
by

SIMON L'ALLIER

B.A., Université Laval, 2006
M.A., Université Laval, 2010

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Abstract

This thesis examines a way to integrate goods movement with Light Rail Transit (LRT) and trolleybus networks used for public transit. In essence, this implies the use of a new concept vehicle to deliver goods within urban areas, named the Trum, for its hybrid nature between a truck and a tramway, that connects with electrical infrastructure also used to power surface transit vehicles. The approach taken in this research is exploratory as its main objectives are to explore the challenges and opportunities related to such an integration, and to present the characteristics of the Trum, a new concept vehicle on which this new approach is based.

To grasp the possibilities of implementing such a system in a more tangible manner, the region of Vancouver is used as an example and a reference case throughout the thesis. The general research question answered by this thesis is: could goods movement be effectively integrated with public transport electrical network?

Chapter 1 – Introduction sets the context that calls for the integration of goods and people transport, and explains the benefits of using a Trum system rather than vehicles powered with alternative technologies using natural gas, electric batteries or hydrogen fuel cells. Chapter 2 – Freight Transport examines trends and figures of goods movement at different levels of data aggregation. Chapter 3 – Unconventional LRT Uses presents examples non-conventional uses of tramway vehicles by European cities that are using, or have used trams to transport goods within their urban areas. Chapter 4 – The Trum introduces the Trum, a concept vehicle compatible with LRT and trolleybus infrastructure and intended for urban goods delivery, and compares the costs of trumming against those of trucking under different scenarios. Chapter 5 – Vancouver Trum City examines the potential application of a Trum system in Vancouver and its implications for the electrification of TransLink’s surface transit network. Chapter 6 – Conclusion summarizes the rationale articulated in the five preceding chapters and proposes policy measures that would help overcome implementation and operational barriers to make Trum concept a reality.
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EJ: Exajoules. Joule is a measure of energy (kg*m2/s2, or W*s), Exa is 1018.
EPA: In the US, Environmental Protection Agency
EROEI: Energy Return on Energy Investment is the ratio expressing the return of energy sources exploitation. If the energy retrieved equals the energy used to extract it, a ratio of 1 would indicate a null return.
Gt: Gigatons, which equals 1 billion tons
GVGC: Greater Vancouver Gateway Council
HDV: Heavy Duty Vehicles refers to the largest category of trucks, which absolute measure varies by jurisdiction. In the Canadian Vehicle Survey, HGV refers to trucks with GVW of 15 tons and over.
IEA: International Energy Agency
GVW: Gross Vehicle Weight
LDV: Light Duty Vehicles refer to trucks under 4.5 tons used to carry goods.
MDV: Medium Duty Vehicles usually refers to double axle trucks with GVW over 4.5 tons, but lighter than HGV. In the Canadian Vehicle Survey, MGV weight between 4.5 and 14.9 tons.
Mt: Mega-tons, which equals 1 million tons
PKM: Passenger-kilometre: measure of people transort, referring to a person travelling over one kilometre. Akin to tkm in the field of freight transport.
RFID: Radio Frequency Identification
TKM: Tonne-kilometre: Measure of freight transport, referring to a tonne of any goods carried over one kilometre. Akin to passenger-km in the field of passenger transport.
UNFCCC: United Nations Framework Convention on Climate Change
WEO: World Energy Outlook
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Dedication

To my parents, Johanne Mongeau and Jean-Paul L'Allier, whose unshakable love and support accompanied me along the sinuous road of academia and without which I would not be where I am today.
Chapter 1 – Introduction

The question raised in this thesis, “can goods movement be effectively integrated with public transit electrical networks?”, stems from a simple yet crucial fact: we are reaching a cross-road in the history of the human enterprise that calls for radical changes in way we are using resources of planet earth. Global warming, biodiversity reduction, over exploitation of finite resources, destruction and disruption of ecosystems are all symptoms of the same challenge: our unsustainable development patterns. This thesis focus on a very precise piece of this puzzle: urban transportation, which plays an important role in the overall change needed to reduce adverse impacts resulting from human activity. Using electricity to transport people and merchandise in urban settings moves us away from a development model based on fossil fuel consumption to one based on electricity, which can be produced with renewable and low-carbon energy sources.

There are many many examples of progressive cities around the world taking actions to make their transportation system more sustainable. Naturally, a common goal of these cities is to increase the modal share of public transport and reduce that of private automobile; cities with good public transport networks have lower GHG emissions from passenger transport per capita than cities more reliant on automobile (UITP 2009). There are also numerous examples of cities taking actions to make the transport of goods more sustainable and to reduce negative externalities associated with trucking in urban environments and that impact urban population and the natural environment. Yet, the movement of people and the movement of goods are still handled, in most societies, completely separately.

This trend is illustrated by transport-related emissions here and elsewhere showing increasing emissions from goods transport in British-Columbia (Office of Energy Efficiency 2010) and around the world (OECD 2010). Apart from goals aiming at increasing rail and water freight, few alternatives to conventional trucking have been found. This contributes to the global overshoot of the human enterprise by requiring ever more energy and resources, which adversely impacts public health and aggravates risks of climate change by releasing an increasing amount of GHG emissions in the atmosphere.

The premise of this thesis is the following: it is possible to integrate goods and people movement with mutually supportive strategies in ways that address climate change, urban development, public health, and financing challenges faced by public transport agencies. My objectives are manifolds. The first two chapters build a rationale for the urgent need of such integration. The third chapter presents
examples in which goods and passengers movement are integrated through the shared use of LRT infrastructures. The fourth chapter proposes a unique concept-vehicle, named the Trum for its hybrid nature between a tram, a trolleybus and a truck. In examining the use of the Trum on LRT and trolleybuses networks, I demonstrate that this system has the potential to revolutionize the transport of goods by creating a new source of revenue for public transport authorities, whilst addressing climate change and public health concerns. The fifth chapter examines the feasibility of implementing such a system in Vancouver and presents some economic analysis of the proposed system. The last chapter concludes by summarizing the rationale presented in the previous chapters, proposes strategies that could be used to make the Trum concept a reality and reflects on its future implementation.

First, the introduction presents key concepts, trends and data from various fields relevant to passengers and goods transportation. Basic scientific concepts relating to the earth and its biophysical nature are followed by considerations on peak oil, biofuels, urbanization, urban density and air pollution. Then, alternative truck technologies are compared to the Trum, briefly presented, and the most appropriate use of each technology is discussed in the light of the challenges described below.

1.1 Global Overshoot

The ecosphere can be seen as a self-producing system with a plurality of possible equilibrium states, in which a variety of sub-systems interact and influence each other to maintain the structural and functional integrity of the whole. According to the second law of thermodynamics, complex systems tend to degrade with ever greater entropy in any closed system. Earth is no exception to this rule. To resist entropic degradation, the ecosphere must “import” solar energy to create conditions suitable for life, and to enable the continuous recycling of matter needed for the system’s self-reproduction. Over the past century, human anthropogenic greenhouse gas (GHG) emissions have increased enough to alter the earth biophysical system, including its climatic equilibrium. Thus, the human enterprise now threatens the ecosphere’s capacity for self-repair.

All indicators suggest the Intergovernmental Panel on Climate Change (IPCC) highest range projections for GHG emissions will be achieved: “Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level” (IPCC 2007, 30).

The further we move from the current climate equilibrium by injecting an ever-increasing amount of GHGs in the atmosphere, the more frequent extreme events will tend to occur (IPCC 2007, 65). The
earth reacts to this increase in energy retention with positive feedback mechanisms compounding one another and further increasing global warming. These effects include the melting of the Arctic ice cap, thawing of the northern permafrost, wide scale deforestation, acidification of the oceans and many more. Pierce (2007) imagines the possibility of a series of interconnected major changes in the earth's environmental systems that would, taken together, disrupt the life on earth with speed and violence. New equilibria are possible, but they could be hostile to human civilization.

Recent data gathered by the US National Snow and Ice Data Center show the Arctic sea ice is melting faster than projected by the IPCC and the Arctic Ocean could become free of ice within the next 30 years, which is 40 years earlier than projected\(^1\). Some fear eventual thermohaline circulation disruption by the melting of Greenland's icecap, which would affect the main pillar of the earth's climatic system. Although this catastrophic scenario is often dismissed by climate change sceptics and technology optimistics, there is irrefutable evidences showing that current GHG emissions trends are pointing in the wrong direction.

A report on GHG reduction scenarios in BC, published in August 2008 by the Sierra Club, used the Victoria Earth System Climate Model to calculate what level of GHG reduction would be needed to keep global warming under 2°C. Their findings show that it would require global GHG reduction of approximately 83 percent by 2050, which translates to annual GHG reduction of 4.1 percent between 2008 and 2100. Under this scenario, the world could safely emit another 223 Gt of carbon in total by 2100 and still have 70 percent chance to keep global warming under 2°C. Global CO\(_2\)-eq.\(^2\) concentration is already at 430ppm and is growing at a rate of 2 to 3 ppm per year; stabilizing temperature increase below 2°C require a global effort to eventually stabilize CO\(_2\)-eq concentration to 400 ppm (Campbell & Stainsby, 2008).

The same report further asserts that if British Columbia (BC) were to be restricted to an “equitable” per capita emission contribution to this total, the province would be allowed to emit 144 Mt until 2100, or the equivalent of 7.4 years of emission at current rates\(^3\). This calculation allocates the same amount of carbon emission to every person the planet. Industrialized jurisdictions like BC already have carbon emission levels much higher than the global per capita average. To meet this target, BC would need to reduce its emission by 12.6 percent annually between 2008 and 2100, with an emission reduction target of 99.7 percent by 2050 (Campbell & Stainsby, 2008). Realistically, we cannot meet

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2. CO\(_2\)-eq refers to carbon dioxide equivalent
3. Note that this paper measures emissions as tonnes of carbon, whereas other publications refer to tonnes of carbon dioxide. One tonne of carbon is equivalent to 3.67 tonnes of carbon dioxide.
this reduction target if we do not drastically change the way we produce and consumes goods and service in every sphere of human activities.

Despite the very difficult, if not unrealistic nature of this goal, the seriousness of risks posed by climate change for future generation requires us to deploy every effort to stay as close as possible to the 144 Mt threshold for the next 90 years. The principle of equity justifies efforts that aim at keeping temperature rise under 2°C if we want to avoid condemning future generation to “massively unreliable and uncertain environments, constrained food supplies, diseases, rising sea levels, and greatly compromised economic and social being”(Campbell & Stainsby, 2008, 5).

The seriousness of climate change was officially acknowledged by the BC government in 2007, with the *Greenhouse Gas Reductions Target Act*, fixing BC's GHG emission reduction target at 33 percent by 2020, and 80 percent reduction by 2050 using 2007 as base year (Campbell & Stainsby, 2008, 8). Total GHG emissions in BC were 68.0 Mt CO₂-eq in 2007, 68.7 Mt CO₂-eq in 2008 and 66.8 Mt CO₂-eq in 2009. Despite a slight decrease between 2009 and 2008, transportation remains the first GHG emitting sector (37 percent). Emission from transport have grown from 18.6 Mt in 1990 to 24.5 Mt CO₂-eq in 2009, which represent a 32.12 percent increase over twenty years and a 8.5 percent increase a decade (1999-2008) (BC Ministry of the Environment 2010). On a per capita basis, transportation emissions increased by 2.84 percent over between 1991 and 2006 to reach 5.94 tonnes CO₂-eq annually (Statistics Canada 2012a, 2012b). Given the low-carbon electricity production potential of British-Columbia, we could achieve significant reduction in per capita GHG emissions by electrifying urban transportation modes as examined in Chapter 5- Vancouver Trum City.

Coherent actions from all levels of government must be deployed to achieve the ambitious provincial emission reduction target. As an important contributor to GHG emissions, the transport of passengers and goods must be better organized and planned to produce less GHGs and negative externalities.

### 1.2 Transport Emissions and Climate Change

The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol, signed in 1997, had set GHG reduction targets at an average of 5 percent below 1990 for the five year period 2008- 2012. These targets represented a “binding” agreement for 37 industrialized countries including Canada, which contributes 3.3 percent of total global emission (UNFCCC 1997).
Figure 1 (p.5) shows 2004 global GHG emissions from anthropogenic sources by sector of activity, which amount to 49 Gt CO₂-eq (IPCC 2007, 36). Looking at the different sectors, transport accounts for 13.1 percent of total global emissions. Differentiated by gas types, CO₂ emissions from fossil fuel consumption generates 56.6 percent of global emissions. Obviously, we should attempt to reduce all GHG sources and types, but focusing on transport emissions is essential, as CO₂ represents more than half of global emissions and transport uses half of global oil production (Pinchon 2006).

1.2.1 Transport in Canada

In 1990, Canada's emissions were estimated at 590 Mt CO₂-eq. The Kyoto Protocol’s reduction target is 6 percent reduction by 2012. However, Canada’s emissions reached 690 Mt CO₂-eq in 2009 (Government of Canada 2011), which represents a 24.4 percent overshoot over the Protocol's target. Clearly, current national environmental policies are not sending the right message to consumers and business in regards to the real cost of carbon emissions. In 2009, carbon emissions from transport represented 27.5 percent of Canada's total emissions (Government of Canada 2011).

Transport is an inevitable component of human activity, and it must become more sustainable. Unfortunately, “[i]t is naive to pretend that there has been any significant move towards sustainable transport over the recent past, and there are at present few signs that this will change in the near future” (Banister, 2005, 79). Despite improvement in fuel efficiency over the last quarter of century, the

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4 Excluding emissions from the Land Use, Land Use change and Forestry Sectors.
increase in transport demand outweigh the benefits achieved by more less polluting vehicles.

Similarly, transport emissions contributed to approximately 27 percent of total U.S. GHG emissions in 2008. Transport is the fastest growing sector of US GHG emissions, accounting for 47 percent of net increase for the country's emissions since 1990 (EPA 2011b).

The underlying argument is clear: a large-scale, radical change is needed in the transportation sector if we are to reduce related carbon emissions. Technology alone, including in fuel efficiency, cannot offer realistic solutions to achieve sufficient GHG emission reductions to address climate change seriously given the growing transportation demand. We must rethink travel patterns, for both passengers and goods. In other words, “[t]o actually achieve sustainable transport requires people and goods to travel less” (Banister, 2005, 78).

In regards to goods transport, this might happen over the long run if oil price keep rising. Long and complex supply chains that currently describe production of most goods are economically justifiable because of cheap oil. Higher energy price could therefore “force” us to buy local products, as carrying merchandise from across the globe would be prohibitively expensive. As stakes are high and time is limited, this change might however happen too late to avoid the earth's climatic system tipping point. Following the widely accepted precautionary principle, we must take action now. We cannot afford to wait until its too late to question the way we produce and carry goods.

1.3 Peak Oil

For finite natural resources, the “peak” refers to that point in time when the highest extraction rate is reached. It generally occurs after half of the resources has been taken, also known as the midpoint of depletion. Oil production follows the bell-shaped pattern expressed by the Hubbert's curve\(^5\). There are now plenty of empirical observations and data supporting the hypothesis stating that peak oil will, or has occurred.

The Association for the Study of Peak Oil and Gas (ASPO) shows that the peak of conventional oil discovery happened in the 1960's and that global peak of production is imminent (ASPO 2011). Some have identified the year 2005 (Deffeyes 2005), others see 2020 or 2030 as the peak of oil production\(^6\), assuming substantial technological improvements (Leggett 2005). Faith Birol, a chief economist with the International Energy Agency (IEA), has publicly acknowledged the peak of crude

\(^5\) Named after M. King Hubbert, famous geologist employed by Shell, who predicted the highest oil production point would level would occur 1970.

\(^6\) Including conventional and unconventional oil production.
oil production happened in 2006. No matter who will be proven right about the exact date, with global oil demand increasing and global oil reserves not expanding; cheap oil is running low.

This does not mean that oil will suddenly disappear. Rather, it means the easily accessible oil is running out and that remaining oil fields will be increasingly difficult, risky and costly to exploit. As exploitation becomes more expensive, the Energy Return on Energy Investment ratio (EROEI) diminishes. Ultimately, there is no gain in exploiting oil if the amount of energy retrieved equals the energy is used to extract it.

The alarming rise of vehicle ownership, and therefore fuel consumption amongst Asian dragons, namely China and India, raises serious questions about the viability of using conventional transport for people and goods movement in the future.

Between 1999 and 2004, China's oil imports doubled. Peak Oil researcher James Kunstler (2006) estimates that at current growth rate, China alone will consume the equivalent of the entire planet's current oil exports within ten years. This scenario doesn't factor in growth in oil consumption elsewhere, and assumes no fall-off in production (Dennis & Urry 2009, 15).

Although it is not within the reach of this thesis to examine the dramatic cost of oil dependence, the twentieth century alone saw enough resources-wars to remind us the risk associated with remaining dependent on a disappearing resource.

Those sectors of the economy heavily dependent on petrol, such as transportation, are particularly vulnerable to oil shortages and price hikes. The transportation sector is 98 percent dependent on oil, which represents 50 percent of global oil consumption and 20 percent of all of global energy demand (Pinchon 2006). The scarcity of oil and its rising price create opportunities for agribusinesses whose biofuel crops are often subsidized despite damageable environmental and social impacts.

1.4 Biofuels

Biofuels are often identified as a convenient substitute to conventional fossil fuel, although there are considerable questions pertaining to the desirability of producing biofuels with fertile lands. These include negative impact of industrialized agriculture on the environment, decreasing EROEI and the ethical implication of this practice. It is highly questionable whether we should use fertile land to produce fuel used by our cars in a time where we still haven't eradicated world hunger.

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Although the IEA estimated that in 2009, one million barrel of oil demand were displaced by oil biofuel production, the 400 percent increase in ethanol production since 2000 (RFA 2007, 22) has put increasing pressure on arable land. There are number of reasons to believe that the ethanol industry is an aggravating factor in the increase of food prices. Growing feedstock to produce biofuels contribute to increasing food price, concentrates land ownership which in turns marginalizes vulnerable population, reduces biodiversity, and increases pressure on water resources (Eide 2009, 4).

Furthermore, we should question the viability of using biofuel production considering climate change. Growing feedstock to produce ethanol increases overall GHG production as it adds to existing fossil fuel consumption and does not replace carbon-intensive energy source by renewable ones. Almost every step of production involves fossil fuel consumption, from seeds collection to harvest and processing.

Improved ethanol production techniques exist, such as those using secondary matter (i.e: livestock feces, industrial byproducts) but not in sufficient quantities to provide for wide scale consumption. Comparing GHG emissions of these types of biofuel shows that biofuels don't have lower carbon intensity. In a review of low carbon technology for heavy goods vehicle produced for the UK Department for Transport, biofuels are shown to vary in energy and carbon intensity. First generation biofuels, namely corn-based ethanol, do not always generate less well-to-wheel GHG than conventional gasoline or diesel (120-140 gram of CO₂/km) (Baker et al., 2010, 76), and various studies suggest that more energy is required to produce crop-based ethanol than contained in the final product (Pimentel 2003); Although second generation biofuels produce generally under 50 grams of CO₂ per kilometre, the problem is that all biofuels have higher well-to-wheel energy intensity (250 to 550 MJ/100km) than conventional fuel (200 MJ/100km) (H. Baker et al. 2010, 76). If we aim are reducing total energy consumption from transportation, we must not only consider GHG emissions but prioritize the development of transport technologies that require less well-to-wheel energy.

Second generation biofuels, with less adverse social impacts than first generation biofuels, play a role in the phasing out of fossil fuel dependence and should not be dismissed, but their high production costs question their commercial viability (Eide, FAO 2009). The position taken in this research is that we should pursue the development of real clean energy sources that do not further contribute to other global crises.

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8 First generation of biofuel includes are usually crops-based (corn, soya) and the second generation includes biofuels produced with biomass or through cellulosic processes.
1.5 Global Urbanization

Globally, more than half of the world population now live in cities (UN, 2010). People have moved from rural areas to cities at unprecedented speed in the last decade, and this trend is projected to continue in the future. In fact, America, Europe, and Oceania already have over 70 percent of their population living in urban areas. Asia and Africa, which urbanization level is still under 50 percent, are expected to continue the trend of urban migration and to follow in the path of industrialized nations. By 2050, 69 percent of the world population expected to be urban (UN 2010, 2).

One of the arguments underlying this thesis is that cities are primary loci for current world challenges. With increasing world population, land scarcity, climate change threats, peak oil, and other facets of the deeper crisis triggered by human industrious activities, cities can provide for a sustainable lifestyle. Concentration of people and activity produces economies of scale, which can ultimately lowers the energy used by of human activities (Naess 1993; Newman and Kenworthy 1989). Although it is true that urban dwellers with higher income have a larger ecological footprint than rural population with lower income (Rees and Wackernagel 1996), population of cities characterized by higher density and mixed land uses require less energy for housing and produce less GHG emissions from transport than those living in low-density, sprawling cities (Norman and MacLean, Heather L. Kennedy 2006). In other words, controlling for income levels, good urban design can provide for a low energy life-style in which transportation and housing deliver the same benefits with less energy input. This doesn’t means the solution of current crises lies only in further urbanization, but undeniable trends (based on cheap energy) indicate that the world will become increasingly urban, which creates challenges, but also opportunities to lower transport and housing carbon footprints.

Less developed countries will experience greater urban population increase, fuelled by natural growth and migration from rural areas. In figure 2, urban population in less developed nations is shown to grow from 2 billion people in 2000 to more than 5 billion people in 2050. Although a global financial meltdown or climate catastrophes could prove these projections wrong, urban sustainability will remain a key elements in addressing climate and environmental sustainability.
As the world is becoming more urban, the concentration of people, economic activity and wealth in cities can be conditions conducive to more sustainable lifestyles with lower energy requirements, namely for housing and transportation, whilst avoiding sprawling car-dependent development.

As discussed in more detail in Chapter 4, intensifying the use of LRT or trolleybus electrical network could have multiple positive impacts urban developments. In addition to attracting commercial and residential development along transit corridors thus contributing to the development of more sustainable urban forms, a Trum system could provide a new source of revenue to the public authorities owning transit right-of-ways, reduce adverse impacts associated with trucking and contribute to the development of higher-quality transit.

### 1.6 Urban Density

Urban density and public transport are interrelated in many ways. This section does not attempt to provide a definitive answer to debates surrounding density, but summarizes various arguments and data that frame the relationship between sustainability, density and public transit.

Density is generally divided between commercial and residential density. Although both are
important in assessing the human activity generated by human presence, residential density has received more attention in the literature (possibly because it is slightly easier to estimate) and refers to the number of people living in a set geographical area. It is often expressed in terms of number of dwellings or people per hectare or acre. For the sake of simplicity and coherence, data on residential density are usually presented as number of dwelling or persons per gross hectare.

Although there is a debate on increasing density, it has been widely recognized that higher density is more sustainable than sprawl, not only from a transportation perspective, but considering land and energy savings from having smaller dwellings closer together.

Banister's (2005) provides figures on density from multiple sources illustrating the density range advocated by those in the discipline. Typical urban residential density in the US is about 18 dwellings per hectare, but cities like New-York, Boston or San Francisco have much higher density. In the UK, average density built in cities is around 23 dwellings per hectares, although Victorians built cities with 40 to 80 dwellings per hectare and Georgians constructions ranged from 100 to 200 dwellings per hectare (Banister, 2005, 107).

The UK Local Government Management Service Board's Sustainable Settlements Guide mentions that density to support bus transit is about 100 persons per hectare, and 240 persons per hectare to support tramway services (Friends of the Earth 2007, 2). Current UK directives plans for new development of about 30-45 dwellings per hectare.

The strategic regional land use and development plan of Montreal's Metropolitan Community (CMM 2011 58) proposes of minimal population density ranges along transit corridors and at rapid transit stations. Heavy rail and light rail minimal population density range 60 units per hectare (low) to 150 units per hectare (very high), whereas those of tramway, BRT and bus services range from 30 units per hectare (low) to 80 units per hectare (high).

These guidelines are only one aspect of urban density, as they do not consider commercial density, often expressed in jobs per hectare; they are also approximate, as many other factors influence ridership and economical performance of tramway lines: the length of the line, its surrounding land use the size of the city centre it deserves and connection with other transit services.

Newman and Kenworthy's (1989) now famous comparative analysis found positive relationship between population density and travel energy consumption per capita. They found a strong decrease in petrol consumption from transportation when population density reached 29 dwellings/hectare, which

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led them to argue in favour of strong city-centres and more intensively used suburbs. Similarly, Naess (1993) also found relationships between urban density and transport energy consumption showing decrease in energy consumption per capita as density increases.

In relation to car trip lengths, Banister (2005) concludes that at density of at least 15 persons/hectare, the distance travelled in each car trip is relatively constant (12km/trip). This distance increases by up to 35 percent (16.2 km/trip) in areas of lesser densities. Similarly, the denser the urban areas, the less people tend to drive. Automobile modal share in higher density areas is half that of lowest density locations.

Distance between home and the nearest transit stop affects modal share in a way that can be intuitively understood. People who live further from transit stop will tend to take transit, walk and cycle less and drive more (Kitamura, Mokhtarian & Laidet, 1997).

In regards to light rail use, Robert Cervero (1994) showed that the proportion of rail journeys decreases as distance between homes and the nearest station increases. In cities like Washington, Toronto and Edmonton, people who lived within 150 metres of a station used rail for a third of their trips. This is twice as much as people living at approximately 900 metres from a station.

Major transport networks, carrying people or goods, have tremendous influence on land use development. These networks shape developments, encouraging dispersion or concentration, depending on regulation, geographical condition and environmental constraints. Although locating development near transit infrastructure increases ridership and reduces car use, providing faster transport mode also encourage longer trips. While a certain degree of mobility is necessary, access should be prioritized over mobility to reduce travel and increase destination choices.

The body of literature linking the built environment to public health is also growing, and strong evidence show correlation between density, land-use, transport mode and beneficial impact on physical activity level and public health (Frank and Pivo 1995; Frank et al. 2004, 2007; Lachapelle and Frank 2009; Oakes, Forsyth, and Schmitz 2007; Pivo and Frank 1994; Saelens 2004).

The fact that density is in general positive and more sustainable than sprawling development touches directly on the question of public health. Planners encourage density along corridors, but in doing so they also increase the number of people exposed to air pollutant caused by heavy vehicle traffic on these arterials.
1.7 Public Health and Air Pollution

The contradiction between the need for greater density in city centres and along transportation corridors and the public health risk related to air pollutant exposure caused by vehicle traffic provides an opportunity for city makers: both climate change and public health command action compatible with one another. As stated in the fourth IPCC report: “...there is high agreement and much evidence that in all analyzed world regions near-term health co-benefits from reduced air pollution, as a result of actions to reduce GHG emissions, can be substantial and may offset a substantial fraction of mitigation costs” (IPCC 2007, 59).

1.7.1 Tailpipe Emissions

CO₂ is not the only GHG produced by transport. Others include refrigerant based on fluorochlorocarbons and hydrofluorochlorocarbons, unburned methane, Nox, and water vapour (WBCSD 2004, 21).

In addition to CO₂, transport tailpipe emissions include particulate matter (PM), volatile organic compounds (VOCs), carbon monoxide (CO), sulphur (SO₂) and nitrogen oxides (NOx). Because NOx and VOCs impacts public health through the creation of tropospheric ozone, we focus on this by-product instead of presenting VOCs and NOx separately. More detailed information on air pollutant from trucking are provided in Chapter 2.

Carbon Monoxide (CO) binds with haemoglobin to form carboxyhaemoglobin, which reduces the oxygen-carrying capacity of the blood. CO is known to be linked with cardiovascular problems (Burnett et al. 1997; Morris, Naumoova, and Munasubghe 1995; Schwartz and Morris 1995; Schwartz 1997).

SO₂ however is responsible for acid rain, which has impacts on the ecosystems and corrodes metal surfaces such as galvanized steel (Baedecker, Edney, et al. 1990).

Fine particulate matter is a component of motor vehicles' emissions. A study on mortality and fine particulates in six US cities (Laden et al. 2006) confirmed causal evidence linking fine particulates to increased mortality. They mention that vehicles can contribute to approximately a third of fine particulate measured in urban areas, an estimation in line with the Ontario Ministry of the Environment (2011), which estimates at 25 percent the share of fine particulate produced by vehicles of the province.
Ozone ($O_3$) is a highly reactive gas essential to life on earth, but it can also have negative impacts on human health depending on its location in the atmosphere. Although ozone is a gas not mentioned in the above primary air pollutants, tropospheric ozone is created by a reaction between VOCs and NOx in sunlight. Stratospheric ozone, or “good ozone”, is formed naturally through the interaction of solar ultraviolet radiation with oxygen molecules ($O_2$). This “ozone layer” extends from approximately ten to fifty kilometres above the Earth’s surface and reduces the amount of harmful UV radiation reaching its surface. Tropospheric ozone, or “bad ozone”, is formed at ground level as a result of a reaction between two major types of air pollutants: VOCs and nitrogen oxides (NOx). VOCs and NOx reaction depends on heat and light, which means ozone peaks usually occurs during hot summer days. Ozone and the pollutants that form it can be carried away from the original production location (i.e. cities) to rural areas many kilometres away (EPA 2010), where it can damage vegetation, including crops.

Despite evidence linking the presence of ozone and human health conditions, literature shows no consensus on the impacts of ozone on human health as its effects are possibly confounded with those of fine particulate matter. Some studies show statistically significant relationship between ozone and mortality (Kinney and Ozkaynak 1991; Moolgavkar et al. 1995); while others show non-significant correlation once controlled for PM (Kinney, Ito, and Thurston 1995). As Zhang et al (2004), we follow McCubbin and Delucchi (1999) in considering that tropospheric ozone impacts mortality. These authors also cite epidemiological researches outlining eye irritation, asthma attacks (Holguin et al. 1985) and other respiratory symptoms.

### 1.7.2 Road Transport Costs on Public Health

The Quebec Public Health Institut (INSPQ), has produced a few reports estimating effects of air pollution on the Quebec population. One report acknowledges that scientific evidences confirm with certainty that air pollution has a negative impact on public health (Wilson and Spengler 1996), more precisely in increasing morbidity and mortality resulting from respiratory or cardiac illnesses. It underlines the fact that there is apparently no threshold under which effects on public health have been observed; foetuses, children, elderly or ill people are however more sensitive to air pollution (INSPQ 2007, 1). This means that any reduction is beneficial to the population and even more so to these people. Overall, the report estimate that Quebec population would be willing to pay 10 billion CA$ yearly to avoid impacts associated with air pollutions (INSPQ 2007).

The example of Atlanta Olympic Games of 1996 is often cited as a reference case regarding the
relation between public health and air pollution. During the period of the game, there was a reduction of asthma acute care incidences of 11 to 44 percent, while morning peak traffic count decreased by 22 percent. Fewer vehicles on roads led to reduced ozone, fine particulate matter and carbon monoxide emissions (Brauer 2002).

In addition to emitting air pollution, transport claims lives of pedestrians, cyclists and car drivers. The report Dangerous by Design 2011, specifies that there was in average 1.6 pedestrian death per 100,000 people in the US from 2000 to 2009, which represents 11.6 percent of all roads fatalities. Canada and Australia, countries with similar infrastructures as the US, have respective rates of 1.1 and 0.6 pedestrian death per 100,000 people respectively (Transportation for America 2011, 5).

In sum, to reduce the public health risks related to transportation, more attention must be paid to vehicle emissions, especially when density is encouraged along corridors and in urban centres. LRT infrastructure can, as seen in Chapter 3, be harmoniously integrated to a high-quality urban environment. Electric vehicles, compared with diesel powered trucks and buses, reduce air pollution along these arterials.

As presented in section 2.2 of this thesis, trucks emit a significant amount of air pollutants, which costs on public health and the environment has been evaluated by different studies over the years. From six sources in the literature, the National Hydrogen Association monetized costs of urban pollution in urban settings. Societal costs given in US$ per metric tonne are PM-10 : 1,608; PM 2.5 : 134,047; S0x: 29,743; CO: 6,592; NOx: 13,844 (Thomas 2009). These estimates are used in Chapter 5 to estimate the monetized public health impacts of transferring goods delivery in urban settings from trucks to Trums.

1.8 Air Pollution Long-Term Trends

Despite GHGs trends heading in the wrong direction, the WBSCD report presents one positive evolution of transport air pollution in OECD countries: the sharp decrease in transport-produced conventional air pollutants, which include NOx, CO, VOC, lead and PM-10. This reduction is due to technological improvement and tighter regulations, which have already virtually eliminated lead as a transport-related air pollutant.

The decrease in transport-related air pollutants in developing countries is not expected to be as rapid or complete as those of OECD countries because of the slower dissemination of cleaner technology and the higher increase of transport activity. Based on these assumptions, non-OECD countries should experience an increase in air pollutant for at least a few decades, which is expected to
As noted by Dennis and Urry most mega cities within developing countries do not meet WHO air quality standards (2009, 23); they correctly add that building a “world of modern cities based on transport tied to the ubiquitous use of fossil fuel adds to rising social instabilities and presents major challenges” (ibid., 24).

1.9 Noise Pollution

Noise is defined by as an unwanted sound that combines the objective phenomenon of sound production and the subjective psychological effects of those hearing it (WBCSD, 2004, 48). There is sound produced by movement, engines, mechanical parts and ground friction of transport vehicles. For road transport, the combination of these factors vary depending on operating condition. Over 80km/h, the tire-road contact (TRC) is the main noise generator; at 50km/h with moderate acceleration (1m/sec²), TRC still accounts for most of the noise produced by road vehicles; at 25-35km/h with greater acceleration (2m/sec²), vehicles' power unit (engine, exhaust, air intake) dominates noise production (WBCSD, 2004, 49).

In terms of acceptable noise from highway and trucking operation, the provincial Ministry of Transportation in Quebec has set the maximum average noise over a 24-hour period at 65 dBA, and is aiming at limiting to 55 dBA noise pollution for new construction or road improvement (CITM 2000, 20).

Heavy trucks will have noise production level at about 77 dBA at 50km/h, 81 dBA at 70km/h and 84 dBA at 90km/h. In comparison, cars produce about 64 dBA at 50 km/h, 70 dBA at 70km/h and 74 dBA at 90km/h (CITM 2000, 45).

By replacing combustion engine by electrical motors, the noise level of Trums is expected to be lower than that of conventional fuel trucks, and would be close to the current noise level generated by trolley bus, which noise production has been measured at 7-10 dB lower than conventional buses at about 50 km/h (Ross and Staiano 2007).

1.10 Alternative Technologies versus Trum

In the light of the information presented in this chapter, it seems clear that transportation of goods and passengers create important adverse impacts that contribute to many crisis and challenges we face
today, including global issues such as climate change and resources depletion, as well as local issues like public health, urban development and land use. This section examines different technological solutions proposed to reduce adverse impacts of goods movements against that of the *Trum*, which is in essence that of existing trolleybus or LRT vehicles. This thesis does not argue for the absolute superiority of *Trum* vehicle versus other technologies. Rather, we argue that the *Trum* technology, which implies using a primary propulsion mode relying on contact to electric catenaries and a secondary propulsion system relying on electrical batteries, is probably best suited for a certain goods movement market (urban delivery), provides superior environmental performances and has structural implication for urban development patterns.

1.10.1 Hydrogen Fuel Cell and Electric Batteries

Fuel cell and battery technologies have been evolving rapidly and will continue to evolve in the future. It is therefore hard to know with certainty what will be the characteristics and performances of battery and fuel cell powered vehicles years from now. Nevertheless, battery and fuel cell trucks currently exist on the market and their characteristics speaks to the challenges of developing heavy-duty vehicles powered by these technology. As the following examples show, these challenges include high production costs, expensive hydrogen production and nonexistent hydrogen distribution infrastructure.

For instance, the Vision Motor Corp Tyrano™ was branded the “world’s first plug-in electric/hydrogen fuel cell powered heavy-duty vehicle” (Vision Motor Corp. 2011). It has a curb weight of ~7.7 tonne and has a GVW of 36.2 tonnes, which means it has a payload capacity of about 28.5 tonnes. Its maximum autonomy is 320 km and the fuel cells can produce up to 65 kilowatts. The cost of a Tyrano™ is between US$ 250,000 – 350,000\(^\text{10}\). The first Tyrano™ was delivered to the Port of Long Beach, California, in July 2011. To provide a point of comparison, a heavy duty truck in BC costs approximately CAN$ 140,000 (see Table 3: Typical trucks specifications p.37). Despite this very high prices, in a report on hydrogen vehicle and technology the National Research Council (NRC) estimates hydrogen fuel cell vehicle unit price to fall from US$ 200,000 in 2012, to just over US$ 23,000 in 2023\(^\text{11}\), an estimation which remains to be proven right by future market prices.


\(^{11}\) In 2005 US dollars.
Another key cost to consider when comparing the Trum and hydrogen vehicles options is the cost of the fuel distribution infrastructure required. The National Hydrogen Association estimates that it would cost $9 billion to add 6,500 hydrogen pumps to existing fueling infrastructure until 2020 in the US. This estimate returns to a unit cost of about US$ 1.4 million per pump.

A survey of petroleum retail outlets in Canada (MJ Ervins & Associates 2011) indicates that diesel fuel is available at 57 percent of the 12,710 sites identified across Canada. Although there are no source able to provide reliable data on the number of fuel retail outlets in the Metro Vancouver region, the study identified 1,419 petroleum retail sites in British-Columbia, or 3.12 outlets per 10,000 people. Assuming this rate is applicable to Metro Vancouver, we could deduct there are approximately 685 fuel retail outlets in the region. Assuming the presence of diesel fuel in these retail sites is similar in BC than in Canada (57%), we can deduct that there are approximately 390 diesel retail sites in Metro Vancouver. If we were to add a hydrogen pump at each of the 685 stations, the estimated infrastructure costs would be approximately US$ 959 million. This estimate represents only the capital costs associated with distribution infrastructure and do not reflect the production and transport costs of hydrogen.

A number of assumptions made by the National Hydrogen Association (2009) that illustrate the challenges of both hydrogen fuel cell, hybrid and all electric (lithium-ion) batteries. As for the Trum, the GHG reduction potential of gasoline plug-in hybrids, all-electric and hydrogen fuel cell vehicles is dependent on the electricity grid becoming “greener” and batteries becoming “affordable”.

The GHG reduction potential with all electric vehicles, powered by either hydrogen fuel cell or electric battery, is dependent on the primary energy source to produce hydrogen and electricity. From an environmental perspective, they perform better than natural gas or hybrid vehicles, as both “hydrogen and electricity can be made from low- or zero-carbon sources including renewable energy (solar, wind and biomass), nuclear energy and coal with carbon capture and storage” (Thomas 2009, 6007). It is worth noting that the report assumes a lower carbon grid sources will be phased-in over the century, which would reduce the carbon footprint of battery and fuel cell vehicles. In reality, such a reduction in the carbon footprint of the US electric grid remains uncertain, and so do the GHG savings expected by the conversion of conventional combustion engines to battery and electric vehicle.

Thomas (2009), compared electric vehicles powered by batteries, and by hydrogen fuel cells and concluded that “for any vehicle range greater than 160 km (100 miles) fuel cells are superior to batteries in terms of mass, volume, cost, initial greenhouse gas reductions, refuelling time, well-to-
wheels energy efficiency using natural gas or biomass as the source and life cycle cost” (Thomas 2009, 6005).

In sum, the high costs of hydrogen and vehicle, and the absence of distribution infrastructure are significant challenges that limit the wide-spread use of this technology in a near future. If fuel-cell trucks become commercially viable, they will be best suited for long-distance, inter-city goods movement.

1.10.1.1 All Electric and Hybrid Vehicles

Lithium-ion batteries (Li-ion) batteries are still very expensive and remains the key determinant of the cost and electric driving range of plug-in hybrid vehicles. Although several types of chemistries for Li-ion are being developed, there are still challenges regarding the essential goals for costs, battery life and range (NRC 2010) set by the industry. As mentioned by the National Research Council report on hybrid vehicles, a significant drop in costs often experienced with new technology is unlikely, as Li-ion batteries are already being produced in large numbers and are “well along their learning curve” (NRC 2010, 1).

Of the two types of hybrid vehicle considered by the report, the PHEV-40, a plug-in vehicle with a forty-mile autonomy on batteries, is the most informative for this thesis. The battery pack of the PHEV-40 is expected to cost between US$ 10,000 - 14,000. Currently, assembled battery packs cost about US$ 1,250 - 1,700 per kWh of usable energy, or between US$ 625 and US$ 850 per kWh of nameplate energy12.

The GM Chevrolet Volt GVW weights 2,063 kg (4,548 lbs), its curb weight is 1,715 kg (3,781 lbs)13 and its 16 kWh battery pack weights 198 kg14, which represents 11.55 percent of its curb weight and 9.6 percent of its GVW. The energy/weight ratio for its Li-ion battery pack is therefore 125 Wh/kg when calculated with nameplate energy, and 80.8 Wh/kg when calculated with usable energy.

With this information, we can deduct15 that the weight of battery needed for a 150 km autonomy of an all-electric truck equivalent to a five-axle semi-trailer16, would be 2,782 kg with an energy density of 200 Wh/kg, 3,710 kg with an energy density of 150 Wh/kg and 6,956 kg with an energy density of

12 The nameplate energy is the maximal potential energy output of batteries, which gives the usable energy once resistance, energy losses and inefficiency are factored-in.
15 Assuming the energy efficiency of electric truck is similar to that of current diesel truck.
16 See p. 37-38, the average of HDV fuel consumption in Canada averages 34.5 litre of diesel per 100 km.
80 Wh/kg. At the cost of US$ 1,250 – 1,700 per kWh of usable energy, the price of an hypothetical battery pack providing 253 kWh of usable energy would be between US$ 316,000 and US$ 430,000.

For a two-axle Medium Duty Vehicle (MDV) (see Table 3: Typical trucks specifications p. 37), the required battery pack to ensure a 150 km autonomy would weigh 1,895 kg at 200 Wh/kg, 2,527 kg at 150 Wh/kg and 4,738 kg at 80 Wh/kg. Using the same price range, the price of a Li-ion battery pack providing a MDV with an autonomy of 150 km would cost between US$ 474,000 and US$ 644,000. To respect Canadian regulations on axle weight and since MDV GVW must be between 4.5 and 14.9 tonnes, the weight of the battery pack would reduce its maximum payload, even more so than for HDV in relation to their relatively smaller payload. This added weight would be particularly problematic for MDV because of weight restriction.

This cost estimation uses current market price for Li-ion battery pack, and although we could expect a price reduction as production of electric battery increases, there is no guarantee that increase demand will not offset production increase and bring prices up. Even if electric trucks would have twice the energy efficiency of current diesel engine, the cost of the battery pack alone would most likely remain prohibitive. In addition to the high costs of Li-ion battery pack is their limited lifetime. As point of reference, the electric battery pack of the Tyrano vehicle is expected to be approximately 10,000 hours. (Vision Motor Corp. 2011), or approximately four years.

Calculated for a 5-passenger sedan (Thomas 2009), batteries emit more GHG than hydrogen fuel-cells mainly because of the added weight of the battery pack required to cover that distance. This reasoning is also applicable to trucks, as their heavy weight requires too much power to be moved by electric batteries with reasonable cost and weight.

From an environmental perspective, since hybrid vehicles still use internal combustion engines powered by fossil fuel, hybrid vehicles alone, plug-in or not, would not be not be sufficient to cut GHGs to 80% below 1990 levels (Thomas 2009).

In sum, battery technology is ill adapted for long-distance goods movement. Li-ion batteries are heavy and expensive and provide for fairly limited autonomy. In comparison with the Trum, the main advantage of both batteries and fuel cell vehicles are their independence from an electrical grid. This characteristics speaks to the most important impact of the Trum on urban development. Precisely because of the need of having access to electric transit infrastructure, the Trum would encourage the location of production and retail sites along transit corridor rather than encouraging the current

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17 The energy equivalent of 23.5 L of diesel.
18 Assuming a use of about 10 hours per week day.
dispersed development pattern allowed by conventional trucks. Because of its limited need of off-grid autonomy, the *Trum* would need much less battery power and wouldn't suffer from the associated weight and costs impacts.

### 1.11 Summary

Despite its many negative social and environmental externalities, transportation remains essential to human activity. Pollution trends are however heading in the wrong direction and will continue to do so for a time as the world population and economic activity increases. Principal negative impacts of transportation on cities, mainly caused by private vehicles and other fossil fuelled vehicles, are summarized by Banister (2005, 7):

1. Growing congestion in cities (increasing with city sizes (Dasgupta 1993), reducing travel speed and other negative externalities.
2. Increasing air pollution
3. Declining road safety
4. Increasing traffic noise
5. Increasing use of space by traffic
6. Degradation of urban landscape
7. Global warming

From these negative impacts stem seven basic objectives of sustainable transportation. These objectives are compatible with the *Trum* system presented in Chapter 4 –The *Trum*, and form the basis of any sustainable transportation policy:

1. Reduce the need to travel.
2. Reduce the absolute levels of car use and road freight in urban areas.
3. Promote more energy efficient modes of travel for both passenger and freight.
4. Reduce noise and vehicle emissions at source.
5. Encourage a more efficient and environmentally sensitive use of the vehicle stock.
6. Improve safety of pedestrian and all road users.
7. Improve attractiveness of cities for residents, workers, shoppers and visitors.

According to the European Conference of Ministers of Transport (OECD and ECMT 1995), this
list would address most problems faced by urban areas, namely congestion, air pollution, noise, safety, degradation of urban landscape, urban sprawl and global warming (Banister 2005, 18). Setting targets in each of these sectors is crucial if we want to monitor the effectiveness of transport and land use policies.

Ultimately, the most sustainable mean of transport is the one that can do the required job while requiring the least amount of energy and resources, which includes the use of space on a finite planet. Walking and cycling, which require no direct non-renewable resources, are the most sustainable. Obviously, these transport modes cannot replace trucking, but they can complement greener goods delivery systems.

As shown in this introduction, challenges faced by civilization and the role played by the transportation sector in this crisis require that we seriously re-examine the status quo and propose better way of transporting people and goods. Three reasons for change summarized by the OECD and the IEA (1997) are energy security, environmental protection and economic competitiveness. In addition to those, concerns of public health, social justice and quality of life should also be considered. Hence, increasing the integration of goods and people movement could result in a more efficient transportation systems and make better use of surface electrical transit infrastructure and reduce the need of constructing roads, which are used by trucks but also encourage the use of private vehicles.

For all these reasons, the Trum's characteristics could make this technology a smarter option than alternative technologies for urban goods movement. On the long term, hybrid vehicles, like natural gas vehicles, still consume fossil fuels and contribute to global warming. First-generation biofuels, with their negative social and environmental impacts, are not better replacement to conventional fuel. Hydrogen fuel cells might play a role in long-distance transportation, but they are still far from viable commercial operation. Electric batteries have limited life-expectancy, are heavy and expensive, which makes them ill adapted as primary propulsion mode for goods movements. In addition, none of these options offer the synergy potential between goods movement and transit infrastructure produced by the Trum, which is consequently the only goods movement strategy that has the potential of affecting urban development patterns at a large scale, by encouraging development along transit corridors.

To answer the research question of this thesis, namely how to integrate goods transport with electric transit infrastructure, the following chapter examines in more detail the goods movement sector and presents trends and data from a variety of sources.
Chapter 2 – Freight Transport

This chapter presents an assessment of current trends and projections in freight transport and their implication in regards to climate change, GHG reduction targets, energy consumption and pollution. The economics of goods movement is also examined; current costs and revenues of the industry provide essential information to understand the market of goods transport by road. Properly assessing this market is indispensable for planning an efficient and sustainable transport system that will integrate goods movement with light rail infrastructure. For this reason, the focus of this chapter is on land-based urban freight transport.

2.1 Global Freight Transport Activity

Gross Domestic Product (GDP) can be used as a general indicator of freight activity, despite variations dependent on the specifics of a country's economic activity and development level. Growth in global trade was twice that of GDP growth between 2000 and 2006, but averages out to GDP growth over a longer period of time (OECD 2010, 122). According to the World Energy Outlook (2002), yearly global economic growth between 2000 and 2030 is expected to be approximately 3 percent, with a 2 percent increase in OECD countries and 4.1 percent in developing countries (WBCSD 2004, 29).

With increasing globalization, businesses now have access to global markets. Following the general growth of the economy, freight transport activities have been steadily increasing worldwide over past decades. The World Business Council for Sustainable Development (WBCSD) expanded on the IEA World Energy Outlook (WEO) projections to produce the report Sustainable Mobility Project, which analyzes global transport trends and projects until 2050. The report suggests that transport activity, for both passenger and freight transport, will respectively increase by 1.7 and 2.3 percent per year (WBCSD 2004, 31-32).

According to Azar et al. (2003), total transport activity, expressed in trillions of tonne-km (Ttkm) in table 1, could experience a fourfold increase over the period 1990-2100. Over the same period, road and rail transport are projected to grow by 625 and 213 percent respectively.

As for any long-term projections, the above mentioned scenarios extrapolates from current

19 The term projection rather than forecast is use throughout this thesis to remain true to the sense of these words. A projection is a mathematical exercise based on rates of change from present conditions; it does not assume that these rates are exact. A forecast assumes that certain inputs are more likely than other to be correct, which implies a sense of likelihood absent from projections.
trends. These projections might not materialize if drastic changes modify the conditions of energy and food production, or if resource crises impact the level and intensity of trade. Despite the uncertain nature of these projections, they still indicate the general direction in which we are headed until proven wrong.

### 2.1.1 Land Based Freight Transport

Figure 3 shows the expected growth in land-based freight activity until 2050. The three modes presented have growth rates between 2.4 percent and 2.7 percent yearly until 2050. The sharpest increase will occur in the category of medium duty trucks (MDV).

Global land-based freight transport is expected to grow at an average yearly rate of 2.3 percent between 2000 and 2050, leading to a tripling of global tonne-km (tkm) over the same period. Medium duty trucks are expected to experience the highest growth, although heavy duty trucks will still account for approximately half of global tkm by 2050.

<table>
<thead>
<tr>
<th>Year</th>
<th>Change 1990-2100 (%)</th>
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<tbody>
<tr>
<td>1990</td>
<td>6.4</td>
</tr>
<tr>
<td>2010</td>
<td>6.1</td>
</tr>
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<td>2020</td>
<td>2.6</td>
</tr>
<tr>
<td>2030</td>
<td>2.9</td>
</tr>
<tr>
<td>2040</td>
<td>0.07</td>
</tr>
<tr>
<td>Total</td>
<td>44.17</td>
</tr>
</tbody>
</table>

(Source: Azar et al., 2003, 964)
Figure 4 shows global land-based freight activity by regions. North America will remain the region producing the highest tkm travelled, but it will experience slower growth than Asia and Latin America. The general trend is undeniable: land-based freight transport activity will continue to follow the global economy. Although we cannot avoid transport as it is an integral part of economic activity, we can influence how this merchandise is transported, improve technologies and plan freight transport better so as to reduce its externalities.

2.1.2 Global Transport GHG Emissions

In 2002, transport-related CO₂ emissions accounted for approximately 27 percent of CO₂ emissions produced by OECD countries. Within this, road transport accounted for approximately 80 percent of transport emissions (OECD 2002).

A direct consequence of the growth of transport activity is the increase in transport-related GHG emissions. Figure 5 shows projected well-to-wheel CO₂ emissions until 2050. Light Duty Vehicles\(^{20}\) (LDV), freight trucks and air transport will remain the three most important contributors to GHG emissions.

\(^{20}\) Light Duty Vehicles include in this case cars, small trucks, SUVs and pick-up trucks.
emissions. Their energy efficiency per unit of transport will increase by 18, 29 and 29 percent respectively, but will be offset by a respective increase of 123, 241 percent and 400 percent in activity level (WBCSD 2004, 32). This will, according to these projections, more than double global transport-related GHG emissions by 2050. Most of this growth in transport activity is expected to take place in non OECD member countries.

From an energy consumption perspective, transport activity as depicted by the WBCSD report in 2050 is expected to require nearly twice the overall energy consumption of 2000, from approximately 75 exajoules to over 150 exajoules.

This increase in energy consumption goes against the rationale expressed the introduction of this thesis, namely the need of reducing energy consumption and GHG emissions to address climate and energy crises.

Despite expected fuel efficiency gains, Azar et al. (2003) project a tripling in energy demand by 2100 for road transport, which is slightly more than the increase of 283 percent for all modes of transport (see Table 2).

As demonstrated in this section, transport activity is expected to keep increasing for the next century. This will in turn increase GHG emissions, making it harder for countries to reduce their GHG emissions. Trucks are

![Figure 5: Transport-related well-to-wheels CO2 emissions, 2000-2050](Reproduced from WBCSD 2004, p. 32, by permission)

<table>
<thead>
<tr>
<th>Yearly energy demand (EJ)</th>
<th>1990</th>
<th>2100</th>
<th>Change 1990-2100 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td>23</td>
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<td>313.04</td>
</tr>
<tr>
<td>Rail</td>
<td>3.1</td>
<td>4.3</td>
<td>138.71</td>
</tr>
<tr>
<td>Domestic Water</td>
<td>1.2</td>
<td>1.6</td>
<td>133.33</td>
</tr>
<tr>
<td>Ocean</td>
<td>5.8</td>
<td>16</td>
<td>275.86</td>
</tr>
<tr>
<td>Air</td>
<td>0.32</td>
<td>0.62</td>
<td>193.75</td>
</tr>
<tr>
<td>Total</td>
<td>33.42</td>
<td>94.52</td>
<td>282.82</td>
</tr>
</tbody>
</table>

(Source: Azar et al. 2003)
responsible for the great majority of freight transport emissions because the majority of freight is currently transported by roads. As shown in the following section, trucks have the highest GHG emissions ratio per tkm amongst all modes of freight transport.

**2.2 Trucking Emissions**

Zhang *et al.* (2004, 334) cite nine sources of air pollution estimates for freight trucks, including (Befahy 1993; ECMT 1998; OECD 1991; Schoemaker and Bouman 1991; Whitelegg 1993). According to these studies, trucks produce between 100 and 451 gm of CO₂ per tkm. Trucks in tractor and trailer configuration, also known as semi-trailer, semi or semi trucks; they usually have lower emissions per tkm than straight trucks as they carry more goods and travel longer distances, two factors that lower fuel consumption per tkm. Given in grams per tkm, the air pollutant emission factors for trucks, reported in Zhang (2004), are: C0 (0.25-2.24), HC (0.32-1.57), S0₂ (0.03-0.43) and PM₁₀ (0.04 to 0.39).

The European Environmental Agency (EEA 2011) mentions that recent European regulations will reduce carbon intensity of transport modes in the future. Passengers vehicles CO₂ emission targets are 130g/km for 2015 and 95g/km for 2020. From 1995 to 2009, EEA data shows that passenger vehicles reduced their CO₂ emissions factor from an average of 125.5 to 113.25 g/pkm, air transport from 166 to 117 g/pkm, maritime transport from 42.9 to 41.2 g/pkm and rail from 61.8 to 44.8 g/pkm. Over the same period, trucks have reduced their CO₂ emissions from 125.5 to 108 g/tkm.

The EEA data differentiates between HDV and LDV CO₂ emissions. In 2009, HDV emitted in average 104.1 grams of CO₂ per tkm, whereas the LDV emitted in average 257.7 g/tkm. In comparison, most recent data estimates that freight transport by rail emits in average 21.4 grams of CO₂ per tkm, inland marine transport 31.4 g/tkm and international maritime transport 13.9 g/tkm.

In urban setting, the CITM (2000) mentions CO₂-eq.²¹ emissions of 254 grams g/pkm for cars, 178 g/pkm for diesel cars, 79 g/pkm for buses and between 200 and 500 g/tkm for trucks. The CITM data shows that in inter-urban setting, trucking emissions are lower in terms of tkm, yet trucks produce six times more CO₂-eq. emissions (114 g/tkm) than train (20 g/tkm) and thirteen times more than boats (9 g/tkm).

From these estimates, we can assume that in Canada, long-distance (inter-city) trucks have CO₂

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²¹ CO₂-eq. Refers to carbon dioxide equivalent, allowing comparisons of other air pollutant global warming potential equivalent in CO₂.
emissions close to 100 gm per tkm, and that short- and mid-distance trucks (local and regional) have CO₂ emissions between 200 and 300 g/tkm.

A report by the RAC Foundation foresees the future evolution of freight transport as mainly technological, where trucks would benefit from technological breakthroughs and become electrical and fuel-cell vehicles. Because they would reject no tail-pipe GHG emission, the report sees their environmental disadvantage against trains greatly reduced (RAC Foundation 2002a). The report is pessimistic regarding the effect of public transit on the amount of cars or trucks on the road, and is sceptical of effort made to increase transit modal share. It clearly situates itself on the side of technology-optimist, even stating that “the environmental case for shifting traffic from road to rail will largely disappear with the next generation of clean road vehicles” (RAC Foundation 2002b). Although this vision seems correct regarding decreasing air pollution, it does not consider the effect of more vehicle on congestion, nor does it consider larger environmental considerations expressed in Chapter 1.

2.2.1 Europe and the UK

2.2.1.1 Europe

In Europe, freight transport is expected to follow economic growth, although the elasticity of freight intensity to GDP varies according to the types goods carried and the relative strength of the various sector contributing to GDP (European Commission 2009).

In 2008, total goods transport activities in Europe (EU27) was

Figure 6: EU freight transport in billion km, 1995-2008

(Source: CEC 2010, table 3.2.1, adapted by permission)
estimated at 4,091 billion tkm\(^{22}\), \textbf{45.9} percent of which was carried by road, 10.8 percent by air, 3.6 percent by inland waterway and 36.6 percent by intra-EU maritime transport. Road transport carried 72.5 percent of land-based freight transport (European Commission 2010, 3.1.1).

European freight transport activity, divided by transport modes, is presented in figure 6. Road transport, followed by water-based transport, have been the two modes with the fastest activity growth. Over the same period, road transport has increased by 45.7 percent, and total tkm (all modes) increased by 33.7 percent. Rail transport, despite better environmental performances than the trucking industry, has experienced a 14.7 percent increase from 1995 to 2008.

The relationship between transport and GDP is complex and influenced by a myriad of factors creating variation by countries and over time. Although car pkm has been increasing more rapidly than GDP for most industrialized countries, the picture of freight transport is not as clear (Banister 2005, 47). European data show that between 1995 and 2008, passenger transport has experienced a annual growth of 1.6 percent per year, whereas both GDP and freight transport have grown by 2.3 percent per year (European Commission 2010a, 3.1.2).

Between 1995 and 2008, the number of duty vehicle in the EU27 grew by almost 50 percent, or 3.7 percent per year. In 2008, there were 33.9 million commercial freight vehicles compared with 231.9 million passenger vehicles (European Commission 2010a, 3.3.11)

2.2.1.2 UK

In the UK, 81 percent of freight tonnage is carried by trucks. The quantity of material transported by freight transport has been relatively constant over the last three decades, but distances over which these merchandise are transported continue to increase. In fact, over the last three decades, the average trip distance has doubled to reaching almost 100km/trip (Office for National Statistics 2003).

Light duty vehicles (LDV) been growing faster than GDP from 1987 to 1994. It is assumed that Heavy Goods Vehicle (HGV) traffic will grow at the same rate as car traffic, but slower than LDV (RAC Foundation 2002a, 27).

Mansell (2001) reports that 28 percent of distances travelled by trucks in the UK are empty runs. To address this situation and optimize goods transport, Online Freight Exchanges have been put in place to to connect available loads with available trucking space. The long run economic viability of these systems still has to be proven (Banister 2005).

\footnote{22 Data includes intra-EU air and sea transport but not transport activities between the EU and the rest of the world.}
2.2.2 Canada and BC

2.2.2.1 Diesel Fuel Sales

In the absence of precise data, it is possible to use diesel fuel consumption instead of GDP as a proxy for freight transport activity. Diesel fuel is mostly used by trucks and buses, and to a lesser degree by heavy-equipment used in construction or resources extraction.

As shown in Figure 7, diesel fuel consumption for BC resembles that of Canada, with a slightly more

Figure 7: Net diesel oil fuel sale in Canada and BC, 2000-2008

(Source: Statistics Canada 2009a, adapted by permission)

Figure 8: British Columbia transport GHG emissions (Mt CO2-eq.)

(Source: Office of Energy Efficiency 2010, BC, table 4, adapted by permission)
pronounced dip in 2001 and height in 2008. Over that period, the average yearly growth in net diesel fuel sales in Canada and British Columbia was 3.0 percent and 3.1 percent respectively (Statistics Canada 2009a), which correlates with GDP and transport activity growth level. Total diesel sales in 2008 reached 16.3 and 1.7 billion litres in Canada and British-Columbia respectively.

Assuming that a 3 percent yearly growth is maintained until 2050, net diesel fuel sales would reach a staggering 56.6 billion litres for Canada and 5.9 billion litres for BC, which is about three and half time the amount sold in 2000\(^{23}\).

2.2.3 BC Carbon Emission

Figure 8 (p. 30) graphs the evolution of BC transportation-related GHG emissions expressed in CO\(_2\)-eq. It shows the increasing share of freight transport since 1990 as part of BC total transportation carbon emissions, from 42 percent in 1990 to 48 percent in 2008. In other words, freight transport increased faster than passenger transport, and its share of GHG emission has increased proportionally. Diesel fuel represented 32.1 percent of total transport-related GHG emission in 2008, a 3.1 percent increase since 1990 (Office of Energy Efficiency 2010).

Measured by the amount of carbon contained in the energy mix (GHG tons/TJ), freight transport carbon intensity decreased by 0.8 percent between 1990 and 2008, whereas passenger transport carbon intensity has decreased by 1.64 percent. This means passenger transport improved energy efficiency approximately twice as much as freight transport. As of 2008, freight transport carbon intensity was 71.5 GHG tonnes/TJ, and passenger transport carbon intensity was 68.1 GHG tons/TJ (Office of Energy Efficiency 2010). This result is in part due to increased engine efficiency, and increase diesel share in freight transport, which is more polluting than gasoline (EPA 2011a)\(^{24}\). Despite this slight energy efficiency increase, figure 9 indicates that total energy consumed by the freight transport has been steadily increasing since 1990.

As shown by figure 9, the most common energy source used to carry goods in British-Columbia is diesel fuel, followed by gasoline and heavy fuel oil. This is not a surprise, as we know that goods movement is mostly done by diesel trucks. In 2008, total energy consumption in BC for freight transport was 175.8 PJ, 63 percent of which was provided by diesel fuel and 15.5 percent by conventional gasoline. The share of diesel has increased by a slight 1.3 percent, whereas gasoline contribution to BC freight transport energy consumption has decreased by 1.8 percent between 1990

\(^{23}\) Precisely 3.47 times.
\(^{24}\) One litre of gasoline contains 2.3 kg of CO\(_2\), versus 2.7 kg for a litre of diesel

Calculated in joules for the period 1990-2008, yearly diesel fuel consumption used for freight movement has increased at about 3.52 percent, slightly faster than gasoline consumption that grew at 2.41 percent yearly (see fig. 9) (Office of Energy Efficiency 2010, table 3).

![Figure 9: BC Freight transport energy consumption by energy sources, 1990-2008](image)

2.2.3.1 BC Road Transport Emissions

Figure 10 shows the evolution of the respective contribution of each road transport mode to BC provincial GHG emissions. A few comments are worth noting. First, the light passenger vehicles' share declined against the growing share of freight transport and particularly heavy trucks. Second, the passenger light trucks (SUVs, Pick-up truck) increased in importance compared with conventional car.
In other words, people are buying bigger cars that have higher fuel consumption. This does not mean that there are less car in BC, to the contrary, the vehicle fleet has been growing at an average rate of about 2 percent yearly.

### 2.2.3.2 Canada and BC Vehicle Fleet

The *Canadian Vehicle Survey* (Natural Resources Canada 2009) provides a snapshot of the vehicle fleet in Canada and in its provinces. It estimates VKT and fuel consumption, and provides information on drivers behavioural characteristics, the age of the fleet and numbers of vehicles. The survey is helpful in estimating the carbon emission reduction potential of Trums, as their market niche is essentially urban delivery, which is currently being done by light, medium, and to some extent heavy duty vehicles.

Canada reached 20 million licensed vehicles in 2007; at the end of 2009 there were 20.9 million vehicles licensed in Canada. Between January 2000 and December 2009, total number of vehicle in Canada grew by 21.5 percent, or at an annual growth of 2.15 percent. Over the same period of time, trends are similar in British-Columbia, where the annualized growth of vehicle fleet is 2.05 percent,
which amounts to 2,726,593 vehicles (Office of Energy Efficiency 2010).

The report divides the Canadian vehicle fleet in three categories: light vehicles, medium duty vehicles (MDV) and heavy duty vehicles (HDV). Light vehicles weigh under 4.5 tonnes and comprise both passenger and goods transport vehicles, MDV are trucks that weigh between 4.5 and 15 tonnes, and HDV are trucks that weigh over 15 tonnes. Light vehicles represent more than 96% of Canada's vehicle fleet and 94 percent of BC vehicle fleet.

Medium Duty Vehicle (MDV), which are usually straight trucks (see fig. 11) and weigh between 4.5 and 14.9 tons, amount to 2.5 percent of the Canadian vehicle fleet and almost twice that ratio (4.9 percent) for British Columbia, which equals 514,055 and 133,371 vehicles respectively.

Heavy duty vehicles (HDV), usually semi-trailers (see fig. 12), amount to 1.58 percent of all Canadian vehicles and only 0.66 percent of British-Columbia vehicles, or 329,994 and 17,927 vehicles. (Statistics Canada 2010).

MDV can be straight trucks or a semi-trailers, but the latter is less common in MDV (only 4.5 percent) than in HDV (Natural Resources Canada 2009, 23). In the MDV category, 75 percent of total vkt was done by straight trucks.

HDV use a wider spectrum of configurations. In the HDV category, semi-trailer with one trailer produced 65 percent of vkt travelled, semi-trailers with two trailers produced 8 percent of vkt, and straight trucks produced 16 percent of vkt. Having two trailers instead of one increase by only 1L/100km diesel consumption and nearly doubles the carrying capacity (ibid., 27), which makes each trip efficient at many levels. Provincial regulations control the use of such trucks and can limit access to road based on vehicle weight and time of the year. HDV are known to impose higher stress on transport infrastructure and increase repair costs.
The most noticeable trend in Canada and BC vehicle fleets is the rapid increase in the numbers of MDV in British-Columbia which grew by 120 percent between 2000 and 2009, and by 39 percent in Canada (Statistics Canada 2010). Over the same period, the share of MDV grew by 2.3 percent in BC and only 0.31 percent in Canada. Heavy trucks share grew by 0.12 percent in Canada and 0.05 percent in BC.

It is hard to identify what causes these differences, however it is clear that British-Columbia trucking industry uses less heavy trucks than does the rest of Canada, and has seen a more important growth in MDV. Light vehicles, which are under 4.5 tons and includes cars and light trucks, have the same share of total vehicles in Canada between 2000 and 2010, but have decreased in British-Columbia by 1.98 percent.

Another significant change since 2005 is that straight trucks vkt increased by 19 percent, whereas tractor with one trailer has decreased by 17 percent. This suggest that shorter distance are being travelled and that straight-trucks are favoured over heavy trucks for their fuel economy (Natural Resources Canada 2009, 10).

### 2.2.3.3 Fuel Consumption

In 2007, vehicles in Canada consumed 31 billion litres of gasoline and 11 billion litres of diesel; 75.3 percent of diesel fuel consumed by the transport industry was consumed by heavy trucks, 14 percent by medium trucks and 11.7 percent by light vehicles, including cars (Natural Resources Canada 2009, 9).

The average fuel consumption for light vehicles was 10.8 L/100km and 21.7 L/100km for MDV. Diesel consumption rates were 23.5 L/100km for MDV and 34.5 L/100km for HDV. In comparison with 2005 consumption rate, the greatest increase in fuel consumption, 10.6 percent, was found amongst trucks of more than 14 years of age (ibid., 2).

However fuel efficiency for heavy trucks has increased by 21 percent since 2000, from 43.5L/100km to 34.5L/100km; over the same period of time, diesel consumption for MDV decreased by 7.5 percent (ibid., 10).

### 2.3 Canadian Trucking Industry

This section examines aspects of the Canadian trucking industry that help to better understand this market. Estimations provided in this section serve as reference against which it is possible to
evaluate the *Trum* economical feasibility and its competitiveness. Most of the information presented here come from Statistics Canada and the report *Operating Costs of Trucking and Surface Intermodal Transportation in Canada*, an annual report sponsored by Transport Canada and prepared by *Logistics Solution Builders Inc.* (2008).

### 2.3.1 Local versus Long-Distance Shipping

Local shipping (trips under 25km), represents a small percentage of all domestic transport. Between 2004 and 2008, local shipping accounted only 0.62 percent of all yearly tonnage carried in Canada, but represented 13.52 percent of total goods value transported yearly. This is explained by the highest value of the cargo carried by local carriers versus long distance trucking. Local carriers often transport manufactured goods, food, alcohol and tobacco, which have high value to weight ratio compared with non-manufactured goods, more often carried by long-distance carrier (Natural Resources Canada 2009, table 403-0004).

### 2.3.2 Types of Businesses in Freight Transport

The trucking industry in Canada can be seen as composed of two types of firms. The “for-hire” firms include companies that haul merchandises owned by others, for financial compensation. The “private sector” is mostly comprises companies hauling their own merchandises, known as owner-operators, and occasionally those of others.

The size of both types of fleet is approximately the same in dollar figures, but they display interesting differences depending on the type of services provided. Private sector is comprised of a large number of small firms that account for 85 percent of all trucking in and around urban areas. The majority of the fleets are made up of only one or two vehicles, mostly straight-trucks. As haul distances increase, so do the share of for-hire firms. They represent nearly 50 percent of the activity for 200 km hauls and 90 percent for 2000 km hauls. As it can be expected, longer hauls are made with larger trucks able to carry more goods.

Smaller fleets tend to pay less in driver’ wages and administrative costs (- 30 percent) than larger firms. Larger firms tend to enjoy advantages that come with the volume purchase of vehicles and consumables such as fuel, tires and oil (Logistics Solution Builders Inc., 2008, p. 36) they often pay up to 10 percent less than smaller firms. Both small and large firms have certain economic advantages, and it is common to see both types operating on the same market place, with similar rates.
2.3.3 Truck Types

Table 3 contains information on two types of HDV, a five-axle semi truck and a two-axle straight truck. Although both vehicles would fall in the HDV category of the Canadian Vehicle Survey, their size, carrying load and fuel consumption confirm their difference. Semi trucks carry merchandise over the larger distances, whereas straight trucks are mostly used for local or regional delivery.

<table>
<thead>
<tr>
<th>Table 3: Typical trucks specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Conventional configuration</strong></td>
</tr>
<tr>
<td>Retail Purchase Price in BC (CA$ 2007)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Engine Power (HP)</td>
</tr>
<tr>
<td>Trailer Tare Weight (tonnes)</td>
</tr>
<tr>
<td>Tractor Tare Weight (tonnes)</td>
</tr>
<tr>
<td>GVW (tonnes)</td>
</tr>
<tr>
<td>Pay Load Capacity (tonnes)</td>
</tr>
<tr>
<td>Vehicle Width (m)</td>
</tr>
<tr>
<td>Vehicle Length (m)</td>
</tr>
<tr>
<td>Vehicle Height (m)</td>
</tr>
<tr>
<td>Trailer Length (m)</td>
</tr>
<tr>
<td>Trailer Capacity (m³)</td>
</tr>
<tr>
<td>Load Density (kg/m³)</td>
</tr>
<tr>
<td>Front Axle Max Load (kg)</td>
</tr>
<tr>
<td>Rear Single Axle Max Load (kg)</td>
</tr>
<tr>
<td>Loading capacity (kg/man-hour)</td>
</tr>
</tbody>
</table>


Images of these typical trucks are shown in figures 11 and 12 (p.30). The five-axle truck shown is very representative of the HDV fleet, which has an average diesel consumption of 34.5L/100km. The two-axle truck is closer to a MDV despite its 16 tonnes, which average diesel consumption is about 23.5 L/100km (Natural Resources Canada 2009, 10). Fully loaded, we can estimate that two-axle trucks use 0.033 litre of diesel per tkm, and the semi-trailers use 0.013 litre of diesel per tkm. Knowing that a
litre of diesel contains 2.7 kg of CO₂, we can estimate that a straight truck and the a semi truck would produce, in optimal conditions, 89 and 35 grams of CO₂ per tkm respectively. Higher CO₂ emissions per tkm reported earlier in this thesis (p.27) indicates that reality provides conditions far from optimal. In reality, trucks fleet are composed of vehicles of varying ages, with older vehicles consuming more fuel. In addition, trucks are not always loaded to full capacity, they make empty runs and travel distances that provide no direct revenue (maintenance, driver's home).

2.3.3.1 Purposes of Trips

Purposes of trips vary in proportion amongst medium and heavy trucks. In 2007, empty runs amounted to 6.2 percent of total medium trucks vkt and 13.9 percent of heavy trucks; service calls and the actual transport of goods amounted to 65.6 percent and 79.8 percent of medium and heavy trucks trips respectively (Natural Resources Canada 2009, 29).

2.3.3.2 Loading/Offloading Capacity

Realistically, loading and unloading performances depend on the type of freight being delivered, the facilities and the availability of manpower. In Canada, observations indicate that 4,000kg per man-hour is representative of dry freight load carried in by semi trucks, which can translate into ratio of three hours per 27 tons load for a driver, assuming adequate availability of manpower. For delivery in straight trucks, loading and offloading capacity is assumed to be 1,600 kg of consignment per man-hour (Logistics Solution Builders Inc. 2008, 15).

2.3.3.3 Daily and Yearly VKT

Distances travelled by trucks vary depending on a variety of factors. The report *Operating Costs of Trucking and Surface Intermodal Transportation in Canada* uses values of 320 km for combination units' round trips, and 100 km for two-axle trucks' round trip, which reflects common practices of the industry (Logistics Solution Builders Inc. 2008, 16). BC Trucking Association considers that most of regional delivery trucks operate within 150 km of their home base.25

The yearly vkt varies greatly according to the market place in which they operate. Long distance haulers, where semi-trailers are sometimes used two shifts per day, seven days a week, have utilization rate of 250,000 km per year in average. Typically, single driver, intercity van fleet utilization rate vary

between 95,000 and 180,000 vkt yearly. Trucks doing local and regional delivery have utilization rates in the range of 40,000 to 120,000 km yearly. There is no difference between for-hire or private firms on these matters (Logistics Solution Builders Inc. 2008, 16).

As the focus of this thesis is urban goods delivery, it would be misleading to use operating costs of long distance hauling trucks for evaluating local and regional transport costs. In order to do so, we focus on two axles straight trucks operating costs, which are usually used for local and regional delivery. Over the course of a year, urban two axle trucks vkt range from 40,000 km to 120,000, representing the low and high range of utilization level assumed in the Logistics Builder Inc. report, with 80,000 km as median case (Logistics Solution Builders Inc. 2008, 16).

2.3.4 Times of Operation

The Canadian Vehicle Survey (Natural Resources Canada 2009, table 405-0040) identifies the level of goods delivery activity at different times of the day. In average, between March 2007 and December 2009, 2.7 percent of VKT for LDV (under 4.5 tons) were travelled between 00h00 and 05h59, 32.5 percent between 06h00 and 11h59, 45.7 percent between 12h00 and 17h59, and 18.8 percent between 18h00 and 23h59.

Averaged over three years\textsuperscript{26}, MDV (4.5-14.9 tons) travelled only 14.2 percent of vkt during weekends and holidays; the proportion increases for HDV, which travelled 16.45 percent of vkt during weekends and holidays.

In 2009, data indicated that medium duty vehicles have travelled approximately 86 percent of total weekdays VKT between 6h00 and 17h59. Over the same period, HGV (over 15 tons) show a slightly different pattern. A lesser proportion of all weekdays total VKT is travelled between 6h00 and 17h59 (75 percent), and a much higher proportion is travelled between 18h00 and 23h59. This is possibly explained by the longer route done by HGV for each trip compared with medium duty truck. It makes more sense to travel during hours where traffic is sparser if possible, whereas urban delivery is more time constrained and is harder to do outside business hours.

In general, data confirms that the majority of the transport activity happens during weekdays business hour.

\textsuperscript{26} Averaged produced with data from December 2006 to December 2009.
2.3.5 Operating Costs

As trucking costs are highly dependent on fuel prices, they tend to increase faster than the consumer price index (CPI), which reflects the rate of inflation through a typical basket of goods consumed by Canadians. Between 2005 and 2007, trucking operating costs rose by 7.6 percent (3.7 percent compounded annually) versus a 4.2 percent increase of the CPI. Another factor explaining this rapid increase points towards drivers' salary adjustment in the western provinces, reflecting the shortage of drivers in the industry (Logistics Solution Builders Inc. 2008, 31).

In 2007, BC truck drivers' wages ranged from $22 to $29 per hour depending on the truck size (ibid., 20). Other fees that must be paid by trucking companies include licensing fees for trailers and power units. In 2007, these were equivalent to $2,229 per power unit (tractor), $30 per trailer and $607 for two axles straight trucks.

Interest paid on working capital cost and administration amount to approximately 12.5 percent of revenue for Canadian trucking businesses, as vehicles are often financed up to 75 percent (ibid., 27-28). Insurance rates accounts for approximately 3 -3.5 percent of total revenues. The depreciation rate used by the Logistics Solutions report 1 percent a month for typical 40' trailer, with an expected life of 8 years; the depreciation rate for a tractor is 79.2 percent over a tractor's life of five years.27

Table 4 contains the results of the Owner-Operator Survey28 from which a owner-operator cost

<table>
<thead>
<tr>
<th>Table 4: Owner-operator cost survey</th>
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</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Driver Costs</td>
</tr>
<tr>
<td>Road Expenses</td>
</tr>
<tr>
<td>Fuel Costs</td>
</tr>
<tr>
<td>Maintenance &amp; Repair Costs</td>
</tr>
<tr>
<td>Tire Costs</td>
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<tr>
<td>Licence Costs</td>
</tr>
<tr>
<td>Insurance Costs</td>
</tr>
<tr>
<td>Depreciation</td>
</tr>
<tr>
<td>Interest</td>
</tr>
<tr>
<td>Total Tractor (on road)</td>
</tr>
<tr>
<td>Communications</td>
</tr>
<tr>
<td>Business Overhead</td>
</tr>
<tr>
<td>Worked Hours</td>
</tr>
<tr>
<td>Total Costs</td>
</tr>
</tbody>
</table>

(Source: Logistics Solution Builders Ind. 2008, 40, adapted by permission)

27 These estimations were obtained by the authors from truck dealers quotations.
28 The Owner Operator was conducted in 2007 with assistance of the Owner Operators Business Association of Canada (OBAC). 300 questionnaires were mailed to members, from which 54 useable responses were received.
model was built. The average GVW of vehicles owned by the respondents was 41.5 tonnes. Fuel costs represented in average 34 percent of the operating cost, drivers cost 22 percent, depreciation 11 percent, and maintenance and repair 10 percent.

Operating costs of maintaining a tractor on the road for one hour, including driver costs but excluding communication and business overhead costs, is $49.64. Owner-operator transporters usually pay a lower salary to drivers than do for-hire businesses, which would explain the difference between the $11.71 per hour wage reported in the survey and the higher representative wages for Canada, which range from $15 per hour in maritime provinces to $30 per hour in the Northwest Territories (Logistics Solution Builders Inc. 2008, 19). The owner-operator model results in a cost of $0.91/km, whereas the comparisons of different truck types over time shows cost about $1.60/km for similar five-axle semi truck (ibid., 30).

Also, because MDV travel much shorter distance, operating costs for a two-axle straight truck in BC presented in table 5 are significantly higher than those reported for semi trucks. The average cost estimation is $CA 3.54/km.

<table>
<thead>
<tr>
<th>Table 5: Two-axle straight truck operating costs in BC, 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly Utilization Rates</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>40,000 km</td>
</tr>
<tr>
<td>80,000 km</td>
</tr>
<tr>
<td>120,000 km</td>
</tr>
<tr>
<td>Average</td>
</tr>
</tbody>
</table>

(Source: Logistic Solutions Builders Inc. 2008, 65, adapted by permission)

As noted by the report, because of the diversity of the industry and the sparseness of data, it is almost impossible to produce satisfying statistical results. Cost estimates presented here have no statistical value, but they are the product of “the application of an activity based unit cost model using information from experts opinion [...] consultations with the industry, suppliers to the industry, etc.”

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29 Results of the report's analysis include a conservative assumption of ± 5 percent accuracy in their operating costs operations.
2.3.5.1 Profit Margins and Revenue

Although it was common in previous decades to see average operating profit margins around 10 percent, current profit margins for trucking companies are closer to the range of 2.5 to 5 percent. Interestingly enough, companies that provide specialized service such as time-sensitive and express services, still retain the highest operating profit margins (ibid., 28). In regards to the Trum system, this observation is interesting as it points out the added-value of providing faster transport services. The same report recommends using 5 percent profit margin as a good indicator if exact margins are unknown. The Canadian trucking industry's stable operating ratio reflects a relative economic stability in the freight transport sector. This does not imply a stagnation in freight operation, where revenue have been increasing for the past decade (see fig. 13, p 42).

Amongst the three group of carriers, large operators are the ones that have most increased their revenue since 2000. They have increased their market share at the expense of medium and small operators. (ibid., 31).

![Figure 13: Operating revenues for transport carriers in Canada, 2000-2008](image-url)

(Source: Statistics Canada 2009b, adapted by permission)
carriers and have produced the largest part of the industry total revenue increase (see fig. 13). Total operating revenue for freight transport carriers in Canada have reached $8.7 billion in 2008. From this sum, close to $6.7 billion went to larger carriers, $800 million to medium carriers and $1.2 billion to small carriers. This shows that large companies dominate the freight transport market in Canada, a fact that is considered when demonstrating the organizational options of a future Trum system.

2.3.6 Freight Transport Figures in Vancouver

Gateway Council, at the 1998 BC Business summit, mentioned important key figures on the employment created by transport activities in Vancouver and the region. The document mentions that the transportation industry (focused on international trade and tourism) generates 28,000 person years of employment annually. If indirect employment is considered, 65,000 are dependent of Gateway transport activity in the region, or one of every twelve job in the region.

Considering the important role played by freight transport in the region's economy, radical change like the introduction of a Trum system must be carefully presented and underscored as a positive development for the region rather than a threat to trucker's jobs.

The TransLink 1999 Lower Mainland Study Truck Freight Study, as summarized by Dale Bracewell of the city of Vancouver (Bracewell 2000) shows a snapshot of trucking activities in a typical day of November 1999 and provided baseline data to forecast truck operation in the region. The study mentions that:

- There were 187,000 trucks trips made on a typical day, 91 percent of which are internal to the region, 5 percent are external and 4 percent for special trip generators.
- In general, trips from special generators and from outside the region are done by heavy trucks (more than two axles)
- Close to 10 percent of the trips of all heavy truck trips generated from Vancouver originated from one of the two Port freight terminal, Centerm and Vanterm.
- Only 7 percent of all external trips had destination within the city of Vancouver.
- Vancouver generated 25 percent of total truck trips (46,000 trips), and 30 percent of all light truck trips in the Lower Mainland.
- Heavy trucks were predominantly generated South of the Fraser River, while Vancouver generated 16 percent of all heavy trucks trips, mostly from the Port.
- Light trucks averaged 10 trips per day, with an average trip length of 9km.
• Heavy trucks averaged 8 trips per day, with an average of 16km
• Approximately 70 percent of deliveries were made during regular business hours (9am-4pm)
• From 1996 to 1999
  ◦ Regional traffic count has been increasing at twice the rate of population and employment since 1996.
  ◦ The North Arm of the Fraser River and Burrard Inlet have seen 24h traffic increase of 8 percent and 3 percent respectively
  ◦ Vancouver CBD traffic count has increased by 3 percent.
  ◦ Overall, the regional traffic count indicates a 8 percent increase over 24h.

Compared with the previous study of 1988, two tendencies can be seen. First, trucks reduced the distance travelled during each trip; light trucks average trip distance decreased from 12.1 km to 8.5km (-30 percent), and heavy trucks average trip distance decreased from 18.5 km to 15.8 km (-15 percent). Second, both light and heavy trucks increase the number of trips by 19 percent and 20 percent respectively. The major truck corridors in Vancouver include Knight Street, Southeast Marine Drive, Grandview Highway, and Boundary Road.

There have been other studies on goods movement in the region which mostly focus on long-distance and international transport. The most recent study of that nature is Greater Vancouver Goods Movement Study, funded by Transport Canada, BC Ministry of Transportation and the Greater Vancouver Gateway Council and on which TransLink, BC Trucking Association, Metro Vancouver, Vancouver Airport and the Port of Vancouver collaborated.

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30 BC Transportation Freight Study, Transport Canada (1996); 1999 Lower Mainland Truck Freight Study, Greater Vancouver Transport Authority (2000), Freight Transportation in BC (Transport Canada, 2002), Economic Impact Analysis of the Major Commercial Transportation System (Greater Vancouver Gateway Council, 2003), Lower Mainland Rail Infrastructure Study (GVGC, 2004); BC Ports Strategy (BC Ministry of Transportation)
Chapter 3 – Unconventional LRT Uses

This chapter presents three cities that have used, or still use, tramway vehicles to transport goods rather than passengers, as tramways usually do. These cities are Dresden, in Germany, Zurich, in Switzerland and capital of the Netherlands, Amsterdam. Each case presented in this chapter has developed an original system in which tramways are used to transport goods. These cases illustrate the possibilities and challenges related to the integration of goods transport with LRT infrastructure. This chapter concludes by drawing lessons from these examples.

3.1 Dresden

The city of Dresden is the capital of the Free State of Saxony in Germany. It is located in the former socialist German Democratic Republic, close to the Czech border. As of April 30, 2011, the official population count for the city was 524,208 inhabitants (Statistik Sachsen 2011). Its population density is 1,574 persons/km². In Dresden, Volkswagen developed the first modern example of tramways used to transport goods. This vehicle (see fig. 14), the CarGoTram, transports car parts from a “logistics centre” located in the western part of the city (Dresden-Friedrichstadt) to the assembly

Figure 14: Dresden's CarGoTram in operation

(Reproduced from VW 2011, by permission)
plant, the Transparent Factory\textsuperscript{31}, located in the eastern part of the city, as shown in figure 15.

The CarGoTram began operation in 2001, but the interest of Dresden's public transport agency, the DVB AG, in reintroducing goods movement on tramways began in 1994. In 1998, Volkswagen announced the construction a new car factory in Dresden. The choice of the location for the new factory, Straßburger Platz, received strong opposition from citizens.

The process resulted in an improved project, in which the idea of the CarGoTram was developed as part of the “green” branding of the factory. Indeed, this factory does not look like any other car factory in the world. Its high-tech assembly line, the CarGoTram and multiple cutting-edge environmental features of the building make Volkswagen Transparent Factory an attraction for tourist and visitors.

It took only three years to go through phases of conception, test runs, and on-street operations. This shows that innovative transport practices can happen quickly when the required infrastructure is already in place, and when a shared vision of a common project incites collaboration.

Dresden has an important tramway network, of 132 km, and a bus network covering 148 km (DVB 2007, 8). Pre-existing tramways infrastructure made the realization of the CarGoTram project easier, and provided a good network on which to connect the Volkswagen factory and the multimodal transfer hub.

The two routes taken by the CarGoTram are shown in figure 15. The blue is the regular and the most direct route; the red is the alternate route. The multimodal logistic centre, located about four kilometres west of the assembly plant, is where car parts from trains and trucks are received and trans-loaded onto the CarGoTram. The CarGoTram leave the logistic centre to travel about five kilometres on the cities tramway tracks that are also used by passenger tramways. The CarGoTram usually makes six trips per week day.

A major characteristic of the CarGoTram, which has been underlined by DVB AG and Volkswagen, is that CarGoTram's operation does not affect passenger transport on conventional trams.

\textsuperscript{31} In German, Volkswagen Gläserne Manufaktur
In addition to reducing negative trucking externalities in the city centre, the use of the CarGoTram addresses logistics limitation of the factory. The logistics centre offers more space to unload material from trucks and trains, and provides an area where trucks can wait, which reduces the space needed at the factory where available space for trucks was limited.

In addition to the new logistics concept itself, Volkswagen developed the CarGoTram vehicle. There are currently two blue 60-metre long CarGoTram. Each of them has the capacity of 214 m³ and can carry up to 60 tonnes of materials. Each CarGoTram replaces the equivalent of three HGV. A CarGoTram power unit measures 11.9 metres long and 2.2 metres wide, weighs 21.8 tonnes empty, and can carry a payload of 7.5 tonnes in 26.8 m³, powered by four electric motors of 45 kW each. Container cars have similar dimensions. They weight 17.4 tonnes and have a payload capacity of 15 tonnes with a 53.5 m³ of loading pace. They also have the same motors as the power unit, 4 electric motors of 45 kW each. In total, each CarGoTram is composed of 2 control cars and 3 freight cars, with total electric power of 900 kW and can reach speed of 50 km/h.

This means that at maximum capacity, the train has a ratio of 6 kW/tonne. In comparison with trucks, 40 tons semis are usually equipped with a motor of 380 HP, which represents a ratio of 7 kW per tonne; the ratio for straight trucks is 6.3 kW per tonne (see table 3, page 37).

The CarGoTram could give birth to other similar projects, as the city of Dresden has undertaken discussion with other partners to further implement goods movement on rail in the city. Furthermore, a sister organization of the DVB AG, the VCDB\(^{32}\), exports the expertise built around the CarGoTram around the world, to help other cities develop similar projects (DVB 2011).

### 3.2 Amsterdam

Amsterdam, the capital of the Netherlands, is famous for its canals, bike lanes, coffee shops and unique architecture. As of December 31, 2010, official population counts indicated 780,152 people living in the city, 1 million in the metropolitan area, and 1.5 million in the larger urban region (Centraal Bureau voor de Statistiek 2011). The city covers 165 km² and has a population density of 4,648 persons per km² (Dienst Onderzoek en Statistiek 2011). Its tramway network comprises 16 tramway lines totalling 80 km of tracks (GVB 2011).

In 2007, Amsterdam experimented with a pilot project to demonstrate the feasibility of having tramways transporting goods into the city for urban delivery without disturbing passenger transit.

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\(^{32}\) VCGB stands for VerkehrConsult Dresden-Berlin GmbH, or Dresden-Berlin Transport Consulting
services. This concept was inspired by Dresden's CarGoTram, but was planned with noticeable differences. The main difference is that the full scale project was to be implemented at a regional scale, whereas Dresden CarGoTram was used by a single entity, Volkswagen, and had one pick-up point and one drop-off point. In addition to this difference in scale, Amsterdam's project also called for the construction of a few multimodal logistic centres, and would have required additional electric vehicles to complete the delivery to businesses.

3.2.1 CityCargo

In 2007, the city approved a pilot project in which two “CityCargo” tramways, which had been branded as freight transporters, circulated on the city's tramway network (see figs. 17 and 16). This pilot project was deemed a success as these modified trams operated on public right-of-ways without disturbing passenger transport provided by regular trams. The main objective of the project was to show that it was technically feasible to have passenger and freight tramways sharing the same tracks harmoniously.

This pilot project was the first step in a planned large-scale, regional system in which multimodal transfer hubs located at the edges of the city would allow merchandise to be transferred from other transport modes (mainly trucking) to these freight trams.

The existing regulation on trucking within the city limit provides an appropriate regulatory environment in which these CityCargo trams would be able to compete effectively with the trucking industry. Deliveries to the city centre are limited to specific hours, a system that help manage congestion but that creates cues and delays for truck operators.
Type of trucks allowed for urban delivery is also regulated. Smaller trucks respecting certain emission standards are the only one allowed into the city, which reduces the inconvenience of allowing HDV circulating on urban streets: congestion, air and noise pollution. As an alternative to using these smaller trucks, CityCargo would allow local delivery producing no local air emission and would more efficient than trucking operations, as a larger payload can be carried by CityCargo than by MDV or LDV.

3.3 City Cargo Project's Specifics

3.3.1 Multimodal Transfer Hubs

This first characteristic central to the regional CityCargo scheme is the necessity of multimodal transfer hubs. Although no real commercial delivery took place during the 2007 pilot project, a facility located in the end of a line stretching to the limit of the city was upgraded to show and example what these small warehouses could resemble.

Figure 18 is a picture of this facility, a small terminal used mainly by tramway drivers with adjacent tracks to park vehicles between scheduled runs.
Figures 18 and 20 are close-up pictures of these small warehouses designed to facilitate goods transfers from trucks to CityCargo vehicles. The location of these warehouses at the outskirt of the city and the immediate surrounding environment illustrate how such a system could operate if it were to be implemented at a regional scale. Note that these warehouses have doors on at least both sides and are literally a few feet away from trucks or tram doors, as shown in figure 18.

### 3.3.2 E-Vehicles

Cargo Trams shared tracks with passenger tramways to reach the city centre and stopped at two locations to simulate a real delivery. Then, merchandise is loaded on smaller electric vehicles (e-vehicles), shown in figure 21. As seen in figures 22 to 23, a small electric fork-lift is used to load this e-vehicle.
There are many challenges inherent to such a system, most of which relate to the CityCargo trams' inability to leave tramway tracks to unload their merchandise. This lack of flexibility requires additional tramway sidings throughout the city that allow CityCargo vehicles to be immobilized for a certain period of time while deliveries are done.

It also requires using an e-vehicle, which adds a transfer, takes time and costs money.

### 3.3.3 CityCargo Termination

Unfortunately, the CityCargo pilot project did not evolve into a full scale regional scheme integrating people and goods movement. According to Jupinj Haffmans who was directly involved in this project, a few factors can explain this.

The company operating CityCargo had been granted the right of using public tramway infrastructure for a period of ten years under the form of a concession. Despite this agreement involving the Amsterdam public transit agency (GVB), local governments and CityCargo, there was a moderate support for the project from politicians and from the transit agency.

According to Mr. Haffmans the transit agency perceived the CityCargo project as an annoyance rather than an improvement. The reason for this seems to be the need to share its tracks with a third party, which would complicate their operation compared

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33 Personal communication with Jupinj Haffmans, July 2010.
with maintaining the status quo. Political support was there but possibly not strong enough to carry the project forward. The project required investing millions of dollars to build the multiple multimodal transfer hubs, and laying down tramway sidings to link these hubs, and others to allow CityCargo vehicles to be immobilized without disturbing passenger tramway services.

Furthermore, the global economic downturn in 2008 made access to private capital more difficult. As a result, CityCargo's private partners were not able to provide financial resources that would have sufficed to cover the up-front capital cost. The ten-year concession was too short a time frame to recoup initial investment.

Although this information reflects the point of view of people deeply invested in this project, the reasons explaining the project's termination remind us of the difficulty of implementing a regional project requiring a high level of cooperation between various agencies, public bodies and the private sector.

Nevertheless, the fact is that Amsterdam, a progressive city in terms of sustainable transportation, did seriously consider developing such a scheme despite the numerous economical and political barriers, and technological limitation. This legitimizes further exploration of goods movement integration with tramway infrastructures.

### 3.4 Zurich

The city of Zurich is the largest city of Switzerland. It is characterized by a high population density despite its relatively small size. Its population is just under 400,000 people inhabitants (about 200,000 dwelling units) and is located in a valley delimited by mountains and Zurich Lake, forming a catchment area delimited by the white line on figure 24. The region, home of 1.9 million people, is internationally recognized for its high quality of life, beautiful natural landscape and aesthetically pleasing built environment.
The city is also known for its progressive environmental policies, and was the first to adopt the concept of the “2,000 Watt-Society” developed about ten years ago by the Swiss Federal Institute of Technology (ETH).

The concept, which aims at limiting per capita energy consumption to 2,000 Watts, was adopted by referendum in 2008. This concept is based on the result of dividing the current global energy demand, at every moment, by the number of people living on the planet: the result is approximately 2,000 Watts. The aim is to reduce Zurich energy consumption to the fair share of energy consumption per capita in order to stay within the Earth bearing capacity. According to the ETH experts, this vision is feasible within a time-range of about 50 to 100 years.

### 3.4.1 Waste Management and Cargo Tram

Although one cannot apply such a scheme directly to Vancouver or the current absence of tram infrastructure, general trends in waste logistics are valid for almost every modern city. These include growing or stagnating waste volumes, more recycling by separation of waste, changing legal frameworks, privatization and liberalization of the market, closures of landfills and replacement by less but larger incineration plants, waste management plans in urban areas and new technological development (Ruesch & Neuhold 2005, 15).

In addition to the yearly 100,000 tonnes or urban waste produced by Zurich's citizens, the city has been having issues with illegal waste dumping (see fig. 25). In 1996-1997, up to 3,000 tonnes of waste was illegally disposed of in the city. This problem was partly addressed by the Cargo Tram, used by the city to collect and transport large and bulky waste products (Neuhold 2005).

The Zurich Cargo Tram which originates from the refurbishment of old tramway vehicles that found a new life in carrying bulky wastes products. The Cargo Tram, usually composed of three cars, carried 579 tonnes of bulky waste products in 2005, 120 tonnes of which were metals (Neuhold 2006).

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34 As comparative, per capita energy consumption (every second) is about 12,000 Watts in the US, a barely 500 Watts in rural area of China (City of Zurich, 2011).
The initial cost paid by the public transport company (Verkehrsbetriebe Zürich, VBZ) and the city waste management department (Entsorgung & Recycling Zürich, ERZ) was about €32,000 and was used to refurbish the old trams and adapt special tram cars that can carry a metal container (see fig. 26).

Zurich, as most other European cities, has allocated less space for car use (parking or circulation), and has kept its original tramway network. The Cargo Tram stops at specific tramway stops for four hours per day at each stop, once a month. Between 15h00 and 19h00, people can come and drop off their old television sets, furniture and scrap metal.

The Cargo Tram operations began in April 2003 with originally four collection points, and now operates with ten stops, used by the Cargo Tram and the E-Tram, which collect electronic devices. They accept waste brought by pedestrians (or cyclists) only. Citizens can bring their bulk or electronic waste on transit, but car delivery is not allowed. This interesting feature is possibly a response to capacity limitation of the Cargo Tram vehicles and road capacity constraints. It also favour people that do not own cars, which represents approximately 40 percent of the city's population.

Figure 27 is an image of the Burgwies stop. Having the Cargo Tram stop on the street would disturb regular passenger service, a problem that is addressed by availability of other trams track located beside the main right-of-way. In the case of the Burgwies stop, this space seems to be also the Tram Museum entrance. This type of operation is greatly facilitated if there is sufficient existing tram infrastructure in place.
Figure 27 is representative of places where the street space has been divided giving a greater share to public transport and a lesser one to automobiles, as only one lane in each direction is available. Because of narrow streets, trams sometimes share the lane with motor vehicles and sometimes benefit from a dedicated right-of-way. Tram stops are almost always designed so as tram vehicles do not block other traffic and to facilitate passengers boarding and alighting.

Once collected, the bulky waste is brought to a recycling centre in the westend of the city, where tram siding was built and integrated into a facility to permit efficient loading and offloading of the Cargo Tram. From there, materials are then transported by trucks to recyclers and incinerators.

A compression container (see fig. 28) was purchased as the capacity of regular container was insufficient for the amount of bulky goods brought by citizens. The container is loaded on a platform (see fig. 29) pulled by the Cargo Tram power unit (see fig. 30).

Over one year, it was estimated that the Cargo Tram covered 5020 km and had 960 hours of running time while vehicles were stationary. Because they use electricity provided by overhead catenaries instead of diesel fuel used by conventional garbage trucks, they achieved the equivalent of avoiding the consumption of 37,500 litre of diesel, which represents 4.9 tonnes of CO2, 80kg of NOx, 14kg of CO, 1.4 kg of S02, 2.3 km of PM10 and 4.2 kg of NMVOC35 (Neuhold 2005).

35 NMVOS refers to non-methane volatile organic compounds
In sum, partially using an old rolling stock, the city of Zurich developed a concept that seems to be unique in the world. At minimum costs, the concept addresses at the same time the issue of bulk and electronic waste, illegal dumping and reduces the use of garbage trucks. The use of the Cargo Tram made sense, as the city has about 165 km of tramway network and a low car ownership rate of 385 vehicles per 1,000 inhabitants, which is well below the Swiss average of 500 vehicles per 1,000 inhabitants (ELTIS 2010).

3.5 Lessons

Dresden was the first city to implement goods delivery with tram vehicles. Its fairly simple scheme inspired Amsterdam, who has tried and failed to expand the concept to a regional scheme of goods delivery. Zurich also uses tramway vehicles to carry materials, but instead of bringing goods to shops, these vehicles collect bulk or electronic waste. It completes the loop of goods movement, returning waste material to waste collection and sorting centres.

In all three cases, existing tramway lines was an essential pre-existing condition to the development of the projects. These original schemes optimized the use of existing tramway infrastructure and reduced trucking (delivery or garbage trucks) in their respective city centres.

The first lesson to be drawn from these experiences is that city and transportation planners should, in planning future transit infrastructure, consider the interoperability and compatibility of rail infrastructure with goods movement delivery. Because of its high capital cost, we should aim at optimizing the use of LRT infrastructure in ways that produce revenue, improve the quality of the urban environment and address environmental, social and economics challenges.

Second, these examples show us that it is technically feasible, although challenging, to share tramway tracks between passenger and freight vehicles.

Third, Amsterdam’s case speaks to the challenges of implementing a regional system, rather than a simple system with a one line and constant service as in Dresden. Political support, the right
economic conditions, and a common will to cooperate are essential to the success of such a complex project.

Fourth, despite its technical feasibility, having tramway vehicles transporting goods on tramway right-of-ways requires additional sidings that allow freight to be unloaded. As shown by the case of Amsterdam, an additional transfer to an e-vehicle that carries the merchandise to businesses doors is also necessary, which involves higher costs and reduced economic competitiveness with the trucking industry.

Fifth, it is possible to complete the circular life cycle of consumption by transporting waste matter with tram vehicles, as does Zurich for particular waste products. Collecting waste with tramway vehicles could, just like the Dresden CarGoTram concept, be implemented at a regional scale.

In sum, these examples show that the implementation of a Trum system is technically feasible but very challenging, especially in the North-American context where the trucking industry faces little restraining regulations compared to the European context. The fact that Dresden is the only example of goods delivery speaks to the challenge of implementing a regional system, but gives insights on conditions that make a limited track sharing easier to implement. In Dresden, there was a high demand for goods movement between a single origin and a single destination point from a single (operating) organization.
Chapter 4 – The Trum

This chapter presents the *Trum*, a freight vehicle powered by electricity that can be best pictured as a concept vehicle, hybrid between a truck and a tramway, that is designed to circulate primarily on LRT or trolleybus infrastructures and which battery system provide for a limited off-grid autonomy. The development of the *Trum* concept stems from a will to find an alternative to trucking. It builds on the experience of the three cities presented in Chapter 2, and was refined through careful thinking and numerous discussions with people working in people and freight transport. Its unique characteristics address weaknesses and build on strengths of these three cases, which gives the *Trum* a unique flexibility that makes it suitable for urban freight delivery.

This chapter comprises three sections. The first section presents the vehicle itself, and the required systems that will be needed for a *Trum* system to operate. The second section builds a business case for the *Trum* and presents an economic analysis associated with *Trum* operation. These elements feed into next chapter’s high-level costs-benefits analysis associated with the implementation of a *Trum* system in Vancouver.

4.1 The *Trum* - A Vehicle on Tires

The main point differentiating the *Trum* from CarGoTram and City Cargo vehicles are its rubber tires. Indeed, it is not equipped with steel wheels, but with rubber tires similar to those of trucks. This modification was motivated by the challenges and limitations of Amsterdam's City Cargo system, which uses tramways that cannot leave the right-of-way to stop and unload their merchandise. Zurich's Cargo Tram has the same limitation, but in the latter case it does not seem to be problematic due to the existence of extra tramway sidings, and the particular nature of the Cargo Tram schedule.

As seen in the case of Amsterdam, this lack of flexibility creates two major challenges to the implementation of a regional system: the need for additional tramway sidings, and an additional transfer to e-vehicles to complete deliveries.

In most cities, road space is already well used, and the space needed to park a long tramway vehicle is rather difficult to find, in addition of involving additional capital costs. Furthermore, an additional transfer in the logistics chain increases handling time and costs by imposing additional work on drivers and requiring an additional vehicle. Purchase and maintenance costs of these e-vehicles further increase expenses. This process lowers the economic competitiveness of the supply chain, and
decrease successful integration within the goods delivery market. Having a vehicle equipped with rubber tires instead of traditional steel wheels addresses these issues, allowing the vehicle to enter and leave the right-of-way. This way, Trums can reach their final destination and unload their merchandise at client's doors, without requiring the use of a smaller vehicle nor involving an additional transfer.

### 4.1.1 Low Floor, High Floor

At this point in time, there is no specific design for the Trum. One of the design options is whether Trums should have low or high-floor. Floor height affects docking compatibility and loading/offloading time. A low-floor Trum would have slightly lower carrying capacity and which would be better suited for urban delivery for medium and smaller business, generally not equipped with high loading docks.

To be compatible with current infrastructure based on trucks dimensions and ensure speedy loading and offloading, it is expected that most Trums would have high floors. This would require an integrated lift system to unload merchandise where no high floor loading dock is available.

In a way, the low-floor version of Trums would resemble tramways on tires, which are used in some European cities. It would not need the guidance system seen as seen in figure 31, which shows Nancy's guided tramways.

4.1.2 Overhead Connection with LRT and Trolleybus Catenary

Whether Trums are intended to share the right-of-way an LRT or a trolleybus network will determine the type of pantograph system required to ensure speedy and safe connection/disconnection with overhead catenaries.

One of the challenges of having vehicles leaving and entering transit right-of-way is the connection between these vehicles and the catenary network charged with 700 volts DC. The process of connecting and disconnecting these vehicles to the catenaries must be fast, reliable and easy to operate for drivers.

Until recently, only one type of overhead connection system seemed to meet these requirements: LRT pantographs, as seen in figure 32. Recent development in pantograph technology now allows for automatic connection with catenaries, as seen with Rome’s trolley buses.36 The main difference between the two is that LRT and tramway catenary systems use a single electric wire, whereas trolleybus catenaries are composed of two wires. The electric return provided by the second trolley wires is not required in a system where vehicles' steel wheels make contact with the steel rails.

As seen in Rome, the Trum pantographs would need a mechanism allowing it to be raised or lowered to allow for automatic connection/disconnection. Because the Trum uses tires and not steel wheels, a metallic contact with tramways rails will be needed for the electrical return if it were to operate on LRT and tramways right-of-ways.

4.1.2.1 Battery Kit

Trums would be equipped with batteries providing off-grid autonomy of approximately five to ten kilometres. As demonstrated in Chapter 1, the main advantage of the Trum vs. current electric trucks is their limited need for batteries, which are expensive, polluting and heavy, given the energy used by Trums is mostly drawn from overhead catenaries. This limited autonomy is essential to allow Trums to leave the catenary network and reach their destinations. For a complete Trum system to work,

36 A video on YouTube shows the connection process: http://www.youtube.com/watch?v=pTJYsldZITg
cities must have electric surface transit network with good coverage, providing an electric infrastructure along arterials and commercial streets. This would ensure a geographical coverage that would guarantee that destinations located a maximum of 2-3 kilometres from a tramway line can be reached. This means Trums would only need to cover a short distance on battery power before reconnecting to the catenary network and recharge batteries.

As modern LRT and tramway vehicles, Trums would be equipped with a regenerative breaking system to recover energy produced when breaking. These systems allow to reduce total energy consumption between 10 and 30 percent, depending on operating conditions.

4.1.2.2 Vehicle Frame

The vehicle frame will ideally be made of materials that are recyclable, durable, solid and light. Its lateral walls, instead of having large windows like passenger trams, will accommodate large doors resembling garage doors. These doors would slide up or sideways, as for Dresden CarGoTram vehicles (see fig. 33).

In regards to the articulation and length of the vehicles, various options are possible. The requirement that must be met by the vehicle frame and design pertains to turning radius. They must be short enough to engage in back alleys, where most commercial delivery occurs. This would probably involve rotating wheels and a system of articulation between cars. As a guideline, semi trucks, with total length of 21 metres need a minimum road width of 8.1 metres to do a 90° turn.

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38 See http://www.thetruckersreport.com/turning-radius-info-on-eighteen-wheelers/
4.1.2.3 Carrying Capacity

Trums carrying capacity is directly determined by its length, given its height are keep constant. As for trucks and LRT, Trums length could vary to make them suitable for different types of delivery. Longer Trums have clear advantage over shorter ones: they can carry more materials, which increases the payload transported in each trip. It also lowers driver costs and makes better use of the right-of-way since a limited number of vehicles can access ROW at any given time. In reality, many locations would be too difficult to access by a 60m vehicle. Considering the length of city blocks, some Trums could be shorter, maybe as short as 20 metres. Another important factor to consider regarding Trums length: the costs of the electric system (motor, pantograph, batteries) might be prohibitively high for vehicles under a certain size. As a general indication, the electric system on a trolleybus is worth approximately half of the vehicle's value\(^\text{39}\), which amounts to approximately\(^\text{40}\) $450,000 (APTA 2009).

Taking the Dresden CarGoTram as example, the longest Trums would be approximately 60 metres long, 2.2m wide, 4 metres high. This would provide approximately 215 m\(^3\) of loading space and could carry up to 60 tonnes. Although the DVB (2011) mentions that each CarGoTram operating in Dresden replaces three trucks tend, the space provided is about double that of North-American semi trucks, and provide 2.3 times their weight carrying capacity.

4.1.2.4 Technological Requirements

*Trums* would be equipped with IT and communication technologies that would allow real time geo-location (most likely GPS) and communication between a control centre and *Trum* drivers. To ensure maximum safety and avoid accidents between passenger and freight vehicles, which will enter and leave LRT right-of-ways at designated sections, a secondary system should also allow real-time location of vehicles on tracks.

This secondary system could be based on Radio Frequency Identification (RFID), which is a set of technology that uses radio frequency to track objects in space and time. RFID is a type of automatic identification data capture (AIDC), as are bar codes and magnetic stripes. This technology has been proven and tested since its first use in the Second World War, where it differentiated allies from enemies planes (Moroz Ltd. 2004, 2).

The main component of this technology is the “transponder”, more commonly called tag, smart


\(^{40}\) Average price for 2007-2008 trolleybuses were adjusted for inflation to obtain 2011 US$. 

tag or radio tag. The transponder usually comprises a chip and an antenna. The chip itself consists of a processor, memory and radio-transmitter. The chip communicates via radio frequency to a reader with its own antenna, which then sends the information to a main computer, wired or wireless. The memory component of the chip can vary from a few characters to kilobytes.

There are two types of RFID technology: active and passive. Active RFID transponders are self powered, which allows the transponder to communicate over larger distances and have increased memory capacity.

Although it is not within the objective of this thesis to focus on the technical issues related to RFID technology, it is easy to understand its potential application within a Trum system, allowing for precise tracking of delivery and for vehicle traffic control. More specifically, transponders could be used to track Trums and individual containers or shipment they carry. This would allow business to know exactly the location of their merchandise and the time of arrival, thus being able to plan their logistics needs accordingly.

From a system operation perspective, RFID allows to track pick-up and drop-off points, the route chosen or assigned, the distances travelled by each vehicle and for individual delivery, etc. Depending on the information carried by the transponder, the specifics of the merchandise can also be known to better control delivery of hazardous merchandise or cater to special needs such as the delivery of fragile or perishable merchandise. The ultimate technological choice will lay in the hands of expert technicians and engineers, and should be influenced with the specifics of Trums vehicles and the Trum system.

Notwithstanding what technology could best serve this concept, a control centre will be necessary to manage Trums and tramways traffic in the network. Although most of the process should be automatic, human supervision will still be required for safety and security purposes, and to address problems when they arise.

4.2 Infrastructures Requirements

The Trum concept, to be implemented as a regional transportation system, needs two essential components: logistics centres and surface electric transit infrastructures (tramway, LRT, trolleybuses).

4.2.1 Logistics Centres

Logistics centres, also referred to as transfer hubs, provide storage and trans-loading infrastructure in which goods arrive by other modes (trains, trucks, boats, planes) and are transferred
Amsterdam had also envisioned building a few logistics centres at the outskirt of the city, but never got to build them as the project was abandoned for the reasons mentioned in Chapter 2.

Ideal locations for these logistics centres are industrial and commercial land located at the outskirt of metropolitan area. Logistics centres need substantial space to allow for trucks, trains and other modes to unload their merchandises. These centres attract high truck traffic, which produces air and noise pollution and other inconvenience not suitable for residential neighbourhoods.

Although it is difficult to estimate the cost of these centres, each would likely cost a few tens of millions of dollars. More discussion on capital costs of logistics centres are presented hereafter (Business Case, p.67)

### 4.2.2 Right-of-Way

Technological characteristics of the *Trum*, namely the use of rubber tires that provide crucial flexibility in allowing *Trum* vehicles to enter and leave LRT and trolleybus right-of-ways, also create the need for a specific type of right-of-way to be used.

In regards to LRT and tramway systems, tracks must be embedded into the pavement, which means that the pavement is at the same height as the tracks upper edge. This type of track can be protrusive or not, as shown in figures 34 and 35 (p. 65) respectively.

In both cases, vehicles, cyclist and pedestrians can cross over the tracks, as no physical barriers are used to isolate the right-of-way. This improves the seamless integration of tramway tracks into the urban environment and poses no obstacle to accessibility requirements.

As shown in figure 34, other road vehicles can share these right-of-ways. However, it is preferable to plan for dedicated right-of-ways whenever possible to ensure higher speed of tramways...
Integrating the *Trum* with trolleybus networks is not as problematic, given both vehicle need a flat surface to roll on. As for LRT and tramways, integrating a *Trum* system with a trolleybus network would benefit from dedicated right-of-way, given the reliability challenges caused by operating vehicles in mixed-traffic.

Although using metal barriers to isolate surface rail or trolley right-of-ways from road traffic can provide more safety to pedestrians and other vehicles in restricting access to the tracks, which allows for faster operation, such barriers affect the harmonious integration of the surface transit system within the urban landscape and raise capital costs. Physical barriers would also interfere with the Trums movement entering and leaving right-of-ways.

During the 2007 pilot project, there were two off-loading stops used by CityCargo vehicles. One of them is presented in figures 37 and 36, which show two angle of the same corner. As seen in these pictures, tramway tracks can easily be integrated into dense urban areas and narrow street. When only one lane is available for all vehicle traffic, these stretches are shared between tramway and other road users.
The second drop-off point is shown in figure 38 located in another central neighbourhood of the Dutch capital. The advantage of this second drop-off point is undoubtedly the extra siding, visible on the right hand side of the picture, which gave the possibility of having parked CityCargo vehicles without disturbing passenger tramway services.

Although Amsterdam has an extensive tramway network, extra siding such as that are not that common and would have had to be constructed if a regional CityCargo system were to be implemented. The first drop off-point was used because the tracks went in a residential detour from arterial traffic, which means it could be blocked to allow for CityCargo vehicles to off-load their cargo.

The extra siding requirement for CityCargo vehicles, as well as for Zurich Cargo Tram or Dresden CarGoTram, is a major inconvenience, as space available on streets is usually scarce. Construction costs for a track siding of about 80 metres, assuming Trums of 60m long. This barrier is what spurred the idea of the Trum, fitted with rubber tires and not steel wheel.

The downside of this is the use of rubber, which must be changed more often than steel wheels, increasing non-renewable material needs for operation. Recycled tires should be favoured by the new vehicle, as by the transport industry in general. Despite their lower performance over steel wheels, rubber tires allow for the most important feature of delivery, a door-to-door service. The choice of right-of-way will influence the speed and the service quality provided by vehicles using it. To achieve operating speed over 30 km/h, a separated, off-street right-of-way is usually required, as those used for subways, SkyTrain and other mass rapid transit systems.
Choosing on-street right-of-ways reduces financial cost of buying land to make a separated right-of-way, and does not require extensive engineering work as in the case of elevated or underground structure. Operating speed will however be more limited, usually between 10 and 25 km/h. In any case, best practices and lessons drawn from current LRT operation show that on-street LRT infrastructure must avoid sharing tracks with other road users to conserve acceptable operating speed and service reliability. This can be done with harmonious integration of the tramway infrastructure to the streets, as shown by figures 39 and 40.

4.3 Business Case

Because the Trum remains a concept dependent on many variables that are themselves dependent on other factors, it is hard to provide precise figures pertaining to capital and operating costs. We can however estimate plausible ranges of costs both for capital and operating expenditures based on current figures from the trucking and public transport industry. Estimations provided here must be understood as such, and not seen as hard data on capital and operating costs. Somme benefits produced by replacing trucks by Trums are mentioned but not monetized, as such exercise requires case-specific information.

4.3.1 Capital Costs

4.3.1.1 Logistics Centres

Logistics centres, essential to the transfer of goods from other transport modes onto Trums, are expensive infrastructure to build. Although it is impossible to evaluate the cost of these centres without knowing their dimensions and physical requirements, a point of reference is provided by recent capital costs of bus garages, which have similar physical characteristics to those of logistics centres.
An article published in the *Toronto Star* 41 reported that construction costs for Toronto's new bus garage were approximately $CA 92 million. The garage is 23,000 m² and can hold approximately 200 buses, including 70 articulated buses. Knowing that articulated buses are usually 18 metres long and that buses are usually 12 metres long, the garage capacity can be estimated to approximately 235 regular buses.

Assuming that *Trums* would be 60 metre long, this infrastructure could contain approximately 47 *Trums*. Rounding up these numbers, we can estimate that $CA 100 million are enough to build a garage (similar to logistics hubs) that could park 50 vehicles. Additional costs should be expected for additional infrastructure, particularly is marine and air transport modes are part of the multimodal system, and that more space might be needed to allow for efficient trans-loading, which would also increase capital cost.

### 4.3.1.2 Right-of-Way Costs

**LRT and tramway networks**

Capital costs of building LRT and tramway right-of-way are also dependent of a variety of factors. This make very difficult any estimation of LRT infrastructure capital costs without knowing the specifics of the physical conditions and of the right-of-way projected use. Nevertheless, examples of cost in various cities can help define capital costs plausible range.

Condon et al. (2008) present a list of LRT lines' construction costs per kilometre of double track against operating speed of these lines. As shown in figure 41, there is not a direct relation between the cost of construction and the achievable operating speed of these systems, but certain general rules can help makes sense of price ranges and options.

On-street, shared right-of-ways are the cheapest to provide. They should however be avoided as much as possible, as maintaining satisfactory operating speed in heavy traffic is quite problematic. The *Trum* would need on-street dedicated or segregated right-of-ways. The former is cheaper than the latter, which implies a physical barrier between streetcars tracks and other traffic lanes. There is however little cost difference between on-street dedicated right-of-ways and on-street shared right-of-ways.

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In figure 41, streetcars systems, which use on-street right-of-ways, have been identified by star symbols. The capital cost per kilometre of double track range from approximately SCA 10 million and SCA 50 million. If we were to estimate average costs, a range between $ 25 and 40 million per kilometre of double track would be reasonable. As a point of reference, the three future tramway extensions planned in Dresden future tramway extensions are expected to cost SCA 20.1, 29.6, and 11.6 million per kilometre double tracked\(^\text{42}\).

**Trolleybus networks**

If Trums use trolleybus right-of-ways, no track work is required. In this case, a report (Moore 2006) on construction costs in the UK mentions reference costs for road construction to be £3,050 per linear metre for double lane urban road\(^\text{43}\). This is equivalent to approximately SCA 6 million per linear kilometre. Trolleybus overhead catenaries and underground electrical station cost approximately a million dollar per kilometre (Grewal et al. 2011).

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\(^{42}\) Sums in Euros converted to Canadian dollars, with a rate of 1 EUR = 1.40 CAD, as of August 31, 2011. [www.xe.com](http://www.xe.com) (Accessed on August 31, 2011)

\(^{43}\) Exchange rate of SCA 1.96 for one British pound, as of December 31, 2007. [www.xe.com](http://www.xe.com) (Accessed on March 5, 2011)
4.3.1.3 Vehicle Costs

Because the *Trum* is still a concept and no prototype has been built, one cannot know exactly how much building a vehicle would cost and what would be its retail price. We can however look at transit vehicles to have an approximate idea of their retail price. According to Coast Mountain Bus Mountain Company\(^44\) a 40 foot diesel bus costs approximately $CA 400,000, a 40 foot electric trolley, $CA 750,000, and a 60 foot articulated trolley, $CA 1.2 million.

According to APTA, the average price for a trolleybus was approximately $CA 900,000 in 2007-2008 (adjusted for 2011 dollars) and prices for LRT and tramway vehicles approximate the million dollar per car (APTA 2009) Toronto's new streetcar vehicles, Bombardier's Flexity, were bought for approximately $4.9 million per vehicle\(^45\). The German transit agency of Hannover has awarded Vossloh Kiepe and Alstom with the delivery of 50 tramways, at a total cost of approximately US$ 176.6 millions, meaning US$ 3.5 million per train, or $US 1.2 million per bogie\(^46\).

A 60 metre *Trum*, which would have only one control cars and four freight cars, could cost between 1.5 and 3 million dollars. Costs would be lower than regular tramway costs because freight cars are more simple than regular passenger cars, and because there is no need for two control cars, as *Trums* are expected to have better turning radius than tramways and would move mostly forward. These two factors contribute to lower vehicle construction cost. However they would remain however significantly more expensive than diesel trucks, because of the electric and communication system and regenerative braking.

In 2007, the purchase price of a tractor unit in BC was close to $130,000; the price of a trailer was $ 27,000 and the price of a straight truck was approximately $ 80,250 (Logistics Solution Builders Inc. 2008, 25). A *Trum* vehicle, which has twice the capacity of a diesel semi truck, would however cost between 9 and 18 times more. For the *Trum* to be economically competitive, significantly lower operating costs need to offset these higher capital costs.

4.3.2 Operating Costs

In freight transport, fuel and driver costs, followed by depreciation and maintenance costs, are the

main components of operating costs (see table 4, page 40). As mentioned, higher purchase price of these vehicles would need to be offset by increased efficiency resulting in lower operating costs. The factors aforementioned are discussed in this section, with the exception of depreciation costs. The Trum is not, a priori, expected to have lower depreciation costs, although we can hope that Trums that would keep their value overtime better than trucks.

4.3.2.1 Energy Cost

Because Trum are powered by electricity, energy costs in most part of the world would be much lower than current fuel prices. As seen in the introduction, peak oil and global transport forecast announce for increasing fuel price in the future, which would give an even larger advantage to Trums over trucks. We know that one litre diesel equals 10.75 kW/h and 38.70 MJ, and that the average consumption factor for HDV in Canada were 23.5 L/100km for MDV and 34.5 L/100km for HDV in 2007 (Natural Resources Canada 2009, 10). From this information, we can deduct that the average energy consumption per kilometres for MDV and HDV is 2.5 and 3.7 kW/h per kilometre, or 9.0 and 13.2 MJ/km respectively.

Assuming a diesel retail price of 1.30 $/L, MDV and HDV pay approximately 0.30 $/km and 0.44$/km in fuel consumption.

In BC, large industries with total energy usage higher than 550,000 kWh or annual peak demand of 150 kW, are charged [1] a basic charge, [2] a demand charge, [3] an energy charge. They also have discount if they reduce their consumption under their average monthly consumption. Energy charge is $0.08/kWh until 14,800 kWh, $0.04 per additional kWh until baseline, and $0.06 per additional kWh over the baseline. Demand charge for large consumer is: free for 0-35 kW, 4.51$ per kW between 35 kW and 150 kW and 8.66 per kW over 150kW.

At these rate, if trucks were using electricity and charged an energy rate of $0.06/kWh, which is within the range of BC Hydro industrial rates for large consumers, MDV and HDV would pay the equivalent of $0.15 and $0.23 per kilometre, which in line with energy costs of trolleybus operations (Grewal et al. 2011). This returns to approximately half of the costs of diesel truck operation energy costs at current fuel price. A MDV that travels 150 kilometres per day would save $23.08 in energy consumption; a HDV that travels 300 kilometres per day would save $67.77 in energy consumption. Over 260 weekdays of year, these savings would amount to $6,000 for a MDV and $17,621 for a HDV.

Knowing that fuel costs are currently representing about 34% of trucking operating costs (see
table 4, page 40), providing electricity that is half the price of gas could cut operating cost by approximately 17%.

4.3.2.2 Drivers' Wages

Drivers' wages would have to be competitive with the current trucking industry practice and possibly offer wages above average, considering the more complex task of operating a Trum in a new system.

In BC, wages ranged from $22 to $29 per hour. We could assume Trum driver wages to be close to $25-35 per hour. Assuming a driver works 40 hours per week, 50 weeks per year, yearly cost of a driver in BC would be between $44,000 and $58,000.

Because of the higher carrying capacity of Trums, which is twice that of a semi truck, efficiency gain could theoretically double as a driver could transport twice as much merchandise. Knowing that drivers costs represent approximately 22 percent of total operating costs of trucking, this could amount to 11 percent reduction in relative operating cost.

4.3.2.3 Maintenance

Maintenance costs include tires and repairs. Transit vehicle maintenance costs provided by Statistics Canada (2009c) amounted to 0.32 $/km for a diesel transit bus. In 2007, trucks maintenance costs in Canada were close to 0.28 $/km (Logistics Solution Builders Inc. 2008, 34). Trums maintenance cost would likely be higher than trucks or buses at first, since new technologies are more expensive to maintain. As a conservative assumption regarding maintenance cost, we estimated maintenance costs at 0.85$ per kilometre.

Assuming all other factors influencing operating costs of trucks would have similar share of Trums operating costs, energy and drivers' costs could provide efficiency gain up to 28 percent. Knowing that fuel prices will most likely keep increasing in the future, we can assume that the share of fuel costs in operating costs of trucks will also keep increasing. This is a very positive trend for Trums, whose advantage in using electricity, with minimal battery kit, will keep increasing over time.

4.3.3 Comparative Analysis Trum vs. MDV

One of the central question underlying this analysis is the Trum economic return for transport businesses. In order to provide a point of comparison, a comparative analysis between an hypothetical
MDV and a *Trum* was performed. Numerous assumptions, informed by the information presented the first three chapters, had to be made to compare the two vehicles.

These assumptions are presented in table 6. A ten year period was used to calculate the revenue-expense ratios associated with the operation of these vehicles. Ten years was chosen as a valid time period to compare return on investments rates, because of common use in investment evaluation, and because it is reasonable life expectancy for both vehicles. Because of its resemblance to some transit vehicle, the *Trum* would most likely have a life expectancy that is closer to transit vehicles. Indeed, the current practice of the industry shows that transit buses are often expected have a useful life of about fifteen years, whereas LRT and trams vehicles life span is about 30 years (Portland Bureau of Transportation 2009). For the sake of comparing both vehicles on common ground and because there is a high level of uncertainty regarding the actual lifespan *Trums* can achieve given none has yet been built, it was conservatively assumed that this *Trum* has ten years of useful life.

Other assumptions pertain to land costs and added maintenance costs on overhead infrastructures, which were not include in the calculation. In regards to land costs, the reasoning behind its exclusion stems from the impossibility of estimating the current land requirement of trucking (right-of-ways, parking, back alleys etc.) and the future land requirement of the *Trum*. In not including these costs, it is assumed that no additional costs would be required by for *trumming* over trucking. A similar challenge exists regarding the estimation of additional maintenance imposed on LRT or trolleybus catenaries. Indeed, estimating the additional wear on catenaries stands beyond the proposed research framework, which is justified by the impossibility of accessing reliable estimations. Nevertheless, more research focused on this aspect of *Trum* operations would provide additional precision and possibly make the

<table>
<thead>
<tr>
<th>Table 6: Comparative analysis constants</th>
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<tr>
<td><strong>Trum and medium duty vehicle constants</strong></td>
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<tr>
<td>Constants</td>
</tr>
<tr>
<td>Purchase price</td>
</tr>
<tr>
<td>Initial cash down</td>
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<tr>
<td>Life Expectancy</td>
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<tr>
<td>Payload (weight)</td>
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<tr>
<td>Carrying capacity (m3)</td>
</tr>
<tr>
<td>Maintenance costs</td>
</tr>
<tr>
<td>Maintenance costs yearly increase rate</td>
</tr>
<tr>
<td>Energy consumption</td>
</tr>
<tr>
<td>Driver salary</td>
</tr>
<tr>
<td>Yearly work hours</td>
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</tbody>
</table>
case for a more intensive use of these infrastructures, as proposed in this research.

Maintenance costs and purchase prices for the MDV were estimated using data available in a report on the operational costs of trucking in Canada (Logistics Solution Builders Inc. 2008; Work Truck Magazine 2012), and those of the Trum were estimated using both trucking and transit vehicle costs information (APTA 2009; Grewal et al. 2011).

The use of a MDV instead of a HDV truck in this comparative analysis is justified because most urban delivery are done by MDV, and because the costs of urban delivery, as opposed to inter-urban delivery, are better reflected by MDV than HDV operating costs. For the base case, was also assumed that assumed that both the MDV and the Trum travel in average 150 kilometres per day, 260 days per year, as per industry practices (Logistics Solution Builders Inc. 2008). The length of the Trum compared is 40 metres, which provides approximately 150 cubic meters of loading space47, or three times that of a typical MDV (see Table 3, p.37).

To estimate the energy consumption of a 40 metres Trum able to carry up to 40 tonnes in payload, the average energy consumption of an MDV was multiplied by two and converted to kWh. Although each Trum is worth approximately three MDV in terms of carrying capacity, we assumed an overall 33 percent energy efficiency gain given the economy of scale related to the carrying capacity and a better energy efficiency of the electric motor, which is said to be as much as four time more efficient in converting stored energy into movement, (Shah 2009).

The factors carrying the highest uncertainty level are the price of diesel fuel, and to a certain degree that of electricity. An additional variable used in the sensitivity analysis is the distance travelled every year, which reflects the intensity of use of the vehicles, as per industry standards (Logistics Solution Builders Inc. 2008).

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47 The two third of Dresden Cargo Tram carrying capacity.
The three scenarios chosen regarding energy price evolutions and distance travelled are presented in table 7. The electricity increase rates have been decided upon considering the historic prices of electricity in British- Columbia, which have been maintained at rates close to inflation; between 1915 and 2010, the inflation rate in Canada averaged 3.26 percent\(^{48}\). The starting rate is $0.10 per kWh, considering the price of the current electricity production projects; even Site C, a huge project with very low production costs, will produce at a cost close to that rate (BC Hydro 2011).

Regarding diesel fuel cost, a starting price of $1.45 per litre was chosen to reflect current diesel fuel prices in Vancouver. The increase rates were based on previous trends and future expectations; between 1987 and 2012, the price of a litre of diesel fuel in Vancouver has increased by 2.5 percent annually, once adjusted for inflation (Natural Resources Canada 2012)\(^{49}\). The price increase was more pronounced over the last decade, which with saw an annual 6.3 percent increase, once adjusted for inflation.

Table 7: Sensitivity analysis variables

<table>
<thead>
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<th>Energy costs</th>
<th>Slow increase</th>
<th>Moderate increase</th>
<th>Fast increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity cost</td>
<td>2.00%</td>
<td>4.00%</td>
<td>6.00%</td>
</tr>
<tr>
<td>Fuel cost</td>
<td>2.50%</td>
<td>6.00%</td>
<td>10.00%</td>
</tr>
<tr>
<td>Distance travelled</td>
<td>Low usage</td>
<td>Medium usage</td>
<td>High usage</td>
</tr>
<tr>
<td>Yearly km travelled</td>
<td>40,000</td>
<td>80,000</td>
<td>120,000</td>
</tr>
</tbody>
</table>

Table 8: Trum versus MDV revenue/costs ratios

<table>
<thead>
<tr>
<th>Yearly km driven</th>
<th>Slow increase</th>
<th>Moderate increase</th>
<th>Fast increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>40,000</td>
<td>-19.00%</td>
<td>-17.70%</td>
<td>-15.90%</td>
</tr>
<tr>
<td>80,000</td>
<td>-7.5%</td>
<td>-5.40%</td>
<td>-2.30%</td>
</tr>
<tr>
<td>120,000</td>
<td>1.4%</td>
<td>4.10%</td>
<td>8.20%</td>
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inflation (Ibid.). In each scenario, the electricity cost increase rate remains lower than that of diesel cost increase.

The complete cash-flow analysis under each scenario is presented in Appendix 1. A summary of the results is shown in table 8 (p.75). These percentages are the relative performance of the Trum compared with a MDV with hypothetical profit margin of five percent. This means that a 1.4 percent increase, as shown in the lower left corner of table 8, would provide a 6.4 profit margin. As seen in each scenario, greater distance travelled yearly yields greater savings due to the cost difference between the two energy sources. The greatest efficiency increase is found in the “fast increase and high usage” scenario, where the Trum becomes 8.2 percent more profitable than the MDV. Of course, these results are based on assumptions that carry a high degree of uncertainty. However the exercise shows that from a business perspective, the Trum can become economically viable under the right conditions. The first condition is the price of each energy sources.

Under the slow increase scenario, diesel fuel would cost $1.81 per litre after ten years, versus $0.12 per kWh; given the current state of affair presented in Chapter 1, higher increase in diesel fuel price is likely. The moderate increase scenario returns the price of a litre of diesel at $2.45, and the price of a kWh at $0.14 after ten years; the high increase scenario yields the price of a litre of diesel at $3.42, and that of a kWh at $0.17.

The second condition is the level of usage of the vehicle. Because the Trum is expected to have an initial capital cost approximately 25 times higher than a regular MDV, a high usage is required to recoup the costs over a ten years period. With 120,000 kilometres driven yearly, the Trum is very close to be at par with the MDV revenue/costs rate.

Realistically, the implementation of a Trum system is more complicated than the simple cash-flow analysis presented in this section, but considered only from a business perspective, everything boils down to profitability. If such a system were to be implemented, a variety of policy, market and regulatory tools would be used to ensure that this cleaner system is given advantages over traditional trucking. These tools, examined in Chapter 6 - Conclusion, must be used to adjust the price signal sent by the market to ensure the buy-in of businesses. In sum, the Trum must be made an economically competitive option compared to conventional trucking.
Chapter 5 – Vancouver Trum City

This chapter examines the city and region of Vancouver and discusses costs and benefits related to the implementation of a Trum system in the region. Regional challenges are first examined, followed by the analysis of key points relating to the implementation of a Trum system. Two perspectives reflecting two scales of analysis are also presented. The first perspective focuses on a specific case, the Broadway corridor; the second perspective looks at the regional implementation of a Trum system. It examines the options offered by the current trolleybus network and estimates the benefits of reducing CO₂ and air pollution emissions by shifting freight transport from trucking to “trumming”.

5.1 Regional Challenges

The Metro Vancouver region faces particular challenges that will shape the region's development in coming decades. In relation to the Trum system, the most relevant challenges faced by the region pertain to population growth, land use and transportation.

5.1.1 Population Growth

Until 2040, the region is expected to grow by over 35,000 per year, for a total population increase of approximately one million people. This strong population increase poses challenges as the region aims to avoid sprawl and create more compact and sustainable developments. This goal is enshrined in the Regional Growth Strategy (RGS) (2011) through the strategy's five main goals. In regards to transportation, “Goal 1 – Create a Compact Urban Area”, speaks directly to the interplay between land use and transportation. It focuses on TransLink's Frequent Transit Network, an approach compatible with the Trum system development. These Frequent Transit Corridors correspond to bus routes with higher frequency and ridership than other bus routes.

In regards to the Trum, two strategies than can ensure the region surface electric transit system compatible with Trums: expanding the trolleybus network or building a regional light rail /tramway system. Given the existing trolleybus infrastructure, it would be cheaper to choose the trolleybus option, which would still require road work to create dedicated right-of-ways shared by Trums and trolleybuses.

Tramway lines would, if an LRT plan is eventually developed, replace the busiest of these Frequent Transit Corridors, laying down the first branches of a regional Trum system.
Urban centres and Frequent Transit Development Areas will accommodate most of this population growth, and are expected to see their dwelling units counts grow by 50 and 27 percent by 2041 respectively (2011, 17). From a regional perspective, most of this growth will occur south of the Fraser River, where potential for development is much higher than in Vancouver itself. This is an opportunity to have a tramways system influence the future built environment of these municipalities, as LRT systems tend to concentrate urban development close to alignments to a greater extent than non-rail transit, as shown by the recent example of the Portland Streetcar (E.D. Hovee & Company 2005).

As mentioned in chapter one, by adopting the Greenhouse Gas Reduction Targets Act (2007), the Provincial Government committed to addressing climate change and to reduce GHG emissions. The RGS is aligned with the provincial strategy and contains strategy pertaining to the reduction of GHG emissions through integrated planning, transportation and land use policy.

In relation to the Trum, and in agreement with the approach advocated by Patrick Condon (Condon 2009), transportation investment should prioritize projects that have high impact on development and that are affordable enough to offer the widest regional coverage possible. Although heavy rail transit is a major attractor of development, it remains too expensive to provide a wide network and could not realistically be extended to lower density areas. Surface transit system operating in dedicated right-of-way meet these criteria.

### 5.1.2 Land Uses

Land use challenges are directly related to population growth forecasts. Densifying residential areas is a politically challenging task, as seen in the recent Eco-Density program of the city of Vancouver. Existing neighbourhoods are often resistant to increase residential or employment density, as they fear more people living in their neighbourhood will decrease the quality of life and decrease land value.

In Metro Vancouver, industrial lands are also facing development pressure, as they have lower land value than commercial and residential uses. Metro Vancouver's RGS has acknowledged the issue and includes a strategy to protect the supply of industrial lands.

A regional Trum system would need to make the best use of these industrial lands and would offer an incentive for companies to be located close to Trum lines, reducing pressure towards displacement of industries in peripheral areas.
5.1.3 Transportation

TransLink's *Transport 2040* outlines the region's transportation challenges and strategies for the next 30 years. Directly impacted by the increase in population, transport activity is expected to keep increasing throughout the region. As of 2006, the modal share of transit as transport mode to commute to business parks was 7 percent. This figure rises to 34 percent for commutes to the metropolitan core (TransLink 2008). This speaks to the importance of locating growth in centres and along transit corridors. Unfortunately, although transit ridership has been growing in recent years, no major shift in modal shares is perceivable at a regional level.

As a result of regional dynamics, TransLink faces a challenging financial situation (TransLink 2012a) that will make even more difficult choices regarding new infrastructure investments, as shown in the UBC line versus Surrey lines debate. Because surface rapid transit modes costs a fraction of heavy rail, investing in electric surface transportation can result in transit improvement with a greater geographical coverage; it would also lay down the infrastructure for a Trum system. As already mentioned, the city of Vancouver has a rich trolleybus network that can be used as the base grid for a regional Trum system.

5.2 *Trum* on the Broadway Corridor

The Broadway corridor is currently under study for the implementation of a rapid transit line. More than 100,000 thousand trips are made everyday on this corridor, and about 2,000 people are passed-up daily by full buses (TransLink 2012b). No decision has been made regarding what technology will be used, but phase two of the study has narrowed down the different scenarios examined, ruling out BRT for capacity reason (Stear Davies Gleave 2011).

In regards to goods movement, the busiest section of the corridor is the eastern section, particularly between Commercial Drive and Main Street. In this 2.3 km long section, 6 percent of vehicles are trucks, which amounts to approximately 800 trucks per day (Ibid.). Although the truck count on the entire corridor is unknown, for the purpose of the exercise it was assumed that 500 of the 800 truck counted between Commercial Drive and Main Street travel from Commercial Drive to Alma Street, a 8.5 km distance.

Because the size of these trucks is unknown, it was assumed than a Trum, which can carry as much merchandise as two semi-trucks or three straight truck, replaces 2.5 trucks. This means that 200 Trums would travel 8.5 kilometres daily on this LRT right of way. Realistically, Trum delivery would
be reduced during rush hours, as headways become too frequent for track sharing. Assuming these
*Trums* consume in average 506 kWh/100 km, the energy consumption by *Trums*, between Commercial
Drive and Alma Street would be 8,602 kWh. If electricity was priced at $0.10 per kWh, this would
represent $860 per day, or close to $225,000 per year. If $0.10 per kWh was the profit made by public
authorities, like TransLink or the City of Vancouver for instance, this would mean a quarter of million
dollar more in revenue every year.

This simple calculation is not a prediction of the profitability of *Trums*, but it aims as
demonstrating that by integrating freight movement with electric transit infrastructure can result in a
new revenue stream for public authorities.

Using the costs estimation for the LRT option, $65 millions per kilometre without contingency
funds, we can estimate that the costs of 8.5 kilometres is close to $550 millions. This means that within
10 years, profits from *trumming*, using the above mentioned estimations, would have amounted to 0.4
percent of total construction cost.

### 5.3 City-Wide *Trum*-Trolleybus Network

The intended use of the *Trum* is not limited to a corridor or to a particular area in the city. It it
intended to become a city-wide, and ideally a regional system that can be integrated with high-coverage
surface electric transport network. In Vancouver, this network exists; it's the trolleybus network. In
order to identify possible routes on which electric surface transit infrastructure could be shared with
*Trums*, a series of maps were produced with a GIS software.

#### 5.3.1 Trolleybus Network

The current trolleybus network counts thirteen routes. These routes amount to 231 km of routes
which, because some routes overlap, amount to 158 km of overhead wires. Using TransLink's 2011 Bus
System Performance Review, a list of 22 routes with the highest ridership and running on strategic
arterials was identified.

Overlaid with the high-ridership diesel bus routes, figure 42 (p.81) shows that to achieve a
complete grid of trolleybus network, approximately 150 kilometres of additional trolleybus catenaries
should be installed. At the cost of approximately one million dollar per kilometre (Glaeser et al. 2001),
Figure 42: Vancouver trolleybus network and high ridership routes

Legend
- **Trolleybus routes**
- **Diesel High Ridership Bus Routes**
- **Burnaby**
- **UBC**
- **Vancouver**
the electric infrastructure required would cost close to $150 millions.

In addition, the map presented in figure 43 (p.83), which shows population density, trucks routes, main roads and Business Improvement Associations (BIAs) in Vancouver, also shows that often, truck routes, high ridership transit routes and commercial areas overlap each other. In addition, these corridors have higher population density and more destinations than residential streets. This means that these corridors are particularly suitable to have transit improvement, either through with better trolleybus right-of-ways or LRT infrastructure.

On busy arterial, where transit vehicles headways are under 2-3 minutes during peak hours, Trums operation could be limited to off-peak hours. Flexible pricing could also be used to encourage off-peak hours travel and discourage peak-hour travel. This means that valuable delivery could still be made during peak hours against high track usage fee, but that trips with lower time value would be made when usage fees are lower.

**5.3.2 LRT Network**

As mentioned, Trums can be integrated with either trolleybus or LRT/tramway networks. If the long-term strategy is the development of an LRT system instead of the extension of the current trolleybus system, capital costs would be significantly higher. Using Patrick Condon's estimations (2008), which are in the lowest range of LRT infrastructure costs, we can estimate that the cost of implementing the tramway/Trum network in figure 43, with close to 175 km in length, would be close to $3 billions, or almost $6 millions per kilometre.

Although these numbers seems high, one must not forget the economic returns from selling the electricity and other benefits associated with the Trum systems, which are discussed hereafter.
Figure 43: Possible *Trum* corridors for Vancouver
5.3.3 Logistics Centres

As mentioned in this thesis, a regional Trum system would require a few logistics centres to allow goods to be transferred from other freight transport mode into Trums. These logistics centres should, ideally, make the best use of existing freight infrastructure and be connected to existing transload centres shown in figure 44. This vision is compatible with the view presented by the City of Vancouver (2008), which foresee railways as becoming more viable for shorter haul rail links that to access industrial lands “that can be used for intermodal services” (City of Vancouver 2008).

Figure 44 shows this infrastructure is located on the south shore of Burrard Inlet, on Roberts Bank and on the Fraser River. From Centerm and Vanterm, approximately half of the import containers are loaded onto rails to be shipped outside the Lower Mainland, often to eastern provinces.

In terms of tonnage, the Port Metro Vancouver which regroups the former Vancouver Port
Authority and Fraser Ports, had almost 120,000,000 tons transited through its infrastructure in 2006. Three quarter of this passed through the infrastructure of the former Vancouver Port Authority and the rest through Fraser Ports. Within this, domestic shipping ports clearly accounts for the great majority carried tonnage, leaving little freight to the international facilities (Davies 2007, 8).

In terms of TEU units, as of 2006, container traffic in Vancouver was over 2.2 million TEU. Of this number, approximately 1.2 million TEU are serve by Centerm and Vanterm terminals, located on the south shore of the Burrard Inlet. They represent approximately half of the container capacity of Port Metro Vancouver (City of Vancouver 2008).

In addition to existing freight terminal, the location of Trum logistics centres will have to make the best use of the limited industrial land available in the region. Industrial lands in Metro Vancouver are shown in purple by figure 45, originally presented in Metro Vancouver Regional Growth Strategy (Metro Vancouver 2011).

This thesis doesn't go as far a proposing specifics locations for future regional logistics centres, but
because the main objective of a *Trum* system is to reduce trucking in urban area, these logistics centres could very well be located in New Westminster, Port Coquitlam, Richmond, Surrey, Langley, Vancouver and North Vancouver. In sum, current freight infrastructures and industrial lands should be carefully examined as potential locations, as they are essential components of Vancouver’s regional freight transport.

### 5.4 Regional *Trum* System Impacts

As shown in this chapter, the easiest way to integrate a *Trum* system in Vancouver would be use the existing trolleybus network as a base grid and to expand it strategically on commercial arterials. For the sake of concision, and to keep the analysis more focused, the city of Vancouver was used as an example of such an implementation. However, the idea of electrifying freight transport makes more sense at a regional level than at a municipal level.

Impacts of a regional *Trum* system for the region, and estimations of GHG reduction for the Lower Mainland are discussed below.

#### 5.4.1 *Trum* and Land Use

In regards to density, although no absolute numbers exist on the minimal urban density required to support LRT systems, minimum residential and employment density of 44 persons per hectare have been deemed the minimal threshold, versus 66 persons per hectare for the SkyTrain (To 2009). Friends of the Earth mentions that it takes about 240 persons per hectare to support tramway services. According to this figure, the map in figure 43 shows that not all corridors in Vancouver have, at this time, the required density to support tramway services. The *Trum* system would provide additional revenues to pay for tramways capital investments, which could justify laying down more tramway lines than would otherwise economically justified. This means more tramways lines could be built sooner, which in turns attracts higher development density that bring more ridership to tramway lines. This creates a virtuous cycle that would facilitate LRT expansion and clean goods movement delivery.

Given the lower cost of the trolleybus option, Vancouver's urban density is generally sufficient to support trolleybus operations. Nevertheless, the rational presented above is applicable to the integration of a *Trum* as with LRT networks: the *Trum* would provide additional revenue that could justify the initial capital investment for larger rapid transit network provided by electrical surface transport modes.
5.4.2 *Trum* as a City Crafting Tool

In a report advising government on sustainable transport policy in the retail sector, the Commission for Integrated Transport in the UK examined citizen modal choice to reach retail and leisure location. They acknowledge the advantages provided in locating retail sites on the edge or out of town, which are easily accessible to customers by cars and trucks for delivery (CfIT 2006). This should not be a surprise as it simply reflects the fact that the economic dynamics of consumerism is based around car infrastructures: roads and highways, which provide high easy access to car users.

From a consumer's perspective, the report concludes that:

- trip to peripheral and out-of-town locations are mostly made by car.
- modal choice has little relationship with amount spent at these location compared to income.
- parking availability is a variable influencing modal choice, but not as much as the shopping experience (shop variety, built environment experience, pedestrian friendly streets, etc.)
- people who do not drive to shop are more likely to support local town and city centres.
- people who do not drive to shop are three times more likely to walk or cycle than to take public transport.
- bigger items (household goods, construction material, etc) are usually carried by car, while smaller items are more convenient to carry using other modes.
- investment in public transport is part of the solution to maintain access to city centres where highway demand is managed.

(Source: (CfIT 2006, 6)

The growth in peripheral retail sites, a phenomena seen in virtually all growing urban area has been assumed to contribute to a number of trends that are detrimental to the sustainable development of cities. These include:

- an increase in the number of retail related trips
- the clear dominance of car as transport mode for shopping related trips (more than 80 percent of trips made by car, compared to 44 percent for retail site in urban centres).
- a high parking demand and provision
- costumers’ increased ability and willingness to travel, therefore increasing retail and leisure-related trip generation

(Ibid.10)
These conclusions confirm the right orientation of the Trum system, as it would influence both passenger and goods transport and help concentrate activities along corridors and in urban centres. Without decisive actions and investment required to move away from this car-dominated urban environment, tendencies outlined below are expected to continue, which perpetuates unsustainable city development. Concentrating urban development along corridors and in centres is part of Metro Vancouver Regional Growth Strategy (Metro Vancouver 2011). As demonstrated in this thesis, a Trum system would reinforce these goals in providing transport infrastructure that could serve for passenger and goods movement.

These factors make cars increasingly attractive to use, as more retail and leisure locations are accessible almost exclusively by car. These trends are in part due to transportation modes themselves, as car and trucks offer a high degree of freedom, which leads to decentralization and dispersion of destination across the urban tissue. The Trum system would offer one more tool to counteract these trends by making the proximity to transit and Trum corridors a substantial asset for businesses. Rapid transit lines are seen by businesses as a mean of access for their consumers, but in a Trum system, these transport lines would also be seen as a mean of bringing goods and merchandises, therefore increasing the desirability of being located close to them.

This would also facilitate access to retail sites by walking, cycling and transit instead of driving, in addition of making these locations convenient from a logistics perspective. Hence, by locating more retail locations along corridors and in urban centres, the economic activity concentrate in areas that are well served by transit. Transit improvements are great opportunities to enhance the built environment and make it more pedestrian friendly, as seen in the cases of many European cities. The French cities of Bordeaux or Montpellier have been particularly successful in using tramway projects as urban revitalization tools, where the design work on vehicles and catenaries create an harmonious integration with high quality spaces.

5.4.3 C02 and Air Pollution Reduction

Direct benefits are derived from avoiding trucking tkm by using Trums, which emit no tailpipe emissions. As a result, air pollution would be reduced at the extent to which Trum comes to replace trucking as mode of goods delivery in urban areas. A 60 metre Trum vehicle, with approximately 215 m\(^3\) of loading space and a carrying capacity over 50 tonnes, is equivalent to approximately four MDV. Based on trucks emissions range that were presented in Chapter 2, emissions reductions estimates for
every tkm made by Trum are shown in table 9.

Statistics Canada data shows that in December 2009, there were 151,298 vehicles over 4.9 tonnes in BC. Of this number, 133,371 are MDV and 17,927 are HDV. BCTA\(^5\) estimates that between a third and 40 percent of these vehicles operate in Metro Vancouver. This means that between 49,000 and 60,000 of these trucks operate within the lower mainland.

Knowing that local delivery trucks typically operate within a 150 km radius area from their base garage and that class 8 vehicles, also known as “pick-up and delivery” vehicles, travel typically 150 km/day for an average of forty to sixty-thousand km/year, it is possible to estimate the yearly \(\text{CO}_2\) emissions reduction possible if a share of these delivery were done by Trums.

Using average diesel consumption rate 23.5 L/100km for MDV, and if 44,000 to 53,000 MDV travel 150km daily in the Lower Mainland, we can estimate that replacing half of MDV delivery by Trums would reduce \(\text{CO}_2\) emissions between 2,094 and 5,044 tonnes per day. If we assume these vehicles operate only on weekdays, yearly \(\text{CO}_2\) emission reduction could approximately 0.54-1.31 Mt. This would represent a reduction equivalent to 4.3 to 12.4 percent of total \(\text{CO}_2\) emission produced by freight transport in BC in 2008.

### 5.4.4 Source of Revenue for Public Authorities

Using assumptions presented in this chapter, the amount of money spent on diesel fuel by MDV in the Lower Mainland is between 2 and 2.4 $ millions per day.

If this energy, currently supplied by diesel fuel, was sold with at $0.10 per kWh, this would represent between $1.6 and $2 million per day in profit. Although a few billions dollars will be required to build infrastructure and vehicles for a Trum system, this new system would not only contribute to reducing air pollution and \(\text{CO}_2\) emissions and support regional development strategies, it would also create a new source of revenue for public authorities. These estimations provide an idea of the

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magnitude of potential financial profit that could be made in selling electricity to Trums.

5.5 Barriers and Solutions for Implementation

The list presented below contains the six categories of barriers to change presented by Banister (2005, 70-72).

A. Resource barriers: Resource barriers refer to insufficient resources (i.e. Time, money, personal, etc.), required to implement policies. Financial resources are often linked to institutional barriers.

B. Institutional and policy barriers: refers to problems of coordination between or even within organizations or conflict with other policies.

C. Social and cultural barrier: refers to the general acceptability of public policies. A useful way of conceptualizing policies is dividing them between “push” measures aiming at reducing (detrimental) behaviours, and “pull” measures aiming at enhancing (positive) behaviours. In general, pull measures are more popular than push measure.

D. Legal barriers: new policies often means different ways of doing things, and laws often have to be modified to allow for these changes to be implemented.

E. Side effects barriers: any policy will tend to affect reality beyond the immediate regulated object or behaviour to which the policy applies, in both positive and negative manners.

F. Other (physical) barrier: relates to physical limitation in terms of space, dimension, topography, etc.

Lets us consider the barriers that the development and implementation of a Trum system would face:

A. Resource barriers: As exemplified by the recent and projected transport investment in the province of British-Columbia, funding can delay significantly a project’s implementation (Evergreen line) or assure its realization (Canada Line). A regional Trum system would first require substantial tram infrastructures, representing hundreds of millions in investment.

Planning for an eventual Trum system influences today's decisions on transport technology, and gives surface electric rapid transit (light rail, tram, trolleybus) option a considerable advantage over its competitors (rapid transit line and BRT). At grade (and
preferably dedicated) right-of-way is the only type of infrastructure that can accommodate the integration the *Trum* system and provide high quality transit service at reasonable costs.

**Solutions:**

A.1. Demonstrate that it is economically viable for transit operation to allow third parties onto their network, which would recover initial infrastructure cost, but would also slightly raise maintenance costs.

A.2. Convince government of the supreme importance of moving away from fossil fuel dependence, if only for pure economical reasons and as adaptation to climate change is much cheaper than the “wait and see” option, in which climate change induced perturbation would be equivalent of losing between 5 and 20 percent global DGP yearly (Stern 2007)

A.3. Underline the fact that the energy supplier becomes, in the case of Vancouver, BC-Hydro instead of oil companies.

B. **Institutional barriers:** Generally, institutions are resistant to change practices. As shown by Amsterdam's City Cargo project, local transit agencies may be reluctant to share their network with private carriers. Developing a new system to control traffic increases the complexity of their operation, etc. Another crucial aspect of the implementation is the consideration of current shipping and trucking companies that would feel threaten by the implementation of *Trums* and certainly lobby against it.

**Solutions**

B.1. Pertaining to transit agency resistance to change : see solution given in 1.1

B.2. Pertaining to the trucking industry: Have them take part in the new system, either by selling them shares of the new company, or by taking them as subsidiary operators, as *Trums* vehicles will slowing appear on the market, giving trucking companies the time to gradually change their fleet to incorporate more *Trums* for urban delivery and keep a certain amount of diesel trucks for delivery outside urban areas.

C. **Social and cultural barriers:** From a public perspective, there is no foreseeable barrier. Businesses will however need to adapt their logistics chains as delivery hours might be limited
to off-peak hours for businesses located on busy corridors.

Solutions

C.1. To convince businesses that Trums are an appealing business solution even with an additional transload (at regional logistics centres) the formula has to make economic sense. To do so, numerous measures can be used to raise conventional trucking costs and decrease Trum costs. This can be done by

C.1.1. Regulate type of trucks allowed in urban centre, either by imposing emissions or simply forbid HGV to enter large urban centres (as in many European cities)

C.1.2. Subsidize electricity, or even provide it for free during the first years of transition, which would encourage carriers to buy Trums despite higher capital capital costs

C.1.3. Implement traffic priority measures (mostly in regards to traffic lights) and dedicated right-of-way are provided faster commercial speed for carriers, even to the extent of tolerating higher car and truck traffic for the first few years on the regular lanes of Trums corridors.

D. Legal barriers: In North America, rail transport legislation does not allows simultaneous operation of light and heavy rail vehicles on the same track, as the focus is put on crash-worthiness (how vehicle resist potential crash) and not on operational safety (based on advanced control system). That being said, Trum systems are not expected to operate on national railways as they would not be quipped with steel wheels but with rubber tires. However, it would be conceivable to retrofit sections of existing railways located in urban core to increase network connection and decrease implementation costs by reducing the need of purchasing right-of-ways. In this case, a new legislation would be needed to change the theoretical foundation of the current system from crash-worthiness to operational safety.

Solutions

D.1. Convince Transport Canada and other authorities that the current legal system is a barrier to a better use of infrastructure which would provide additional revenue over regular
operation, and involve no significantly higher risks.

E. **Side effects barriers:** It is hard to foresee all the side effects accompanying such a thorough change in goods transportation. The obvious side effects include: decreasing local air pollution and exposure to these pollutants; reduction in fuel consumption and CO$_2$ emissions produced by trucking, increased rail coverage; increase electricity consumption for freight and passenger transport; decrease truck traffic and increase in visual pollution by overhead electric wires. The impact on the overall congestion and traffic is hard to evaluate. Factors that would increase congestion are: increased population and car ownership, increase overall transport intensity, reduction of regular traffic lanes as dedicated right-of-ways would be implemented on suitable arterial roads. Factors that would decrease congestion include: shift from car use to public transit as trams increase coverage of rail transit service and shift from trucking to “trumming”.

**Solutions:**

E.1. To be determined for each specific side effect.

F. Other (physical) barriers: The most obvious issue linked to physical limitation is the width of commercial streets and arterial roads, some of which might not be able to accommodate two dedicated *Trum* lanes in addition to two regular traffic lanes, bike lanes, parking spots and sidewalks.

**Solutions:**

F.1. Choices will have to be made on the most appropriate way of allocating limited space based on contextual specificity. In narrower streets, one-way lanes are to be expected, which would imply shared right-of-way. Inevitably, in some cases parking spaces might have to be removed.

In sum, the possible barriers presented in this section are not impossible to overcome, far from it. Political courage, cooperation between all parties, public support, and the right economic policies would make the *Trum* system possible. With these, the *Trum* presents itself as a plausible system that could replace most of trucking within the Vancouver urban area. This process will not happen over a short period of time, but planning in advance for it will allow companies to plan their fleet turnover and
eventually phase-out diesel trucks by *Trums* for urban delivery, as “it takes 10 years to change the production process, and another 15 years to replace the existing car fleet” (Banister 2005, 23) we could imagine a *Trum* system starting operations within 20-30 years.

This time frame would give Vancouver enough time to start develop its LRT network or expand its trolleybus network, which is an essential element to the implementation of a regional *Trum* system. It would also allow private companies to develop the vehicle and begin commercial production. By that time, fuel prices, air pollution and congestion will most likely create condition more suitable for the system to be viable.
Chapter 6 – Conclusion

As shown in this thesis, it would be possible to integrate passenger and goods transportation to improve the urban development and air quality of cities, while at the same time providing a new source of revenue for public authorities. After setting the context in the Introduction, Chapter 2 and Chapter 3 examined different trends in freight transport and presented alternative uses of tramways that inspired the Trum concept. The vehicle and various considerations relating to its operations were presented in Chapter 4, including a comparative economic analysis between an MDV and the Trum. Chapter 5 examined the case of Vancouver and discussed a future implementation of a regional Trum system.

The conclusion builds on these chapters to bring additional points of reflection to answer the research question underlying this thesis: “how can goods movement be effectively integrated within light rail transit infrastructure?”. Additional policy measures, which can be used to support the implementation of a Trum system, are examined in the light of the main characteristics of the system, followed by reflections on alternative uses of a Trum concept and its future implementation.

6.1 Trum-Supportive Public Policies

Implementing a Trum network is in essence redefining the logistic process of an entire metropolitan area. Of course, the new Trum system would be based on best-practices and high standard of logistics practices\(^\text{51}\) (Yvon Bigras 2004, 50), namely:

- Connectivity: transparent and efficient communication network between the different partners involved in the supply chain.
- Collaboration: essential building block widely recognized as crucial to provide competitive services by collaborating with the right partners.
- Visibility : Information visibility allow the different partners to know exactly the location, status and other information on goods being produced and transported.
- Execution and Synchronization : Ensure that efficient combination of technology, processes, infrastructure and human resources work in-sync to deliver goods on time to costumers.

\(^{51}\text{The above list compiled by Bigras was developed by Cap Genemi Ernst & Young and the University of Tennesse. seems the most relevant amongst a variety theories and school of thoughts on logistics to examine the Trum network concept See Bigras (2004) for a comprehensive literature review on logistics}\)
• Optimization: Using the best decision making tools to optimize transport, warehousing and distribution strategy.

• Speed: Crucial component of the supply chain; speed to adapt to changing market demands and speed in transforming operation in values.

These characteristics are compatible with three central considerations pertaining to the sustainability of transportation, as published in a report from the Design Centre for Sustainability at UBC (Condon and Dow, 2008):

• Shorter trips are better than longer trips: longer trips, even made by very green vehicles, require more energy than shorter trips. As production of every type of energy comes with associated costs, increasing access to destinations should be prioritized over increasing mobility.

• Low carbon is better than high carbon: encourages using low-carbon energy (hydro-electricity, solar or wind powered electricity) over high carbon energy (fossil fuel, natural gas).

• Choose what is most affordable over the long term: the entire life cycle of transportation modes and systems must be considered if one is to evaluate long term costs and benefits.

In his new book Seven Rules for Sustainable Communities: Design Strategies for the Post Carbon World, Patrick Condon presents updated figures that speak to these three principles in relation to the environmental performance of streetcars compared to other transportation modes. Because electric surface rapid transit network are generally aligned with these considerations, public authorities should implement policies that support their implementation, and that of a Trum system.

Banister (2005, p. 136) presents a list of various pricing instruments that can be applied to transportation, as originally presented in the collective book The True Costs of Road Transportation (Maddisson et al. 1996):

• Uniform carbon tax to equalize the costs of abatement between all sectors of the economy

• Fuel tax (or subsidy)

• Purchase or ownership tax based on the emission characteristics of vehicles

• Air quality related charge to account for air pollution caused by road transport

• Extensive road pricing to control for pollution and congestion; preferably distanced based to reflect the intensity of transport use, particularly on HGV where road damage caused is influenced by vehicles' weight, axles and distanced travelled.

• Speed limit “revisited” to balance time saving benefits with accidents and fuel consumptions costs.
In addition to these policies, the *Trum* system could use a pricing scheme that, in guaranteeing a minimal commercial speed, would be a major incentive to move from the slower trucks to faster *Trums*.

Most countries already levy taxes on gas, typically representing between 63 and 73 percent of retail price (Banister, 2005, 68). Increasing fuel prices affects people's behaviour in reducing their transport consumption; doubling prices reduces distances travelled by all forms of transport by 16 percent and car by 20 percent (ibid., 69). Policies that raise prices to reduce transport are efficient but are extremely unpopular with car-dependent industries and citizens. In a democracy, these policies can be politically very dangerous.

Taxes on car ownership in Europe vary from just over 1,100 CAD for Luxembourg to more than $CA 2,50052 for the Netherlands, with the majority of country between $CA 1,800 and $CA 2,300. (CfIT 2001, 22).

However, national policies influencing transport prices have relatively little effect on VKT, as elasticities of demand in regards to prices are low, and because overall increase in demand outweighs reduction in individual usage. In transportation, the rebound effect refers to the idea that the space freed out by drivers being priced off the road is filled by other road users that now see the advantage of using it. This rebound effect reduces the effectiveness of pricing policies.

In 2006, the EU adopted the Act 2006/38/EC, in regards to trucking regulations, which expands the Euro-vignette system, on which tolling fees are based, to all trucks between 3.5 and 12 tonnes. It was previously applicable to HDV only (European Commission 2008).

These regulations tend to be opposed by poorer EU members, namely Spain and Portugal, because higher fees are seen as a threat to export. They were however supported by wealthier countries experiencing a large amount of transit traffic, such as Germany or Austria (Banister, 2005, p. 140).

Many European cities have tried new methods and policies to influence goods delivery. Aalborg, Denmark, developed an optimized system based on cooperation between various shipping companies. Bordeaux, France, uses a transfer hub to optimize goods delivery to its urban core. Veloce, Italy, adopted a similar system as that of Genoa. It includes a transfer hub in which goods are taken from conventional trucks and loaded onto electric vehicles. The city of Groningen, Netherlands, also used transfer hubs and regulated goods delivery by time-specific windows. Monaco, banned HDV from its centre, which is accessible only to electric vans. London, UK, tried a consolidation centre for construction materials. Results of the two-year pilot project included a reduction of vehicle travel by 68

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52 As of January 2, 2011. Rate of 2.24 CAD for one GBP.
percent. Bremen, Germany, had adopted policy limiting access for trucks to its core, including a special parking area for vehicle meeting the EURO5 standard (ELTIS 2010).

The *Trum*, although a unique concept, is in line with the aforementioned innovative policies adopted by progressive cities. There is a variety of policies that can be used to send the right signals to the freight transportation market and to support the *Trum* concept. None of these policies alone are powerful enough to affect the transportation market, but together they create the appropriate regulatory framework in which more sustainable freight delivery would also be more economically viable.

### 6.2 The Future of the *Trum* System

There are still numerous barriers to be overcome before the *Trum* system becomes a reality. Notwithstanding these difficulties, the current conditions and trends presented in Chapter 1 work in favour of the *Trum* system, as regular trucking will become less and less viable. Peak oil, climate change, road congestion and public health all call for major changes in the transportation sector. It is possible to see the *Trum* being implemented in some cities faster than in others.

#### 6.2.1 The First *Trum* Cities

Although Vancouver was the city chosen in this thesis to expand on the application of a regional *Trum* system, it will most likely not be the first city to implement the system. Two types of cities are foreseen to be more suitable to implement a *Trum* system: cities that already have important on-street, LRT or trolleybus infrastructure, and cities that are newly designed and built.

The best example of the first kind of city are found in Europe. Cities like Amsterdam, Brussels or Zurich, which experience heavy congestion, already regulate trucking and have a rich tramway network, would need to overcome fewer barriers than those lacking these conditions. Capital costs for these cities would essentially be for regional, multimodal logistics centres, as new tracks would be less necessary.

The second type of city is mostly found in developing countries that are experiencing urbanization of an unprecedented magnitude. China, for instance, will have to build cities for approximately 300 million people in the next decade or so[^53]. The scale of urbanization happening in developing countries is an unprecedented opportunity for us to plan these new cities with proper transit and freight transport infrastructure. Given the speed China has developed its high-speed rail system,

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which increased from 649 kilometre in 2008 to 8,400 km in 2011 as reported in *The Economist*, it would not be impossible to see a regional *Trum* system implemented within a few years.

This does not mean that cities like Vancouver can do nothing to make freight transport more sustainable. Cities that choose to invest in surface, electric rapid transit networks and lay down on-street dedicated right-of-ways are building the backbones of the future *Trum* network. By doing so, these cities reduce the future costs of adapting the network to *Trums*, can plan locations of multimodal logistics centres and reserve the eventual right-of-ways.

### 6.2.2 Alternative *Trum* Uses

Two aspects of the *Trum* system presented in this thesis have the potential to result in alternative uses of *Trums*: the scale of the system and the type of merchandise carried.

The scale of the *Trum* system presented in this thesis is intended to be regional, although the municipality of Vancouver was used to illustrate options for its implementation. If a smaller scale if hardly imaginable, given the nature of goods transport in urban areas, a larger scale could make even more sense. Indeed, electrifying the main interurban transport corridors would allow to substitute more trucking by *trumming*. This option is currently being explored by Swedish firms interested in developing inter-city electric trucks that would draw electricity from overhead catenary (Projektengagemang Energi & Klimatanalys AB 2012).

The type of merchandise that is usually delivered to urban areas is composed in majority of manufactured goods, food and other types of high-value merchandise like alcohol or tobacco. There are two other types of merchandise for which *Trums* could be used. With alternative vehicle designs, *Trums* could transport containers, bulk, or even liquid merchandise, which are typically very heavy and intended for long-distance travel. It could also transport solid wastes and replace current garbage trucks, which would increase the appeal of electric surface transit networks and further optimize the use of their infrastructure.

Despite this important potential, the current state of affair in North-America would pose significant challenges to the implementation of a regional *Trum* system. Indeed, higher fuel price and more stringent regulations would likely encourage alternative to trucking.

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6.2.3 Phasing-in

In large-scale technological commercialization, the tipping point marks the moment after which benefits of owning and using a certain device (cell phones, smart phones, computer) increase as more and more people use the same device, creating a switch in paradigm (Gladwell 2000). As argued in this thesis, this could happen with the Trum once the right market conditions and the adequate public policies will make Trums the most advantageous system.

Cities and transit agencies have limited resources and must address needs of a growing population.

According to APTA, nearly 80 percent of public transit agencies in the US have implemented transit service cuts and fares increase in 2010 to address decreasing operational and investment funding. 2011 was not much brighter, as 6 out of 10 larger public transit agencies have implemented or approved hiring freeze, 31 and 20 percent delayed vehicle acquisition and capital maintenance respectively.

In planning for future transportation networks, transit agencies should carefully consider the flexibility of their system in regards to the integration of goods movement. This integration would provide additional revenue and help pay for infrastructure and operating costs.

Although more research is needed on the exact details of the Trum vehicle and the wider Trum scheme are required to choose the optimal technology to be used, as the concept remains at its infancy, a regional Trum system can be seen as a post-truck goods delivery system that would be integrated with surface, electric rapid transit infrastructure.

Because primary source of energy used to produce electricity influence the overall environmental performance of the Trum system, we should seriously consider taking advantage BC’s clean electricity grid for transportation purposes, given 95 percent of the electricity is produced by clean energy (BC Hydro 2011).

Nevertheless, phasing-in a Trum system should consider the most appropriate Trum corridors to showcase this type of integration. As shown by Dresden, a corridor with high goods movement demand from a single operator would have more chance to be economically viable than a truly regional system, in the absence of a radical changes in goods movement practices and policies.

To conclude, a citation of Buckminster Fuller on systemic changes summarizes the challenges that lies ahead for the *Trum*: “You never change something by fighting the existing reality. To change something, built a new model that makes the existing model obsolete” (Dennis and Urry 2009, 9). This is what the *Trum* might do with the current truck-dominated system of goods movement in urban areas.
References


———. 2007. “Stepping towards causation: do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity?” Social Science and Medecine 65(9): 1266-73.


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3.


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———. 2010. Canadian Vehicle Survey Table 405-0005 - Canadian vehicle survey, number of vehicles on the registration lists, by type of vehicle, province and territory, quarterly. Ottawa.


Appendix 1 – Comparative Cash Flow Analysis

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<th>9</th>
<th>10</th>
<th>Total</th>
<th>Revenue/Cost Ratio</th>
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<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
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<td>$0.11</td>
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<td>Revenue/Cost Ratio</td>
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### Cash-flow comparative analysis between Trum and medium duty vehicle (medium usage, low increase)

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<td>Electricity Cost</td>
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<td>-$98,131</td>
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<tr>
<td>Diesel Fuel Cost</td>
<td>At 2.5% yearly increase</td>
<td>$1.45</td>
<td>$1.49</td>
<td>$1.52</td>
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Total Revenue/Cost Ratio: 1.06
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<th>Revenue/Co Cost Ratio</th>
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<td>(at the end of each period)</td>
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<td>$52,952</td>
<td>$54,275</td>
<td>$55,632</td>
<td>$57,023</td>
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<td>$59,910</td>
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<td>$-121,086</td>
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<td>$52,952</td>
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<td>$62,943</td>
<td>$564,650</td>
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Calculated from adjusted total costs at 5% profit margin
<table>
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<tr>
<th>Year</th>
<th>Trum Vehicle Costs</th>
<th>Initial Cash Down (10% of total vehicle costs)</th>
<th>Yearly Payment on Capital 6% interest rate (at the end of each period)</th>
<th>Driver’s Salary 30$/h</th>
<th>Energy Costs per km</th>
<th>Maintenance, Repair and Tires $0.85/km increasing at 2.5% a year</th>
<th>Costs Subtotal Discounted 6% yearly discount rate</th>
<th>Total 3 times that of MDV</th>
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**Revenue/Cost Ratio**

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<th>Revenue/Cost Ratio</th>
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### Cash-flow comparative analysis between *Trum* and medium duty vehicle (low usage, medium increase)

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<th>8</th>
<th>9</th>
<th>10</th>
<th>Total</th>
<th>Revenue/Comment Ratio</th>
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<tr>
<td></td>
<td>Vehicle Costs</td>
<td>$80,250.00</td>
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<tr>
<td></td>
<td>Initial Cash Down</td>
<td>10% of total vehicle costs</td>
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<td>$0</td>
<td>$0</td>
<td>$0</td>
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<tr>
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<td>Yearly Payment on Capital</td>
<td>6% interest rate (at the end of each period)</td>
<td>$-9,813</td>
<td>$-9,813</td>
<td>$-9,813</td>
<td>$-9,813</td>
<td>$-9,813</td>
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<td>$-9,813</td>
<td>$-98,131</td>
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<tr>
<td></td>
<td>Diesel Fuel Cost</td>
<td>23.5L/100km</td>
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<td>$1.54</td>
<td>$1.63</td>
<td>$1.73</td>
<td>$1.83</td>
<td>$1.94</td>
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<td>$2.31</td>
<td>$2.45</td>
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<td>$0.42/km increasing at 2.5% a year</td>
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<td>$-19,483</td>
<td>$-19,970</td>
<td>$-20,469</td>
<td>$-20,981</td>
<td>$-188,217</td>
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<td>Maintenance, Repair and Tires Costs</td>
<td>$0.42/km increasing at 2.5% a year</td>
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<td>$-102,643</td>
<td>$-103,881</td>
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<td>$-112,677</td>
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<td>$-116,222</td>
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<td>Discounted Subtotal Costs</td>
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<td>$-730,876</td>
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<td>Estimated Revenue</td>
<td>Calculated from adjusted total costs at 5% profit margin</td>
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### Cash-flow comparative analysis between Trum and medium duty vehicle (medium usage, medium increase)

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<th>Total</th>
<th>Revenue/Cost Ratio</th>
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<tr>
<td>Vehicle Costs</td>
<td>$2,000,000 (10% of total vehicle costs)</td>
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<tr>
<td>Yearly Payment on Capital (6% interest rate (at the end of each period))</td>
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<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
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<td>Energy Costs 506kWh/100k per km 0.85</td>
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<td>Maintenance, Repair and Tires 0.85/km increasing at 2.5% a year</td>
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<td>Estimated Revenue 3 times that of MDV</td>
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### Cash-flow comparative analysis between Trum and medium duty vehicle (medium usage, medium increase)

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<th>Yearly Payment on Capital at 6% interest rate (at the end of each period)</th>
<th>Driver’s Salary $30$/h</th>
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<th>Energy Costs Maintenance, Repair and Tires per km $0.42/km increasing at 2.5% a year</th>
<th>Maintenance, Repair and Tires Costs Subtotal Adjusted for 6% yearly discount rate</th>
<th>Discounted Subtotal Costs Estimated Revenue Calculated from adjusted total costs at 5% profit margin</th>
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<td>$158,000</td>
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<td>$-969,899</td>
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Revenue/Cost Ratio: 1.05
<table>
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<th>Trum Year</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Total</th>
<th>Revenue/Cost Ratio</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-$200,000</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
<tr>
<td>Initial Cash Down (10% of total vehicle costs)</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
<td>-$244,562</td>
</tr>
<tr>
<td>Driver’s Salary 30$/h</td>
<td>$0.10</td>
<td>$0.10</td>
<td>$0.11</td>
<td>$0.11</td>
<td>$0.12</td>
<td>$0.12</td>
<td>$0.13</td>
<td>$0.13</td>
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<td>$0.14</td>
<td>$0.14</td>
</tr>
<tr>
<td>Energy Costs Maintenance, Repair and Tires per km $0.85</td>
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<td>$0.87</td>
<td>$0.89</td>
<td>$0.92</td>
<td>$0.94</td>
<td>$0.96</td>
<td>$0.99</td>
<td>$1.01</td>
<td>$1.04</td>
<td>$1.06</td>
<td>$1.06</td>
<td>$1.06</td>
<td>$1.06</td>
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<tr>
<td>Maintenance, Repair and Tires $0.85/km increasing at 2.5% a year</td>
<td>-$102,000</td>
<td>-$104,550</td>
<td>-$107,164</td>
<td>-$109,843</td>
<td>-$112,589</td>
<td>-$115,404</td>
<td>-$118,289</td>
<td>-$121,246</td>
<td>-$124,277</td>
<td>-$127,384</td>
<td>-$1,142,745</td>
<td>-$1,142,745</td>
<td>-$1,142,745</td>
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<td><strong>Total</strong></td>
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<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
<td><strong>1.09</strong></td>
<td><strong>-</strong></td>
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Cash-flow comparative analysis between *Trum and medium duty vehicle (high usage, medium increase)*
## Cash-flow comparative analysis between Trum and medium duty vehicle (high usage, medium increase)

<table>
<thead>
<tr>
<th>Year</th>
<th>Initial Cash Down (10% of total vehicle costs)</th>
<th>Yearly Payment on Capital 6% interest rate (at the end of each period)</th>
<th>Driver’s Salary 30$/h</th>
<th>Diesel Fuel Cost At 6% yearly increase</th>
<th>Energy Costs per km at 23.5L/100km</th>
<th>Maintenance, Repair and Tires at 0.42/km</th>
<th>Discounted Subtotal Costs at 2.5% a year</th>
<th>Adjusted for 6% yearly discount rate</th>
<th>Estimated Discounted Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$80,250.00</td>
<td>$-8,025</td>
<td>$-9,813</td>
<td>$-62,400</td>
<td>$23.5L/100km</td>
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<td>$-8,025</td>
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<td>$0.42/km</td>
<td>$-51,660</td>
<td>$-8,025</td>
<td>$1,208,922</td>
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<td>$-9,813</td>
<td>$-62,400</td>
<td>$-45,944</td>
<td>$0.42/km</td>
<td>$-52,952</td>
<td>$-8,025</td>
<td>$1,269,368</td>
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<td>$-9,813</td>
<td>$-62,400</td>
<td>$-48,701</td>
<td>$0.42/km</td>
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<td>$0</td>
<td>$-9,813</td>
<td>$-62,400</td>
<td>$-51,623</td>
<td>$0.42/km</td>
<td>$-57,023</td>
<td>$-8,025</td>
<td>$1,269,368</td>
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<tr>
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<td>$0</td>
<td>$0</td>
<td>$-9,813</td>
<td>$-62,400</td>
<td>$-54,720</td>
<td>$0.42/km</td>
<td>$-58,449</td>
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<td>$1,269,368</td>
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<tr>
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<td>$-9,813</td>
<td>$-62,400</td>
<td>$-58,003</td>
<td>$0.42/km</td>
<td>$-59,910</td>
<td>$-8,025</td>
<td>$1,269,368</td>
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<tr>
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<td>$0</td>
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<td>$-62,400</td>
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<td>$0.42/km</td>
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<td>$0</td>
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<td>$-65,172</td>
<td>$0.42/km</td>
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<td>$0.42/km</td>
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<td>$-8,025</td>
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</tbody>
</table>

**Total Costs Subtotal**

**Revenue/Cost Ratio**

Calculated from adjusted total costs at 5% profit margin
### Cash-flow comparative analysis between Trum and medium duty vehicle (low usage, high increase)

<table>
<thead>
<tr>
<th>Trum Year</th>
<th>Initial Cash Down (10% of total Vehicle Costs)</th>
<th>Yearly Payment on Capital</th>
<th>Driver's Salary 30$/h</th>
<th>Electricity Cost At 6% yearly increase</th>
<th>Energy Costs at 6% yearly increase</th>
<th>Maintenance, Repair and Tires $0.85/km increasing at 2.5% a year</th>
<th>Subtotal Costs Discounted 6% yearly discount rate</th>
<th>Revenue/Co st Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-$200,000</td>
<td>-$244,562</td>
<td>-$62,400</td>
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<td>-$34,000</td>
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<td>-$380,044</td>
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<td>-$266,779</td>
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</table>


**Revenue/Cost Ratio:**

- **Estimated Revenue:** $2,365,986
- **Cost Ratio:** 0.88
### Cash-flow comparative analysis between Trun and medium duty vehicle (low usage, high increase)

<table>
<thead>
<tr>
<th>Year</th>
<th>Initial Cash Down (10% of total vehicle costs)</th>
<th>Yearly Payment on Capital</th>
<th>Driver’s Salary 30$/h</th>
<th>Diesel Fuel Cost At 10% yearly increase</th>
<th>Energy Costs 23.5L/100km</th>
<th>Maintenance, Repair and Tires per km</th>
<th>Maintenance, Repair and Tires 0.42/km increasing at 2.5% a year</th>
<th>Costs Subtotal 6% yearly discount rate</th>
<th>Discounted Subtotal Adjusted for 6% yearly discount rate</th>
<th>Estimated Revenue Calculated from adjusted total costs at 5% profit margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>-$8,025</td>
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<td></td>
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<td>$-8,025</td>
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<td>$-911,895</td>
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<td>-$18,092</td>
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<td>$-87,212</td>
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<td>-$77,499</td>
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<td>-$24,146</td>
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<td>-$72,430</td>
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<td>$-1,135,600</td>
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</tbody>
</table>

| Revenue/Cost Ratio |                                           |                           |                       |                                        |                          |                                      |                                                 |                                        |                                      | $788,662                                       |

- Total: $788,662
- 1.05
<table>
<thead>
<tr>
<th>Year</th>
<th>Vehicle Costs</th>
<th>Initial Cash Down (10% of total vehicle costs)</th>
<th>Yearly Payment on Capital (at the end of each period)</th>
<th>Driver's Salary</th>
<th>Energy Costs</th>
<th>Maintenance, Repair and Tires</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$2,000,000</td>
<td>-$200,000</td>
<td>-$244,562</td>
<td>30$/h</td>
<td>506kWh/100km</td>
<td>per km $0.85 increasing at 2.5% a year $0.85/km</td>
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<td>$-68,000 increasing at 2.5% a year $-68,000</td>
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<td>$-$691,830</td>
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</tbody>
</table>

Discounted Subtotal Costs Estimated Revenue: 3 times that of MDV $3,182,637

Revenue/Cost Ratio: 1.03
### Cash-flow comparative analysis between Trum and medium duty vehicle (medium usage, high increase)

<table>
<thead>
<tr>
<th>MDV</th>
<th>Year</th>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<th>Revenue/Cost Ratio</th>
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<td>Initial Cash Down</td>
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<td>Diesel Fuel</td>
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<td>$0.42/km increasing at 2.5% a year</td>
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<td>Adjusted for 6% yearly discount rate</td>
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Calculated from adjusted total costs at 5% profit margin

Total costs at 5% profit margin: $1,060,879

Revenue/Cost Ratio: 1.05
Cash-flow comparative analysis between Trum and medium duty vehicle (high usage, high increase)

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<th>5</th>
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<td>(10% of total vehicle costs)</td>
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<td>6% interest rate (at the end of each period)</td>
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<tr>
<td>Driver’s Salary</td>
<td>$30/h</td>
<td>$0.10</td>
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<td>$0.13</td>
<td>$0.13</td>
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<tr>
<td>Electricity Cost</td>
<td>At 6% yearly increase</td>
<td>$-60,720</td>
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<td>$0.85/km increasing at 2.5% a year</td>
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<td>$-511,384</td>
<td>$-519,509</td>
<td>$-528,018</td>
<td>$-536,932</td>
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3 times that of MDV
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<th>Total</th>
<th>Revenue/Co</th>
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<tr>
<td>Vehicle Costs</td>
<td></td>
<td>$80,250.00</td>
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Calculated from adjusted total costs at 5% profit margin