students overseas to assist with the research that will undoubtedly prove invaluable to whatever current project the organization is tackling. After an intern program is complete, CE publishes the findings on its website.

CE does not actually implement any project or advise a community to follow any one particular method to solve a particular problem. All that CE does is research an existing problem and list the data so that community officials can make the right decision. In short, CE takes a problem and researches it, and passes its findings along to officials so the proper authorities can make an educated decision on what changes will be best for the community.

The staff is comprised of doctors in various disciplines, professors, engineers, to energy conservationists and biologists. Christine Loh and Lisa Hopkinson started CE in September of 2000. Loh is responsible for planning CE's long-term goals. Loh has also been acknowledged as being one of *Business Week's* one of Asia's stars for 1998 and 2000. Hopkinson oversees the networking and research activities of CE. She worked as head researcher for Citizen's Party, and an environmental consulting firm in London for 5 years.

CE works with a number of other organizations to help in accomplishing a common goal. School of Design The Hong Kong Polytechnic University and Worcester Polytechnic Institute (WPI) are just two of the schools that CE works with to research and analyze problems in Hong Kong. Some of these organizations like WPI, are on an intern programme in which CE sponsors a project in Hong Kong where the students of schools can help in research. After the students analyze their findings, they bring the analysis back to CE to hopefully be brought before the local authorities to be discussed and implemented.

As mentioned before, CE is not driven by profit, but rather by social needs. It is because of this that CE relies heavily on donations by other organizations. Some of the organizations that donated from September 2001 to September 2002 are Alternative Development Asia Limited, The Asia Foundation, Exxon Mobil Energy Limited, and Sun Hung Kai Properties Charitable Fund Limited. Some of the current projects that CE is researching are carry out a two-year pilot study on air quality management in the Pearl River Delta, provide strategic advice to Clean Environment Campaign, and publish "sustainability snapshot" reports on two Hong Kong companies.

Appendix B: Project Qualifications for an IQP

An IQP, or Interactive Qualifying Project, is one in which students examine how science and technology interact with society. In this project, observation, investigation, data analysis, and evaluation were done to make a comparative analysis and appropriate recommendations were made on zero emission transport methods to our sponsor, Civic Exchange.

To evaluate the performance and cost specifications of electric trolleybuses (ETBs), modern trams (MTs), and light rail (LR), we obtained quantitative and qualitative data of economic, environmental, and engineering issues. The cities that we primarily used for our case studies and archival research were San Francisco, Vancouver, Zurich, Greater London, Singapore, Amsterdam, Bordeaux, and Rome.

While science and technology is essential to our IQP, an understanding of social concepts and analytical techniques is also very important. Before we analyzed the data, we identified the various types of factors that are the chief concerns of our problem. We need to address the performance specifications, construction, configuration, and environmental concerns that we will look at before making any recommendations to Civic Exchange.

Appendix C: Quantitative Charts

	Electric Trolleybuses (ETBs)	Modern Trams (MTs)	Light Rail (LR)
Power Details			
Power Supply - (Rail or Overhead)			
Overhead Voltage (V DC)			
Rail Voltage (V DC)			
Energy Consumption (kWh/v km)			
Efficiency of Motor (%)			
Maximum Gradient (%)			
Lifespan:			
Lifespan of Vehicle (years)			
Lifespan of Overhead Wires (years)			
Lifespan of Third Rail (years)			
Noise:			
Average Operating Noise (dBA)			
Speed:			
Average Distance between Stations (m)			
Average Operating Speed (km/hr)			
Maximum Speed (km/hr)			
Acceleration (m/s^2)			
Vehicle Sizes:			
Vehicle Height (m)			
Vehicle Width (m)			
Vehicle Weight (metric tons)			
Total Capacity:			
Standing Capacity (# of passengers)			
Seating Capacity (# of passengers)			
Overall Capacity (# of passengers)			

	Electric Trolleybuses (ETBs)	Modern Trams (MTs)	Light Rail (LR)
Capital Costs			
Maintenance Costs			
Operational Costs			
Total Costs			

Appendix D: Sources Used for Quantitative Tables

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Appendix E: Rome Tramway Map

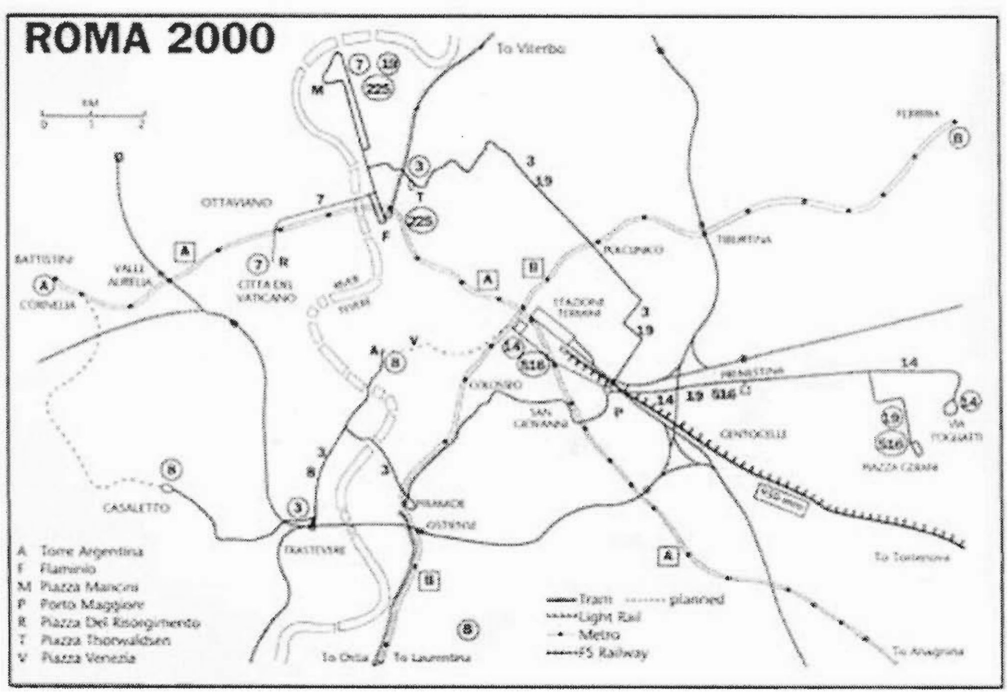

Figure 1 – Rome Tramway Map

Appendix F: John Blay Interview Synopsis

Location: Wong Chuck Hang Citybus Depot
Date: 1 / 15 / 03
Attendance: Professor Lok Lew Yan Voon, Daryl Huynh, Sean O'Rourke, Krystal Tam, Jason Thomas
Time: 10 a.m. – 12:30 p.m.

In 1998, Citybus began to assess cleaner alternatives to diesel fuel. These alternatives included gas buses, LPG, liquefied natural gas, electric batteries, and fuel cells.

The transport authority feels that buses are highly profitable and frequently used, but are not the best long-term option. Therefore, they want to substitute the buses currently in use with more efficient transportation. One such alternative is the electric trolley bus (ETB). However, the transport department did not know detailed information on ETBs. Due to the lack of knowledge of an ETB system, Citybus has constructed a pilot ETB test track by converting an existing diesel bus to an ETB.

The government wants to develop the old Kai Tak Airport area into an urban centre for 250,000 people, and has asked major public transportation companies to submit plans for sustainable transport. So far, Citybus and possibly First Bus have submitted their plans on an ETB system. Even though a decision was supposed to be made at the end of year 2002, it was pushed back to the end of 2003.

In addition to their proposal, Citybus has submitted plans to the government to replace 200 diesel buses on Hong Kong Island with ETBs. The government wants ETBs to go towards traffic-free areas, which are regular roads that have fewer operating vehicles. Although they can convert approximately 50 DBs to ETBs per year, Citybus will buy new ETBs because the current buses are not low-floor for elderly and handicap access. Moreover, due to the large capital costs associated with an ETB system, Citybus will also ask for an increase in the length of the governmental franchise.

Overall, it is easier to implement an ETB system in a newly developed area. The possibility of hanging wires from light posts and constructing power stations in the basements of buildings could be easily done. In addition, Citybus has found that the height of their ETB will safely pass under all existing underpasses and bridges. Existing low-hanging signs in areas of Hong Kong such as Nathan Road must meet the six meter requirement imposed by the government. Citybus chose ETBs over other transportation methods because they feel that ETBs are proven technology seen in various cities around the world. To support their chosen method, Citybus had the Beijing Trolleybus Company start construction of a pilot ETB track in January of 2001, which was later completed in May.

In addition, the trolley bus constructed by Citybus is driven daily by a normal bus driver to simulate wear and tear on parts of the vehicle. Feedback from the drivers was mostly positive; the only reported issue was that once the accelerator was pressed, the bus would have a short delay. Other technical aspects are listed as follows:

Technical Data:

- Compared to diesel buses:
    - Maintenance cost is cheaper due to the absence of oil and filters
    - Eight times quieter when they brake, accelerate, and on hills
    - Acceleration is linear due to absence of gears resulting in less jerking
    - ETB's motor is twice as efficient as a diesel bus engine
- Forty-year life expectancy

- Maximum capacity of 130 passengers
- Weigh 13 tons unloaded and 22 tons fully loaded
- 50% cheaper to convert an existing DB over buying a new one
- Motor:
    - 600 V DC electricity
    - Maximum power of 100 kW
    - Peak output of 230 kW
- AC power comes directly from the overhead wires, increasing efficiency
- Regenerative Breaking
    - Sends power that is lost while braking back to the overhead wires
- Flywheel
    - Stores energy when braking and uses the stored energy while accelerating resulting in 14% energy conservation

Appendix G: Alice Au Yeung Interview Synopsis

Location: Immigration Towers 40th floor
Date: 1 / 28 / 03
Attendance: Professor Lok Lew Yan Voon, Alice Au Yeung, Jason Thomas, Krystal Tam, Sean O'Rourke
Time: 11 a.m. – 12 p.m.

Currently, there is no particular policy for zero-emission transport. Since only one-third of the land in Hong Kong is flat, some of which are natural reserves, the construction of certain types of transportation is limited. A railway system that emits zero street level pollution runs at high speeds and carries a high capacity, is suitable for Hong Kong's large population and the limited amount of land available for use. Due to the growing pollution problem in Hong Kong, the government decided to promote a clean and efficient railway system, serving as the backbone of public transportation.

The government planned to extend the light rail system by one line each year until 2008. This 50 – 70% extension was outlined in the "Railway Development Strategy 2000". In the newly developed area of Tuen Mun, the government constructed an internal light rail system that is environmentally friendly. A similar system, the East Rail, had also been built to connect to Mainland China thirty to forty years ago. The new West Rail, an extension to the East Rail, is currently under construction.

New transportation plans go through the Railway Development Office of the Highway Department. While it is responsible for the planning and finance in the construction of a transport system, the Railway Inspection Department is responsible for the safety standards. This department does a safety audit every year.

Recently, the Environment and Transportation Works (ETW) Bureau asked for proposals for zero emission transport in the Kai Tak reclamation area. They received proposals that included ETBs and hybrid buses. Before finalising any decisions on a proposal, the government will conduct a regional and district consultation of the people's views and concerns. However, a decision on which type of method will be used has not been made, but a conclusion will be drawn by the end of 2003. Some of these proposals have included a hybrid bus, seen in the protocol for Ma Wan. In this newly developed area, no diesel vehicle is allowed to run on the island. The single-decked hybrid bus system was put into trial to see if this technology would be suitable there, which can then be applied to other areas of Hong Kong such as the old airport site.

The Mass Transit Railway Corporation (MTRC) has also submitted plans to extend their network to the southern part of Hong Kong Island. A monorail system was proposed, and initial evaluations were positive. Although the capital cost was quite large, the operational costs were much lower than expected due to the full automation of the system. However, before anything is finalised, the transport department feels that the MTRC should look for a more cost effective way.

The government did studies on ETBs in 2000 (The executive summary of this study, "Feasibility Study of Introducing a Trolleybus System in Hong Kong", was given to us during this interview.) They thought that it is feasible to introduce an ETB system in newly developed areas such as the new airport region because of the advantages it has. An ETB system is emission free, more flexible, and has worked well in many other countries. However, a minor drawback of a single-decked ETB was its lower capacity. These ETBs carry less than seventy passengers and are not suitable for Hong Kong. A medium capacity vehicle (one hundred or more passengers) must be made available for this highly populated city, or the fleet size of the system must be doubled.

Citybus has made the effort to address the capacity problem by introducing the world's first double-decked electric trolley bus without governmental funding. However, the government still has a number of concerns with the ETB system, such as operational, technical, and financial concerns. Some of the technical concerns were: intrusions from the advertisement signs, maintenance required by the system, road construction problems, overhead wires that would block emergency access needed by firemen, and wire constraints with tunnels. These problems would need to be resolved before the government can begin to consider ETBs as a feasible system.

Currently, there is no direct subsidy for public transportation in Hong Kong from the government; however it does provide some assistance. The assistance includes providing free land for construction and office buildings, equity, and granting the development rights for stations for rail operation. The government also helps to build the bus stations while the bus companies pay for the cost to build their depots. In addition, bus companies do not pay a fuel tax, and in return, they agreed to have a fare break for the elderly. In addition to providing indirect subsidies, the government also makes sure that these companies run under franchise regulations.

Any system the government decides for the newly developed areas will result in problems with franchised grants. Since buses have a lifespan of twelve to fifteen years, the bus franchise grant of twenty years is usually not a problem. However, with these new efficient modes of public transportation and the increasing life expectancy of vehicles, the government may want to rethink the franchise grant policy to complement the high capital cost of a new system.

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