The Financial Viability and Sustainability Benefits of Using Cargo Trikes Instead of Vans for 'Last-Mile' Logistics in London in the Age of Online Shopping

The Financial Viability and Sustainability Benefits of Using Cargo Trikes Instead of Vans for 'Last-Mile' Logistics in London in the Age of Online Shopping

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Abstract

Up to 10,000 people die every year in London because of air pollution, a growing proportion of which is caused by emissions from diesel vans delivering goods ordered online. Local authorities have the power to solve the problem but most of them are not acting quickly enough to introduce measures that restrict and reduce access by commercial vehicles to town and city centers. Until they do so, morbidity and premature deaths from air pollution will continue to rise in step with the increase in van registrations and the inexorable rise in online shopping.

The aim of this study was to determine if replacing vans with electric cargo trikes (ECTs) is feasible for deliveries in the "last-mile", the final segment of the delivery chain. My main research question asked if the economic, environmental and social benefits of using ECTs instead of vans are sufficient to induce local authority policy-makers to promote their adoption and use, even if the financial benefits do not accrue to the local authority itself. I hypothesized that a cost-benefit analysis (CBA) model would show that ECTs are more financially viable than vans, particularly if the cost of providing a centrally-located transfer hub is subsidized by a third party.

Data to address the research question were obtained by contacting companies, individuals, government departments, trade associations and others. Additionally, interviews were conducted at conferences in London, Oxford and Vienna. The data were input to a CBA spreadsheet that linked operational, environmental and social costs to a set of independent and derived variables. The model was set up using a

full-cost accounting framework to calculate key financial appraisals and valuations of health and environmental impacts of one ECT and one diesel van operating in London over a seven period (2018 – 2024).

The model was run to calculate changes in gross profit and net present value (NPV) under different operating conditions. A total of 11 different scenarios were modeled by varying the values in the independent variables sub-set. The financial, environmental and social impact of changes in average fee receivable per package delivered, changes in package size, changes in speed of travel caused by traffic congestion, and changes in delivery address density were among the metrics examined.

Sensitivity analysis for variations of +/- 25% on baseline values was conducted in order to establish which variables had the greatest impact on gross profit and NPV. Results showed that riding/driving time, package drops per stop, and vehicle days per year were among the most critical for profitability.

The baseline scenario, using best estimates for independent and derived variables, showed that ECTs are on average 3.1 times more profitable than diesel vans, that they reduce environmental costs by a factor of 19.4, and reduce health and social costs by a factor of 11.8.

The main implication of the thesis is that premature deaths from exposure to diesel emissions from vans could be reduced by 91.5% if local authorities were to introduce measures that lead to the replacement of the van fleet with ECTs in the last mile.

Dedication

"Nobody made a greater mistake than he who did nothing because

he could do only a little"

Edmund Burke (1729 - 1797)

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Definition of Terms

3PL third-party logistics is a company's use of third-party businesses to perform some or all of that company's distribution and fulfillment services.

AV autonomous vehicle

BEP break-even price or break-even point

BEV battery electric vehicle, synonymous with electric vehicle (EV)

cargo cycle: a two-, three-, or four-wheel vehicle that can be human powered or battery powered; also known as cargo bike, freight bicycle, truck bike, load bike, trike or quad

CEPs courier, express and parcel services

CL city logistics, also known as urban logistics

containerization in city logistics: reflects the idea that inter-city logistics operators can deliver containers of parcels to terminals inside or around the city for break-down, collection and onward delivery by smaller vehicles (e.g. cargo cycles).

CV commercial vehicle

DC distribution center

drop density: the density of delivery points in a given area – the closer the delivery points are to each other the higher the number of deliveries that can be effected in a given time with a given vehicle.

DSP delivery service provider, e.g. FedEx, B-Line, UPS, DHL

DSPs delivery and servicing plans

EAPC electrically-assisted pedal cycle. In the UK, the EAPC regulation limits the use of electric assistance to cycles or trikes with a motor not exceeding 250 Watts of maximum continuous rated motor power. Also, the maximum speed achievable by the motor must be no more than 25km/ph or 15mph.

ECT electric cargo trike

energy expenditure: the amount of energy used, for example, in an activity. The most common unit of energy expenditure is the kilocalorie. The daily energy expenditure of an individual is dependent on sex, basal metabolic rate, body mass, body composition and activity level. The approximate expenditure of an adult male lying in bed is 1.0 $kcal^{-1}h^{-1}kg$ body $mass^{-1}$; for slow walking at 25 mm $mile^{-1}$ (1.6 km), 3.0 $kcal^{-1}h^{-1}kg$ body $mass^{-1}$; and for fast, steady running at 6 mm $mile^{-1}$, 16.3 $kcal^{-1}h^{-1}kg$ body $mass^{-1}$. Females have an energy expenditure 10% lower than males doing a comparable activity. See also metabolic equivalent (Oxford Dictionary of Sports Science & Medicine, 3.Ed).

EFV electric freight vehicle

Euro 6: the latest diesel-engine emissions legislation being driven by the European Commission. Since 2015, all new cars registered are required to meet Euro 6 standards, which halve the amount of nitrogen oxides that a diesel car is permitted to emit.

externality: the cost that affects a party who did not choose to incur that cost or benefit (Buchanan & Stubblebine, 1962). Externalities arise when a person or a company makes a choice that affects others but is not factored into the market price.

fulfilment center: in industrial-speak, a fulfillment center is a warehouse, often operated by a third party, where orders are processed for direct shipment to the end-user.

FCC a freight consolidation center is an intermediary logistics facility that intercepts many incoming deliveries destined for a relatively local area and then forwards them to recipients in consolidated loads. [see also ULC and UCC].

FCEV fuel-cell electric vehicle

FTC freight traffic control refers to the practice of setting up and using a third party to control the equitable and efficient distribution of freight across an urban area. FTC is seen as having the potential to realize the achievement of CO_2-free city logistics by 2030.

fuel economy: the energy efficiency of a particular vehicle expressed as a ratio of distance traveled per unit of fuel consumed, usually miles per gallon. Fuel economy is dependent on engine efficiency, transmission, and tire design.

fuel efficiency: the capacity of an engine or vehicle to obtain energy from fuel

functional unit: in the context of life cycle assessment functional unit is a measure of the function of the system being studied; it provides a reference on which comparisons can be mathematically related. Conceptualize the use phase as a unit process, where the function delivered is the output, and the reference flows are the inputs.

FUT future urban transport

GBW gross bike weight is the gross maximum operating weight of the specified bike. It includes the bike chassis, body, cargo box, wheels, motor, battery, standard accessories, rider (weighing 80kg), and cargo. GBW is the maximum total weight at which a fully-loaded bike can be safely operated at a speed of up to 30km/ph.

GVW gross van weight is the gross vehicle weight or gross maximum operating weight/mass of a vehicle as specified by the manufacturer including the vehicle's chassis, body, engine, engine fluids, fuel, accessories, driver, passengers and cargo but excluding that of any trailers.

HGV heavy goods vehicle, defined as having a gross weight greater than 3.5 tonnes

ICE internal combustion engine

ICEV internal combustion engine vehicle

last mile: the final leg in a delivery service whereby a consignment leaves a distribution center and is delivered to the recipient's address or a nominated collection point

LCV light commercial vehicle, having a maximum gross weight of 3.5 tonnes

LEFV light electric freight vehicle

LEV low emissions vehicle, or can also refer to light electric vehicle logistics, the commercial activity of transporting goods to customers

LEZ low emissions zone

LGV light goods vehicle

load length: the length of the area in which cargo is carried

MCC micro consolidation center, situated not on the periphery of the city but as near to the city center as possible

MPG the number of miles traveled per gallon of fuel consumed

multi drop: round-trip delivery route with multiple stops, as opposed to an A to B delivery route

nominal continuous power rating: the amount of power an electric motor can supply constantly, for an hour; measured in Watts passenger kilometer (pkm): the unit of measurement representing the transport of one passenger by a defined mode of transport over one kilometer

PCN penalty charge notice, synonymous with parking ticket

pedelec: see EAPC.

road footprint: the road-space taken up by a given vehicle, expressed in square meters

rolling resistance: the energy lost when the tire of a vehicle is rolling; the extent of the deformation of the tire is the main cause of loss; incorrect tire pressure adds to deformation.

RSS road space sharing—allocating road space to different categories of users at different times of the day

SCE The National Bureau of Statistics of China reports energy consumption in metric tonnes of Standard Coal Equivalent.

traffic congestion costs: Traffic congestion costs consist of incremental delay, vehicle operating costs (fuel and wear), pollution emissions and stress that result from interference among vehicles in the traffic stream, particularly as traffic volumes approach a road's capacity.

UAV unmanned aerial vehicle, e.g. drone

UCC urban consolidation center (synonymous with UDC, and ULC), a terminal where goods are transferred from large vehicles to small ones, normally situated on the periphery of a city or large town; also known as urban distribution center.

ULC urban logistics center (synonymous with UCC and UDC)

ULEV ultra-low-emission vehicle

ULEZ ultra-low emission zone

unladen weight: the weight of a vehicle when not carrying a passenger, goods or other items; it includes the body and all parts normally used with the vehicle or trailer when on a road. It does not include the weight of fuel or batteries in an EV.

urban logistics: the transportation of goods in cities

van 4-wheel light goods vehicle weighing less than 3.5 tonnes gross

Watt hours: voltage x amp hours

WTW well-to-wheel methodology is widely used for policy support in road transport. It can be seen as a simplified life cycle assessment that focuses on energy consumption and CO_2 emissions, ignoring other stages of a vehicle's life cycle. viz. production.

ZEZ zero emissions zone

Chapter I

Introduction

According to the World Health organization (WHO, 2014) 3.7 million people died worldwide in 2012 from diseases directly attributable to outdoor air quality. In Europe an estimated 400,000 people die prematurely every year as a result of breathing foul air and millions more suffer from respiratory and cardiovascular diseases caused by air pollution (EC, 2017). In the UK, around 40,000 deaths are attributable to exposure to outdoor air pollution, costing the country more than £20 billion per year (RCP, 2016). In London alone an estimated 9,500 people die annually from long-term exposure to air pollution (Walton, 2015a).

After energy production, transport is the world's second biggest cause of poor air quality. In Europe, deliveries to businesses and households in cities are a major component of transport, and as the practice of online shopping for express delivery is increasing rapidly so is the number of parcels and the number of delivery vehicles.

Ambient air quality standards matter. Innocent people, including children, are dying prematurely simply through the act of breathing. "Air pollution affects us at just about every stage of life, starting in the womb, continuing through childhood, adolescence and young adulthood into old age" (RCP, 2016). Much of this is attributable to the high proportion of diesel to petrol cars in the UK, in stark contrast to the USA or Japan where diesel vehicles are not common (RCP, 2016).

Nitrogen oxides, particulate matter, and volatile organic compounds emitted from the tailpipes of delivery vehicles and from brake and tire wear are among the main causes. The effects of these toxins after inhalation can take years to develop into a diagnosable disease, during which time they increase incapacity, morbidity, and hospitalization, all of which represent a substantial expense to society. Although emissions occur along the entire length of the supply chain, nowhere are the health hazards posed by transport more lethal than in the final stage of delivery, the stage commonly referred to as the 'last-mile'. Engine 'warm-up' and traffic congestion mean that 40% of CO_2 emissions from transport and 70% of other pollutants from transport occur in the last mile (European Commission, 2015).

The literature contains several references to the high external costs of road transport in the city; however, none appears to have evaluated the cost of emissions from freight vehicles as a discrete category separate from other forms of road transport. And none appears to have quantified the impacts of parcel deliveries from online purchasing, or to have examined the alternatives. These impacts are certain to increase rapidly in coming years as online shopping escalates. To what extent could last-mile deliveries using vans be replaced by bicycle deliveries? What contribution could such a modal shift make? Certainly it would have benefits in terms of human health, and it would also reduce the production of greenhouse gases. But would these benefits be trivial or significant? Businessmen, investors and policymakers are among those who need answers to these important questions.

Research Significance and Objectives

Using London as an example, my research evaluated the costs of ‘business as usual’ (BAU) and compared them with the economic, environmental, and social benefits of using electric cargo trikes (ECTs) for the delivery of e-commerce packages to recipients in the last mile. The environmental benefits were calculated in terms of reduced greenhouse gas emissions, and the social benefits, with a particular emphasis on human health. If shown to be feasible and if adopted and implemented by city planners, my research would contribute to cleaner air and a reduction in deaths from air pollution not only in London but in cities worldwide.

My objectives were:

- To evaluate the financial feasibility of operating a cargo-trike business, and to identify the conditions under which this could be achieved
- To compare the costs of running a cargo-trike operation with the costs of providing delivery services by diesel-engine vans
- To determine whether the social and environmental benefits produced by providing transfer hubs for cargo-trike operations would be sufficient to induce local authorities to adopt policies that would make it happen
- To enable policymakers to make informed decisions about the benefits of ECTs as a substitute for delivery vehicles powered by internal combustion engines

Background

To achieve the stated objectives of this study, it is necessary to conduct a cost-benefit analysis, the overall design of which should be based on the ‘environmental full cost accounting' (EFCA) framework (Wikipedia, 2018) that requires enterprises to include external as well as internal costs in their management accounts. Costs are represented in three discrete bottom line categories. First is the standard accounting measure of operational costs. The second monetizes the environmental impact of an organization's activities. The third category quantifies the costs that the company inflicts on society, with particular reference to human health.

Thus, EFCA aims to measure the financial, environmental and social performance of a company over a period of time, and is sometimes referred to as 'triple bottom line' accounting (Economist, 2009). Companies that have successfully adopted this method of management accounting include: Dell Corporation, Southwest Airlines, DHL, Patagonia, and Ben and Jerry's. Other companies, such as Kellogg, Diageo, Nike and General Motors have adopted the accounting standards of the Sustainability Accounting Standards Board's (SASB) which launched a European initiative on the London Stock Exchange in November 2018 (SASB, 2018).

The publication of the IPCC Special Report on Global Warming (IPCC, 2018) makes it clear that the world's business sector will have to play a major role in implementing policies and practices that reduce carbon emissions. The report specifically mentions transport as one of those sectors that most needs to undertake the "rapid and far-reaching" transitions required if global warming is to be limited to an increase of 1.5ºC.

Practically, the evaluation of transport activity on the environment and on health comes through cost-benefit analysis of several factors, the most significant of which is air pollution from tailpipe emissions.

Health Effects of Air Pollution

Air pollution emitted from transportation contributes to smog and to poor air quality, which have negative impacts on the health and welfare of city-dwellers worldwide. People over the age of 50 appear to be particularly vulnerable to air pollution. According to a large, recent study, “Current limits on fine particulate matter (PM2.5) in the air set by the U.S. Environmental Protection Agency (EPA) may not be sufficient to protect elderly people from the risk of premature death from air pollution” (Harvard T.H. Chan, 2017). Young children are even more vulnerable to lung damage from air pollution. In fact they are at risk even before they are born. Researchers at Queen Mary University (London) found sooty particles in the placentas of pregnant mothers and said it is quite possible the particles had entered the fetuses too (QMUL, 2018). Another impact of air pollution is on worker productivity. Researchers at the U.S. National Bureau of Economic Statistics suggest that a 10-unit increase in the air quality index decreases productivity by 0.35% (Gueorguieva, 2017).

Serious though the situation is in the U.S. it is much worse in many other countries. In the words of the UK Government: “Poor air quality is the greatest environmental risk to public health in the UK” (Defra, 2017).

The World Health Organization (WHO) reported that in 2012 one in 15 of total global deaths resulted from outdoor air pollution exposure (WHO, 2014). This finding more than doubled previous estimates and confirmed that, when added to indoor pollution, air pollution is the world’s largest single environmental health risk.

The WHO data reveal a strong link between air pollution exposure and cardiovascular diseases, such as strokes and ischemic heart disease, as well as between air pollution and cancer. This is in addition to air pollution's role in the development of respiratory diseases, including acute respiratory infections and chronic obstructive pulmonary diseases (COPDs). WHO figures indicate that outdoor-air-pollution-caused deaths can be broken down by disease, as follows: 40% ischemic heart disease, 40% stroke, 11% chronic obstructive pulmonary disease, 6% lung cancer, and 3% acute lower respiratory infections in children (WHO, 2012]. The WHO report said that reducing air pollution could save millions of lives.

The WHO air quality report has had a major impact on public opinion and has led to pressure on national governments and municipalities around the world to bring emissions down to safe levels (EU, 2016). Some are responding. For example, Norway is considering a nationwide ban on petrol and diesel cars by 2025 (Sheehan, 2016). In March 2017 an appeal court in Germany upheld a decision which could mean a diesel ban in Munich, one of Germany's biggest cities (ClientEarth, 2017). And in the UK, the government announced in July 2017 that all internal combustion engine vehicles (ICEVs) will be banned from all the country's roads in 2040.

Meanwhile, logistics firms in London will face Ultra Low Emission Zone fees from April 2019 when non-Euro-6 heavy-goods vehicles (HGVs) will have to pay a daily fee of £100 ($130) to operate in the current congestion-charge zone. The intention is to expand the zone's reach across London and to cover all vehicles by 2021 (Shone, 2017).

Pollutants from Transport

The major pollutants from transport include: nitrogen oxides (NOx), particulate matter (PM10 and PM2.5), hydrocarbons or VOCs, carbon monoxide (CO), and ozone

(O3). The transportation sector is a major contributor of all of the above. In the U.S. it accounts for more than 50% of the NOx emissions inventory, more than 30% of VOCs and more than 20% of PM emissions. The transportation sector also contributes to emissions of air toxics, which are compounds known or suspected to cause cancer or other serious health and environmental effects. Examples of mobile source air toxics include benzene (C6 H6), formaldehyde, and diesel particulate matter (US EPA, 2016). The health effects of the major air pollutants are the following:

- Nitrogen Oxides: NOx, which comprises nitric oxide (NO) and nitrogen dioxide (NO2), is emitted from combustion processes. Road transport is one of the main sources. According to the UK National Atmospheric Emissions Inventory (NAEI), road transport is now the largest single UK source of NOx, accounting for almost one third of UK emissions (Defra, 2017). Short-term exposure to concentrations of NO2 higher than 200 µg m-3 can cause inflammation of the airways. NO2 can also increase susceptibility to respiratory infections and to allergens.

  Studies have found that both day-to-day variations and long-term exposure to NO2 are associated with mortality and morbidity. Evidence from studies that have corrected for the effects of PM indicates a causal relationship, particularly for respiratory outcomes (WHO, 2013b) (Comeap, 2015a).

  In addition to damaging human health, NOx also damages the environment. It contributes to the formation of secondary nitrate particles in the atmosphere. High levels of NOx can harm plants, forests and crops. NOx also contributes to acidification and eutrophication of terrestrial and aquatic ecosystems. And in the presence of sunlight, NOx reacts with volatile organic compounds to produce photochemical pollutants including ozone (Defra, 2017).

- Particulate matter: These are particles which pass through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter (ISO, 2018). This size fraction is important in the context of human health, as PM10 particles are small enough to be inhaled into the airways of the lung. PM10 can be primary (emitted directly to the atmosphere) or secondary (formed by the chemical reaction of other pollutants in the air such as sulphur dioxide SO2 or NO2).

  Research shows a range of health effects (including respiratory and cardiovascular illness and mortality) associated with PM10. No threshold has been identified below which no adverse health effects occur (WHO, 2000). The internal combustion engine is the leading cause of PM10. Other man-made sources include tire and brake wear.

- PM10 also damages the environment. Black carbon in PM is implicated in climate change. Secondary PM includes sulphate, nitrate and ammonium, formed from SO2, NOx and NH3 which are the main drivers for acidification and eutrophication (Defra, 2017), (WHO, 2000).
- PM2.5 is the finer-size fraction of PM210. It can be primary or secondary and has the same sources, the main one being road transport. Emissions from road transport accounted for 12% of PM10 and PM2.5 in 2016 and constitute the third largest source in the UK. (Defra, 2018). However, increasingly, non-exhaust sources of PM10 (for example tire wear) have become a more important consideration as exhaust PM10 has been reduced as a result of tighter emission standards throughout Europe. In fact, in

2015, 69% of emissions from the road transport sector were related to non-exhaust sources (Glue, 2017). A conservative estimate for particulate matter is that it reduces average life expectancy in the UK by around six months, worth £16 billion a year (Defra, 2015b).

- Carbon monoxide (CO): This is produced when fuels containing carbon are burned with insufficient oxygen to convert all carbon inputs to carbon dioxide (CO_2). Road transport is the most significant source of this pollutant (NAEI / Defra, 2018).
  CO affects the ability of the blood to take up oxygen from the lungs, and can lead to a range of symptoms (GOV UK, 2013). CO can also contribute to the formation of ground-level ozone.
- Ozone (O_3): Ozone gas found in the upper atmosphere helps to protect against harmful ultra-violet radiation. In contrast, the ozone gas found at ground level is damaging to human health and ecosystems. Ground-level ozone is produced when nitrogen oxides (NO_x), carbon monoxide (CO) and non-methane volatile organic compounds (NMVOCs) from motor vehicles and industry react with each other in sunlight and stagnant air (NAEI / Defra, 2018). Combustion of fossil fuels is one of the leading causes of NMVOCs and some of their components such as 1,3-butadiene, benzene (C_6H_6), and toluene, are harmful to human health or are known to cause cancer in humans.

Short-term exposure to high ambient concentrations can cause inflammation of the respiratory tract and irritation of the eyes, nose, and throat. High levels may exacerbate asthma or trigger asthma attacks in susceptible people and some non-asthmatic individuals may also experience chest discomfort whilst breathing.

Evidence is also emerging of effects due to long-term exposure. O3 can travel long distances, accumulate and reach high concentrations far away from the original sources (WHO, 2000) (WHO, 2013b).

- Benzene (C6 H6) and health: Ambient benzene concentrations arise from combustion processes, including road transport. Benzene is a recognized human carcinogen which causes changes in the genetic material (mutagenic effect) of the circulatory and immune systems. No absolutely safe level can be specified in ambient air. Acute exposure to high concentrations affects the central nervous system (WHO, 2000) (PHE, 2014). Benzene can also pollute soil and water, leading to exposure for humans via these routes.

Transportation Logistics

Logistics can be categorized by type of transport infrastructure - road, waterways, rail and air. Traditionally, third party logistics operators (3PLs) have had a choice between gasoline-powered ICEVs and diesel ICEVs. Diesel-powered vehicles generally have better fuel economy, and their CO_2e emissions rate per vehicle-mile travelled is marginally lower than for a comparable gasoline-powered vehicle. However, diesel is a major source of harmful pollutants, e.g., ozone-forming emissions, including nitrogen compounds NO_x as well as PM (US Bureau of Transportation, 2015). Thus, gasoline-powered vehicles are more damaging in terms of CO_2, but diesel-powered vehicles are (much) more damaging to human health.

Road transport has a huge impact on the health of the world's population. For example, the cost of the health impact of air pollution in OECD countries (including deaths and illness) was about US$1.7 trillion in 2010, and available evidence suggests that road transport accounts for about 50% of this cost, or close to US$1 trillion (OECD, 2014).

In the U.K. there has been a marked increase in the sales of vans relative to sales of HGVs (DfT, 2016) and the majority of these are diesel powered. It is likely that diesel-powered van sales have increased by a similar amount in other European countries, and elsewhere in the world. Diesel vans are the most favored mode of delivery for 3PLs because diesel fuel is typically cheap compared with gasoline. For this reason, 3PLs are reluctant to abandon the diesel van.

Shopping and Transport Air Pollution

Logistics has always been a major aspect of shopping. A considerable portion of outdoor air pollution is produced by ICEVs transporting goods from supplier to consumer, either collected from retail outlets (personal shopping) or via direct delivery (home delivery). For example, in the U.K. in 2009 an average of 973 trips were made by road per person and the highest proportion of those trips — 20 percent — were made for the purpose of shopping (DfT, 2016). Thus it can be said that shopping is a major contributor to air pollution and its adverse impacts on human health. If the UK is typical of other developed countries it can be said that 20% of personal travel by road is for the purpose of personal shopping, and by extension, if the OECD estimate is correct, it can be surmised that 20% of half of the 3.7 million deaths worldwide annually from outdoor air pollution – 370,000 deaths – are attributable to personal shopping.

In addition to its impact on air pollution and human health, the road transport component of shopping is also a major contributor to inner-city traffic congestion, noise pollution, road accident deaths and injuries, global warming, reduced visibility, inconvenience to pedestrians, and damage to vegetation, water, soil, and buildings. Road transport has a negative overall impact on the quality of life of those who work, dwell in or visit cities.

Increasing Retail Sales and Road Transport

Until we decarbonize the transport system, the impact of transport on human health and the environment is likely to increase in line with global retail sales, and global retail sales are set to increase. The global retail sector was estimated to have achieved revenues of US$22.6 trillion in 2015; this figure is expected to rise to US$28 trillion in 2019, following average annual growth of 3.8% since 2008. The retail sector represents 31% of the world's GDP. Hyper- and super-markets account for 35% of retail direct sales (Business Wire, 2016). More shopping requires more collections and deliveries, and this requires more vehicles, or larger vehicles or more trips, or all of the above, and even though new generation ICEVs may be less polluting than previously, overall emissions from shopping-associated transport are growing inexorably in tandem with population growth worldwide.

Belief that retail sales will continue to grow at 3.8% per annum is bolstered by forecasts for a considerable increase in the size of the global logistics market, which is dominated by road transport and is set to expand from $8.1 trillion in 2015 to $15.5 trillion by 2023. Road continues to be the most favored mode of transport (TMR, 2016).

E-Commerce Changes Transport Logistics

Shopping is not only growing, it is changing. It has been undergoing a transformation since 1995 when Amazon launched its online bookshop. Since then e-commerce has grown dramatically as brick-and-mortar stores throughout the world followed suit and started to offer their products online. None of them has managed to keep pace with Amazon, but virtually all of them now have a presence on the internet (Dhiraj, 2016). The country with the largest B2C e-commerce market is China with sales of US$975 billion in 2016 (Statista, 2018). E-commerce in the U.S. continues to experience strong compound annual growth of 10% per annum, which translates into $480 billion in online sales by 2019, with physical goods leading the growth as sales of digital goods reach maturity. E-commerce in Europe has also shown remarkable growth and this is set to continue at an average of 11.3% per year over the next five years so that by 2022, an estimated 20% of non-grocery retail sales will be online (Forrester, 2017).

The biggest players in the UK's online retail market are Amazon (16% market share), followed by Tesco (9%) and eBay (8%). Other big online retailers are Argos, Next and John Lewis. Fashion and sporting goods are popular product categories in the UK, followed by travel and household items. Other popular product categories are movies & music, and 'books & magazines' (Ecommerce in the UK, 2017). In addition to undergoing 'natural growth', e-commerce is now getting a boost from companies like Shopify and Big Commerce which are doing for online shopping what WordPress did for blogging (Baldwin, 2017).

The growth in online shopping has resulted in the closure of hundreds of brick-and- mortar outlets in the U.S. For example, big-box retailers J.C. Penney, Macy's, and

Sears all announced recently that they would be shuttering dozens more stores as shoppers increasingly shift online. There have been numerous store closures in the UK, and this trend is likely to continue. Many stores that remain open do so only because they provide a location for customers to collect or return goods ordered online (Wahba, 2017). In February 2018 it was announced that two large multi-store retailers, Toys-R-Us and Maplin's, were going into the UK equivalent of the US Chapter 11, with the likelihood that they will go into liquidation. Debenhams could be next.

Meantime, internet transactions now account for around 15 per cent of UK retail sales, excluding vehicle fuel. Some £133bn was spent online with UK retailers in 2016, up £18bn on the year before. This has led to explosive growth in the parcels delivery sector which is now worth nearly £10bn per year (Pooler, 2017).

A survey carried out by the UK Freight Transport Association states that in 2016, as much as 20% of non-food sales are now made online, with the total number of packages delivered to UK homes in 2015 totaling 860 million, up from 600 million in 2012 (SMMT, 2016a). The number of persons working as van drivers increased by 23% in 2015/16 taking the total UK van-driver population to 244,000 (FTA, 2017).

The switch to online shopping is a game-changer for logistics. It puts the focus onto last-mile delivery, and it is happening worldwide. By 2020, global online retail sales will likely be $4 trillion (Figure 1) or nearly 15% of global retail sales. Already in 2016 global e-commerce equaled $1.9 trillion (eMarketer, 2016).

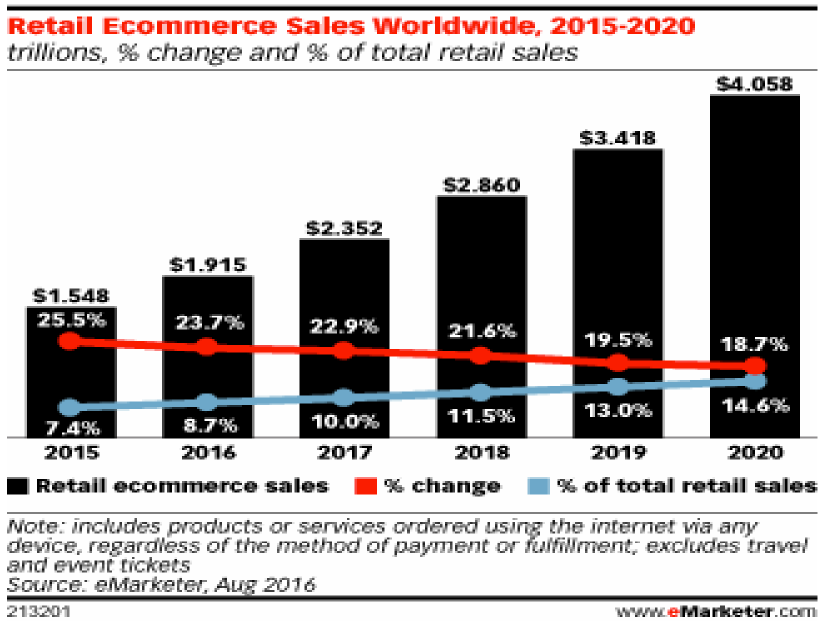

Figure 1. Retail e-commerce sales worldwide 2015-2020.

The emergence of e-commerce to take a significant slice of the world retail market begs the question: Is e-commerce more sustainable than conventional retail shopping in terms of its impact on the environment and human health? Research (Edwards, McKinnon, & Cullinane, 2010) indicates that while neither has an absolute advantage, on average, the home-delivery operation by a service provider is likely to generate less CO_2 than the typical conventional shopping trip. The only scenario in which CO_2 emissions generated by conventional shopping is clearly lower than for online shopping is when shoppers leave their cars at home and travel to the shops by public transport, by foot or by bicycle. Other researchers seem to agree that online shopping has the edge (TerraPass, 2016) and that online shopping is the most environmentally-friendly option in a wide range of scenarios (Weideli, 2013). But being less damaging than conventional shopping does not make e-commerce sustainable. The sustainability of the e-commerce sector may, to a large extent, depend on whether the market leader decides to adopt socially responsible modes of delivery.

Historically, Amazon has not operated its own fleet for deliveries to customers, preferring to outsource to independent contractors. For years it has used the services of established 3PLs, mostly UPS and FedEx in the U.S. (Weise, 2016), and Yamato in Japan; but in September 2015 Amazon started to recruit amateur drivers with their own vehicle to collect packages from Amazon delivery stations (pickup centers) and make deliveries to customers on a part-time basis (Hern, 2015). Called Amazon Flex, this app-based program was rolled out initially in Seattle but is now in more than 30 cities across the U.S. and 17 cities in the UK (Amazon, 2018). In addition to Flex, Amazon has a program called 'Deliver with Amazon'. This uses full-time owner drivers of medium-size vans. Typically, these drivers work for Amazon through agencies or small independent logistics companies. These medium-size vans are too large to be economical for use in the last mile.

In 2015 Amazon recruited some of the industry's top corporate social responsibility specialists. It remains to be seen whether they will reveal Amazon's figures for Scope 3 greenhouse gas emissions, *ergo* their contribution to climate change and the other external costs of ICEVs. Meanwhile, figures from the UK Society of Motor Manufacturers and Traders (SMMT) indicate that the number of van registrations increased rapidly following the arrival of Amazon in the U.K. (SMMT, 2017). Despite a slow-down in vehicle sales in 2017 because of negative publicity around diesel, there has been a substantial increase in the sales of vans weighing up to 3.5 tonnes since 2009.

Last Mile Delivery

This thesis focuses on the last leg of delivery in the B2C logistics delivery chain. This leg – commonly referred to as 'last-mile' delivery – refers to the final stage in the logistics chain where goods are transferred from a depot, fulfillment center, or hub to the recipient's address or nominated collection point.

The term last-mile incorrectly implies an exact distance of one mile. In fact, the distance could be one block, 100 kilometers or any distance in between. However, whatever the distance, it is the very last portion of the final leg that is the main subject of this study. The reason why it is of particular interest to logistics companies is because, in terms of cost per mile, it is the most expensive and inefficient segment of all, all the more so in low-density areas (Figure 2). Some estimates put the cost of last mile as high as 25 to 30% of total transport cost (Kerr, 2018).

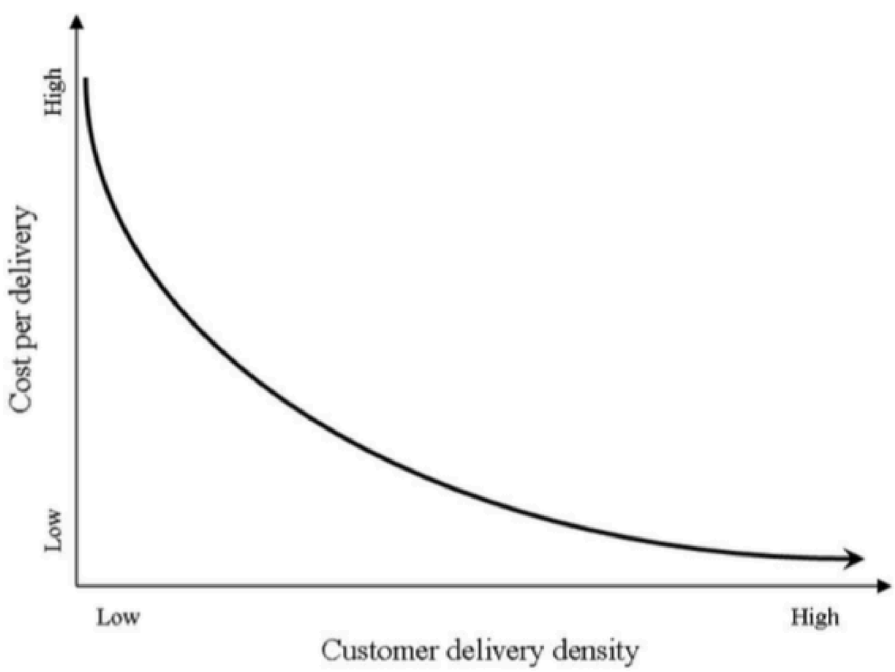

Figure 2. Customer delivery density (Boyer, Prud'homme, & Chung, 2009).

The last-mile stage is also of particular interest to environmentalists and public health officials because it is during the last mile that the greatest amount of PM, CO_2, CH4, NOx, VOCs and other toxins are emitted on a per mile basis. Engine 'warm-up' is one of the factors that makes short trips by far the worst polluters. Some 40% of CO_2 emissions from transport and 70% of other pollutants from transport occur in the last mile (European Commission, 2015). But the main overall cause of last-mile problems is traffic congestion. The congestion problem is both chronic and acute. In 2014, congestion caused urban Americans to travel an extra 6.9 billion hours and purchase an extra 3.1 billion gallons of fuel for a congestion cost of $160 billion. Trucks account for $28 billion (17%) of that cost, much more than their 7% of traffic (INRIX, 2015). Congestion in the UK's biggest cities is 14% worse than it was in 2011 (Begg, 2016), The overall cost of traffic congestion in London, the world's seventh most congested city, was £9.5 billion in 2017 (INRIX, 2018).

As in most countries, main roads in London are typically divided into three tracks, each of which can be seen as a separate system. The widest is the main part of the road used for the bulk of motorized transport vehicles. Outside that is the bus lane, and outside that is the cycle lane. Cyclists, including cargo cyclists, are legally permitted to use any of the three tracks. Vans are only allowed to use the inner portion of the road. Buses are not allowed to use cycle lanes except when they have to pull in at a bus-stop, or where roads narrow and the bus lane merges with the cycle lane. So there is some fluidity in usage between cycle lanes and bus lanes in the UK. In systems where the cycle lane system is completely separated from the bus lane – as it is in the Netherlands –

congestion in the bus lane has no impact on the cycle lane because the two systems are separated. This is not the case in London, where congestion in the main motorized lane and the bus lane does have an impact on average achievable speeds in the cycle lane. Nevertheless, this division of road space gives cargo cyclists a major advantage over van drivers.

The congestion problem is being exacerbated by motorized delivery companies, none of whom appears to be committed to addressing the issue. One company in particular could make a significant difference. Amazon is beginning to represent such a large slice of the e-commerce space in the West that the transport modes they adopt have a significant impact on climate change, the environment and on human health. For example, if Amazon were to eschew diesel vehicles and give notice that only owners of electric vehicles would qualify to make that last-mile delivery on their behalf, local air pollution from deliveries in the city would be significantly reduced. By the same token, if Amazon were to stipulate that only cargo bikes and trikes should be used in the city, not only could air pollution from deliveries be virtually eliminated, congestion could be considerably reduced as well because bikes and trikes can operate in cycle lanes thereby reducing the amount of road space that would otherwise be taken up by delivery vans.

Transport Options for Last Mile Delivery

The challenge for both conventional shopping and online shopping is to reduce emissions to sustainable levels. Business as usual is no longer acceptable. Some logistics firms believe that electric vehicles (EVs) are the solution. For example, when the diesel engine of one of their delivery vans needs to be retired, UPS replaces it with an electric motor. Moreover, specialist EV logistics companies have become established. Gnewt

Cargo operates a fleet of 100 EVs in and around London and is proving to be a financially viable company (Gnewt, 2017). However, generally speaking, logistics companies are reluctant to switch to EVs because they are more expensive to purchase than diesel-powered vehicles.

The EV certainly eliminates the exhaust emissions problem in the last mile, and if the electricity used comes from renewable sources it also eliminates Scope 2 CO_2 emissions at the utility. However, EVs do less well with regard to non-exhaust emissions. A recent study reveals that because of their higher weight - on average 24% heavier than their conventional counterparts – EVs emit a bigger quantity of break- and tire-wear particulate matter (Timmers & Achten, 2016). Further, EVs do nothing to relieve traffic congestion which slows down pedestrians, public transport, fire engines, ambulances, police vehicles, school buses and other essential services. Overall, deliveries by EVs negatively affect the quality of life of city dwellers and visitors by occupying too much space in the urban environment.

Several other possible alternatives to the diesel van are emerging. Drones, robots, and autonomous vehicles are in the early stages of development and application. But, electric cargo trikes (ECTs) are now technologically advanced, and may be the best option to replace vans.

Cargo Cycles – Bikes, Trikes and Quads

There are several types of cargo cycle. The basic one has a payload limit of about 125kg and is an elongated version of a standard bicycle but with the addition of a platform onto which a cargo box is fixed. The second type is in fact not a bike but a trike such as the one shown in Figure 3.

Figure 3. A UPS cargo trike being trialed in Pittsburgh, USA (2017).

Trikes have a payload of up to 300kg (660 pounds), and are more expensive to buy, ranging in price from US$3,000 to US$12,000 (FGM-AMOR, 2017). Quads are four-wheelers and are often of the recumbent type where the rider is seated in a laid-back reclining position.

All three types are available with battery-powered electric motors. Battery-assisted cargo cycles are growing in popularity because they can negotiate hills, enable greater delivery speed, and make it possible to increase cargo-box size up to as much as 3 cubic meters (Walker, 2015), equaling the capacity of a small van. Some key features are:

- Drive units / motors: Motors and batteries are normally supplied in one package, ensuring that they match and function together to best effect. Among the main drive-unit brands in Europe are Bosch, Dapu, Bafang, Shimano, Heinzmann, and Crystalyte.

- Pedelec speed regulations: There are two categories of electric bicycle in type-approval in Europe. L1e-A is for powered cycles with a maximum speed of 25 km/h and maximum 1 kW of power. L1e-B includes speed pedelecs with maximum 45 km/h and 4 kW.
- Health and safety: It is widely believed that by being in the enclosed space of a car or van, motorists and their passengers are less exposed to tailpipe emissions than are cyclists. However, researchers have shown that tailpipe fumes from other vehicles are sucked into the cabin of the car where they remain and are inhaled by the occupants. Thus, it has been claimed that cyclists are in fact less exposed to tailpipe emissions than motorists. Nevertheless, because of increased respiratory rates, cyclists tend to inhale more on-road emissions than those whose respiratory rates are normal for a sedentary position (Ramos, Wolterbeek, & Almeida, 2016). This means that cyclists on electrically-assisted bicycles and breathing relatively normally are less prone to health damage than cyclists only using human pedal power at raised respiratory levels.

  Safety concerns were the prime reason cited for the U.K. General Post Office to get rid of its 24,000 bikes and purchase diesel vans instead (MacMichael, 2010). However, cycling is becoming safer in the UK as municipalities give greater priority to cycling, re-open abandoned cycle lanes, install new cycle lanes and crack down on careless driving by motorists.

  The potential sustainability benefits of ECTs over diesel van parcel delivery prompted the analyses conducted for this thesis research. The business as usual model is to continue using diesel vans to meet the need for more last-mile deliveries as e-commerce increases. However, given the environmental and health costs of diesel-fuel powered vehicles it is critical to evaluate more sustainable modes of delivery in the last mile.

This requires a comparative analysis of the total economic, environmental and social effects of converting to bicycle-powered transport. This kind of analysis has not been conducted before.

Research Questions, Hypotheses and Specific Aims

My overall research questions were: Are the benefits (economic, environmental and social) of using ECTs instead of vans to deliver packages in the 'last mile' sufficient to induce city planners to develop policies promoting their adoption and use? And further:

- Is the adoption of bikes for delivering packages in U.K. cities a financially viable alternative to using vans, if evaluated as an investment over time? In addressing these questions, I expect to examine these specific hypotheses:
- A social appraisal of the use of ECTs instead of vans powered by fossil fuels in last-mile deliveries of packages produces significantly greater sustainability benefits, including a measurable reduction in the death rate.
- An enterprise financial appraisal will show that the last-mile delivery of packages by trike is more financially viable than delivery by van.

Specific Aims

My specific aims in completing the research were to:

1. Develop a business spreadsheet appraisal to differentiate last-mile transport options and scenarios, over time
2. Estimate variables and construct scenarios to make comparisons based on relevant data sources
3. Establish the conditions (the numeric values for specific variables) under which delivery by ECTs is more financially viable than by van
4. Use a financial spreadsheet model to identify the environmental impacts made by vans and compare them with those made by ECTs in the last-mile
5. Quantify, if possible, the relative impact of vans and cargo bikes on human health, incapacity, morbidity and death
6. Evaluate the overall sustainability benefits of using ECTs instead of vans

Chapter II

Methods

This research involved the construction of a financial appraisal comparing the two options — trike and van — and additionally, environmental and social appraisals in which these options are evaluated for their impacts. The model was in the form of an Excel spreadsheet. The architecture of the model is shown in Figure 4 below.

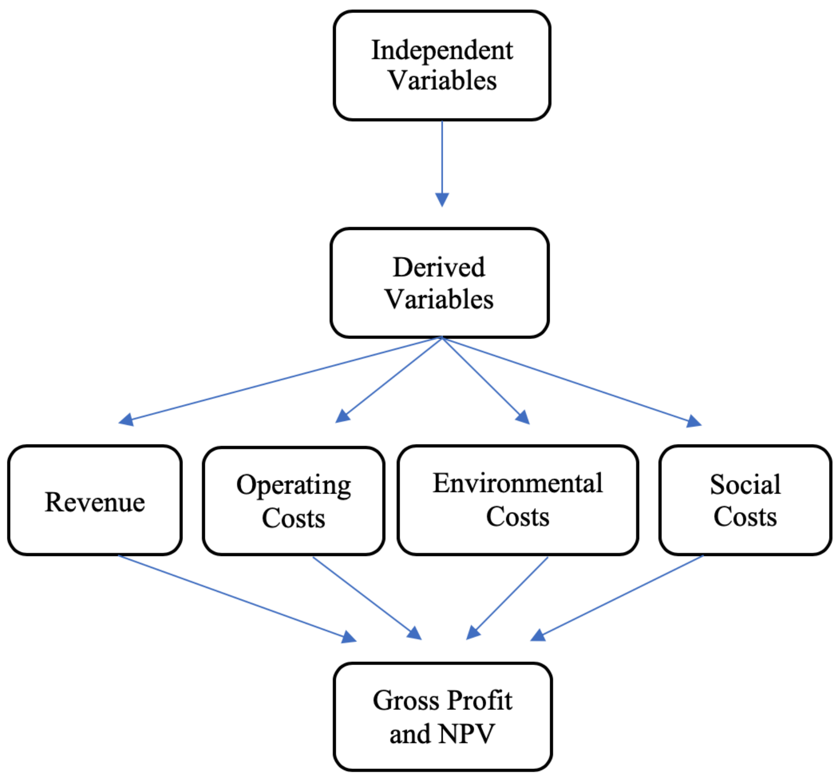

Figure 4. Architecture of the study.

The structure for the cost side of the financial appraisal for the two options was identical, namely 20 line items covering typical overhead and on-road variable costs over a period of seven years. The structure of the environmental analysis was also identical for both options and comprised six line items around greenhouse-gas emissions, upstream costs and ecosystem costs. The third element of the spreadsheet was structured to accommodate data on 13 line items for social costs under categories for PM2.5, PM10, ozone and NO2, and three line items for miscellaneous costs, namely congestion-, road accident- and road-damage costs.

The structure for the revenue side of the appraisal required data on two revenue streams, assignment revenue and redeployment revenue. Quantifying these two streams was at the core of the research and required data for 24 discrete independent variables such as: the distance between delivery stops, the number of packages delivered per stop, carbon price per tonne of CO2e emitted, riding/driving time permitted per day, package size, speed of travel, and so forth. These independent variables were the drivers for 28 derived variables which in turn were the drivers for profit and loss tables that I used to determine the profitability and financial viability of the two options.

It was necessary to obtain and process the data needed to run the model, and identify the conditions under which the trike could profitably replace van delivery of packages in the last-mile space. The default search criterion was for data pertaining specifically to London, but where these were not found, data for the UK as a whole were used. When relevant, use was also made of data from continental Europe and the USA.

Data were obtained by making direct contact with companies, individuals, government departments, trade associations and others. Structured interviews were conducted and meetings were held at conferences and exhibitions in Vienna, London and Oxford, and by arrangement. Email and telephone were the main methods of communication. Although several pieces of related data were often found for a given topic or metric, they typically emanated from more than one source. The result was that the study became like a mosaic, a patchwork composed of many fragments from different sources. This is one of the reasons why there are so many entries in the References.

The data actually input to the spreadsheet model were often determined through adjustment, deduction, extrapolation, inference and triangulation. Where they were evident, levels of uncertainty are mentioned. The methods used to obtain and process data for the model are presented under three broad headings: costs, revenue and variables.

Costs

Costs in this study are classified as operational, environmental or social. The initial task was to identify the line items to use in the financial analysis. I took advice from accounting and industry experts and constructed a spreadsheet with 20 discrete cost labels, divided into overhead costs and on-road costs. The line items are based on commonly used operating factors and are widely applicable. The spreadsheet covered a period of seven years to correspond with the useful life expectancy of the vehicles being studied. I examined trikes and vans in turn.

Operating Costs: Trikes

I contacted manufacturers in Europe and the UK, and operators of ECTs in the UK. I received a high degree of cooperation, though some companies were understandably reluctant to supply what they perceived to be ‘commercially sensitive’ data. Cost considerations and estimates for trikes (Table 1) informing the operational-cost element of the spreadsheet model were:

- Trikes purchase price: The average price of the 16 e-assist trikes included in this study was £8,092. This figure includes the motor, battery and box/container, but excludes electronic dashboard, delivery charges, VAT and other taxes.

Table 1. Operational cost labels for trikes and vans.

Overhead Costs	On-Road Costs
Purchase cost of vehicle	Electricity / diesel fuel
Depreciation	Congestion charge
Road use tax (VED)	Parking fines
Vehicle insurance (comprehensive)	Brake pads/discs (fitted)
Public & employers' liability insurance	Tires
Goods in transit insurance	Repairs
Bookkeeping/accounting/legal fees	Battery
Rental of premises	
Servicing and MOT	
Delivery management software rental	
Rider/driver salary	
National Insurance (NI)	
Advertising and marketing	

Source: Compiled by the author.

- Depreciation: The mechanical demands placed on a cargo bike are proportionate to its amount of use, but putting a value on second-hand trikes in order to calculate depreciation is difficult because the amount of use may not have been recorded. The market for second-hand trikes is still small, so prices vary widely. I asked 12 ECT manufacturers how many years their products would last if operated for 10,000 kilometers per year. The consensus was 10 years. However, trike operators said they expected trikes to have a useful life of only seven years. I used the straight-line depreciation method to spread cost equally over the life of the vehicle down to zero value at the end of the seventh year.

- Road use tax: ECTs are exempt from road use tax in the UK.
- Vehicle insurance: This type of insurance for commercial cargo bikes is not mandatory and arguably may not be important for cargo bikes. But ECTs are a lot more expensive than cargo bikes and it would seem prudent to insure them against theft. I obtained an estimated quote from ETA, a specialist cycle-insurance company.
- Public liability insurance: This class of insurance is mandatory. It was assumed that premiums payable would be the same as for van operators (see below).
- Goods in transit insurance: It was assumed that the premium for this class of insurance would be the same as for vans (see below).
- Bookkeeping/accountancy/legal: as per vans (see below).
- Rental of premises: as per vans, £275 p/m2 for an area of 37.16m2.
- Servicing: Most ECT manufacturers declined to recommend servicing, saying that their products did not need it. Those that did recommend servicing said twice yearly was sufficient. The indicative price averaged £48 per service.
- Delivery management software: as per vans (see below).
- Rider's salary: The average hourly rate paid to employees of European cycle logistics companies is €12.50 (£11.13) (ECLF Survey, 2016). Although some British operators may pay their employees this rate, others probably pay no more than the UK national living wage, which in November 2018 was set at £7.83 per hour. I applied an hourly rate midway between the European average and the UK living wage, i.e., £9.48.

Assuming a working week of 45 hours and a working year of 50 weeks [as it is for vans], the annual average salary would be 50 x 45 x 9.48, for a total of £21,330.

- National Insurance (NI): This was calculated on the same basis as for van drivers.
- Advertising and marketing: This was based on industry averages.
- Fuel (electricity) for distance traveled: Scope 3, see 'Fuel unit cost' below.
- Congestion charge: not applicable.
- Parking fines: not applicable.
- Brake pads and discs. Some of the larger ECTs are supplied with motor-cycle brakes, but most are supplied with MTB hydraulic-disc brakes. Magura is the dominant brand. Disc wear depends on cargo weight, usage and other factors, but it emerged that on average they last about six months and cost £20 per pair.
- Tires: Tire mileage is influenced by tire pressure, cargo load, road surface, ambient temperature and riding style. For example, "when used in hot weather with a heavy load and on rough asphalt, a tire wears much faster" (Schwalbe, 2018). As a general guide, European ECT operators use moped tires or mountain-bike tires from the Schwalbe Big Ben or Marathon range. Although these would typically last 12,000 km in private use, they wear out approximately twice as quickly in commercial cargo use. I found that the tires cost approximately £25 each.
- Repairs: The cost of repairs and replacements on cargo bikes/trikes is a product of many factors, however, distance traveled emerged as the main determinant. Some operators said they kept records of exactly how long each part lasts and how much it costs to replace. Others budgeted an arbitrary amount per month per bike. Some operators performed repairs in-house, others employed the services of a freelance

mechanic costing on average £12 per hour; and some relied on bike shops where costs can be up to £40 per hour. I contacted 24 bike operators and found that the median cost of this category was £0.0125 per bike per kilometer traveled during years 2 and 3, rising to £0.0250 in years 4 through 6, and £0.0375 in year 7. Most ECT manufacturers do not provide a warranty. I aggregated total repair costs and then spread them over the 7-year period on a straight-line basis.

- Battery: The battery is one of the most expensive parts of an ECT. They are mostly of the lithium-ion type and range from around 200Wh to over 1,000Wh in capacity. This study focuses on trikes with a 500Wh battery pack. Battery life is measured in terms of the number of times that it can be recharged; and the number of charges is typically a factor of the distance traveled per charge (the range), as well as the distance per route. I assumed that the battery would be put on charge daily for 250 days per year. Heinzmann guarantees their batteries for a minimum of 600 charge cycles.
- Electricity unit cost: The kilowatt hour (kWh) rate varies from business to business as well as by utility company and contract length. However, the average price paid by small businesses in the UK in 2017 was €0.177 (£0.16) per kWh (Eurostat, 2018).
- Battery capacity: I found that Bosch, Heinzmann, GreenPack and BMZ were the main suppliers to the European trike-battery market, but Heinzmann and Bosch dominate. I obtained data on 25 different batteries and in all cases I was able to obtain figures for voltage, amp hours, and Watt hours. I excluded GreenPack on the grounds that with a capacity of 1,400 Wh it was an outlier. I also contacted operators engaged in delivering packages in the London area, as well as bike manufacturers and

distributors, to obtain details about the most commonly used cargo-bike batteries in the UK. The most common voltage in use was 43 volts and the most common Ah rating was 11Ah. Multiplying these two numbers produced a figure of 473 Watt hours or 0.473 kWh average capacity.

- Cost per charge: Although the overall efficiency of lithium-ion batteries is good, charging efficiency is relatively poor, particularly if a fast charger is used (Toman, Cipin, Cervinka, Vorel, & Prochazka, 2016). Also, fast chargers are expensive, so most trike operators use standard chargers. These, like all chargers, incur charging losses. To account for these losses I added 18% (0.08514) to the average capacity figure (0.473 kWh) to produce a figure of 0.55814 kWh used to charge a 473-Watt hour battery. Multiplying this figure by the unit cost of electricity in the UK (£0.16 per kWh (Eurostat, 2018).) produced a cost-per-charge figure of £0.0893024. This calculation can also be stated as: $K = ((V*Ah)/1000) + L) * P$ where V = volts; Ah = amp hours; L = charging losses; P = unit cost of electricity; K = cost per charge.
- Battery range: I learned that ECT operators only rarely were concerned that their trike battery would not have enough charge to complete a given delivery route. And if there was doubt in their minds, they would issue the rider with a spare battery. I also learned that in most cases, far from exhausting the battery, the trike returned to base with 15% charge still available. This meant that instead of using 0.55814 kWh per day they were actually using 0.474419kWh per day/trip.

Operating Costs: Vans

Vehicle categories in the UK are defined according to the European Commission classification 2007/46/EC as last amended by 385/2009. The vans evaluated in this research come under Category N1, motor vehicles with at least four wheels designed and constructed for the carriage of goods, and having a maximum laden mass not exceeding 3.5 tonnes (VCA, 2018). Figure 5 shows an example of this category.

Costs covered under this heading include: Vehicle cost, Depreciation, Servicing, Repairs, Tires, Battery, Brake pads and discs, Road use tax, Insurance, Congestion charge, Parking fines, Professional fees, Software, Rent, and Fuel costs.

- Purchase cost of vans: The UK Vehicle Certification Agency (VCA) lists 1,865 different vans, and divides them into five categories: small, medium, large, 4 x 4, and pickup. Most package delivery companies prefer to use small vans to deliver in the last mile. VCA lists 325 small vans with manual transmission and diesel engine. The manufacturers are: Citroen, Fiat, Ford, Mercedes-Benz, Nissan, Peugeot, Renault, Vauxhall, and Volkswagen. I obtained the discounted prices of their 10 most popular vans, and calculated the mean average price, excluding value added tax (VAT).

Figure 5. The Ford Transit Courier small van.

- Depreciation: Depreciation on vans is very rapid during the first three years of use (Campbell, 2017). However, for the sake of simplicity, I used straight-line depreciation to spread this cost equally over the life of the vehicle down to a zero value at the end of the last year in the life of the vehicle.
- Servicing: Broadly speaking, van servicing and repairs in the UK are performed by three types of company: manufacturer's authorized dealers, franchised operators and independent garages. Typically, authorized dealers are the most expensive and independent garages the least expensive. I used franchised-operator prices for the financial model in this thesis.

  Recommended service intervals for vans are six months for an interim service, and 12 months for a full service, throughout the life of the vehicle. Servicing by franchised operators is often conducted on a fixed-price basis. The average prices charged by a leading franchise operator were used in this study.

When they are three years old, all vans are required to have what is called a Ministry of Transport (MoT) test for which a fee is charged. I looked at franchised operators and found that prices ranged from a minimum of £25 up to the maximum legally permitted fee of £55. I took the average to be £40 and included this amount in the calculations from year three to year seven, and then applied straight line costing to equalize costs over the seven-year period.

- Repairs/Battery/Brake Pads: Typically, vans being run in inner-city and urban environments require more maintenance than vans running on rural motorways and highways. In order to establish the average cost of supplying and fitting spare parts throughout the life of a van I used as a proxy a case study conducted on the UK's best-selling vans (Parker's, 2015). Having identified the Peugeot Partner van as the median for the vans selected I built a second proxy covering the main repairs likely to occur in the lifetime of a van operating in the last mile. These include: front wiper blades, timing belt, clutch, brake fluid, gearbox and windscreen. I calculated the cost of brake pads and discs separately and did the same for batteries.
- Tires: Van tires are specially designed to provide additional strength and durability over standard car tires. The industry-recognized labeling system for new tires (Evans, 2017) indicated that the correct tire for the Peugeot Partner was 205/65R15/94H, average price £85 each. Delivery operators expect to get at least 20,000 kilometers out of the front tires on a front-wheel-drive car, and double that for rear tires. Vans appraised in this thesis are front-wheel drive. The leading UK auto membership club

recommends moving partially worn rear tires to the front when the fronts become worn (AA, 2017). I calculated costs accordingly.

- Road use tax: It is illegal to drive a van on UK roads without first paying ‘road tax’. The fee for new vans weighing up to 3,500kg is currently £240 per year. Vans being appraised in this thesis weigh less than 3,500kg.
- Insurance: Vehicle insurance premiums depend on numerous factors. I got quotations for each of the 10 most popular vans for an experienced 30-year-old courier driver with a clean license, and a 100% no-claims bonus, driving up to 20,000 kilometers per year. I specified that the van is fitted with a Thatcham category 2 immobilizer, and a Securicor TrakBak tracking device. The median price was £1,432 per year.

  Public liability insurance covers damage or injury to other people or their property in the course of conducting the business. It is considered to be essential for a delivery company. I obtained an online quote that provides all risks cover in the sum of £1 million. I also contacted cargo bike operators and found that they are paying on average £500 per year for this class of insurance.

  Goods in transit insurance covers van delivery companies against claims over loss or damage of an item while in transit from one place to another or being stored during a journey. Courier networks require independent operators to have this insurance in place before they start working for them. I obtained an online quote for all risks cover in the sum of £10,000 per parcel being delivered by the employer or employees.
- Congestion charge: Vans that enter the London Congestion Zone, an area of eight square miles or 21 square kilometers —1.3% of the total area of Greater London —

are subject to a daily charge of £11.50 (RTT, 2017). Some last-mile delivery operators enter the zone only occasionally, while others are in there every day. In the absence of specific data on this variable, I allowed for an arbitrary average of one day per week across 50 working weeks per vehicle. Since October 2017, drivers of older, more polluting petrol and diesel vehicles entering the center of London are liable for a £10 fee on top of the congestion charge. However, vans appraised in this study are assumed to be newly registered Euro-6 vehicles, so the T-Charge does not apply (Matters, 2017).

- Parking fines: These apply not only in the inner city but right across London and beyond. The amount charged for contravention of parking regulations varies according to the area in which the contravention takes place, and for how long. The average amount charged is £130, discountable by 50% if paid within 14 days (UK Gov., 2017). It is almost inevitable that van drivers will incur penalties from time to time; they are an occupational hazard. In the absence of published data and after speaking with seven drivers in London in the Borough of Haringey on November 7, 2017, I concluded that the typical full-time driver will incur six penalties per year, and that these would be paid promptly at the discounted rate.
- Bookkeeping/accounting/legal fees: I obtained data from several websites and found that most small businesses in the UK spend approximately £1,000 per year on book-keeping and accountancy fees (including year-end submission of accounts for income- and corporate-tax purposes) and occasional legal advice.
- Delivery management software: There is a wide choice of software available for last-mile delivery companies to rent. I obtained approximate prices from DA Systems,

Podfather, OptimoRoute, Loginext Mile, LastMileLink Technologies, Insta Dispatch, and Tookan UK. Prices arranged from £10 to £250 per month.

- Rental of premises (urban): Although some startups are launched from home, I decided to include the cost of space to store a van and run a small office. I found that rentals varied considerably throughout London. Downtown sites – where delivery operators mostly want to be – are unaffordable. Suburban sites can be found, sometimes near railway stations. I searched several websites and found that the average amount of space required for a unit with sufficient space to park and turn a vehicle around was 37.16m2.
- Rental of premises (rural): Rental prices for premises in rural areas may be up to 80% lower than for down-town premises. Offsetting this benefit are factors such as a very substantial increase in stem time (see Definitions), as well as increased operating costs, and environmental, health and social costs. I calculated the effects of these changes in 'Distribution center location' in the Results section.
- Fuel cost: In order to calculate the total cost of fuel per van year I multiplied the value for annual mileage by the cost of fuel per liter as at March 01, 2018.
- Driver's salary: Based on 2,067 data points for small-van drivers in London, salaries range from a minimum of £6.65 to a maximum of £15.65 per hour, with a median of £9.14 per hour (Indeed, 2017). Assuming a working week of 45 hours and a working year of 50 weeks, the annual average salary would be 50 x 45 x 9.14, total £20,565.
- Employer's National Insurance Contribution (NIC): Based on an annual salary of £20,565, the amount of NIC was assessed using an online calculator (iCalc, 2018).

Environmental Costs: Vans

My aim was to quantify the amount and the burden of climate change pollutant emissions a) by using vehicle emission factors for vans and trikes and b) by putting a monetary value on estimated emissions. These were both direct emissions from burning diesel fuel, and indirect upstream costs of vehicle production:

- Greenhouse gas emissions / Van: I assessed vans for the most significant three of the seven main Kyoto gases that could be measured in the combustion of diesel fuel, namely: carbon dioxide (CO_2); methane (CH_4); and nitrous oxide (N_2O). Although traces of the 'F' gases (hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride and nitrogen trifluoride) are associated with van operations, they are not present in sufficient amounts to be worth quantifying in terms of environmental costs. Fuel combustion in diesel vans is categorized as a 'mobile activity' under Scope 1 activities in the Greenhouse Gas Protocol (WRI, 2018). I limited the operational boundary for greenhouse gas (GHG) emissions to Scope 1, specifically excluding the emissions incurred in the upstream supply and delivery of fuel to the point of purchase. In order to establish common ground in the Model I also excluded emissions from fuel burned in travel from the driver's home to the distribution center, and fuel used to return to the center with returns after all deliveries had been made, and then driving home.

  I followed WRI (WRI, 2018) recommendations for measuring GHG emissions by 'kilometers traveled'. The UK Government environment agency, DEFRA, was the most accessible source of pollutant emissions conversion factors (DEFRA, 2018). DEFRA has four classes for vans; the small-size vans that are the focus of this thesis are Class III (1.74 tonnes to 3.5 tonnes). I noted the kg/ CO_2 value (0.27377) per kilometer as well as the kg/ CO_2e values for CH4 (0.00001) and N2O (0.00187) as given in the Freighting Goods section of the tables (DEFRA, 2018). I then added 42% to these values in order to reflect real-life emissions as disclosed by ICCT, and I added a further 5.9% to account for the increase in fuel consumption and emissions per kilometer caused by an average 50% cargo load. This method of calculating the cost of CO_2 emissions (C) can be stated as: C = ((((D x K) x P) x L) / V) x P where D = kilometers traveled per year; K=kilograms of CO_2 generated per kilometer (conversion factor); P = percentage added to account for ICCT estimates; L = percentage added to account for cargo load; V = conversion rate from kg to tonnes; P = carbon price.

I also calculated CO2 and CO2e emissions in tonnes for the seven-year-life of the respective vehicles. This calculation can be stated as: T = ((((D x K) x P) x L) / V where T= tonnes CO2eq per year; D = kilometers traveled per year; K=kilograms of CO_2 generated per kilometer; P = percentage added to account for ICCT estimates; L = percentage added to account for cargo load; V = conversion rate from kg to tonnes

- Upstream costs / Van: The environmental impacts of vans can be divided into three parts: production phase, use phase, and disposal/recycling phase. The burden and costs of the disposal/recycling phase are not covered in this thesis because of a lack of data. The production phase for vans includes a) the mining, extraction and refining of materials; b) parts manufacturing; and c) assembly of parts into a finished vehicle ready for use.

The literature does not appear to have discrete data on production-phase emissions for LCVs; however, there are several papers on life cycle analysis of a passenger car. One of the most recent shows that production emissions of CO_2 vary substantially depending largely on emission factors for purchased electricity in the country of production (Hao, 2017). The Hao paper shows that the GHG emissions from the production of a conventional ICEV in China are around 9.6 tonnes per vehicle, 54% higher than the US level of 6.2 tonnes for the equivalent vehicle. I used the central value of 7.9 tonnes for the baseline environmental costs dataset.

- Miscellaneous environmental costs/ Van: Largely through the processes of acidification and eutrophication, air pollution from tailpipe emissions causes serious environmental damage affecting vegetation and fauna, the quality of water and soil, and the ecological services they support. The nine pollutants that do this - either directly, indirectly or both - are: sulphur dioxide (SO_2); carbon monoxide (CO); primary particulate matter (PM); polycyclic aromatic hydrocarbons (PAH); heavy metals (HM); nitrous oxides (NOx); ammonia (NH3); non-methane volatile organic compound (NMVOCs); and methane (CH4) (EEA, 2017). The literature does not appear to state the individual contribution of each pollutant to environmental damage. The state-of-the-art approach for evaluating air pollution effects is the 'damage cost approach' or the 'dose-response method' which focuses on quantifying the explicit impact that the emissions have on several areas, including the environment (MOVE, 2014, p. 27). Using this procedure – which has become known as the Impact Pathway Approach - the Ricardo-AEA Handbook on External Costs of Transport (MOVE, 2014) indicates a value of €ct1.1 per vkm for Euro 6 LCV diesel in urban driving conditions (Table 2). This correlates with a similar estimation (Schwermer, 2014) that stated the figure as of €c1.2 but without specifying the Euro-Class applied.

Table 2. Air pollution costs in €ct for Euro 6 diesel LCVs (2010).

Vehicle	EURO-Class	Urban (€ct/vkm)	Suburban (€ct/vkm)	Rural (€ct/vkm)	Motorway (€ct/vkm)
LCV petrol	Euro 1	1.3	0.9	0.5	0.5
	Euro 2	0.8	0.5	0.2	0.2
	Euro 3	0.7	0.4	0.2	0.1
	Euro 4	0.6	0.3	0.1	0.1
	Euro 5	0.6	0.2	0.1	0.1
	Euro 6	0.6	0.2	0.1	0.1
LCV diesel	Euro 1	5.3	2.4	1.4	1.3
	Euro 2	5.9	2.5	1.4	1.3
	Euro 3	4.6	2.0	1.1	1.1
	Euro 4	3.2	1.5	0.9	0.8
	Euro 5	1.4	0.8	0.6	0.6
	Euro 6	1.1	0.5	0.3	0.3

Source: Update of the Handbook on External Costs of Transport (MOVE, 2014).

Environmental Costs: Trikes

The propulsion of cargo trikes with the assistance of electrical power from batteries requires electricity, the production of which produces greenhouse gas emissions, unless it is from renewables.

- Greenhouse gas emissions: I calculated the amount of electricity used by ECTs on the basis that they recharge their batteries once per day. It was noted in the aforementioned battery capacity and cost-to-charge calculations, that, including charging losses of 18% and allowing for residual carry-over of 15%, the average trike battery uses 0.474419 kWh per day. I used the DEFRA tables for Scope 2 UK electricity (DEFRA, 2018) to calculate kg CO_2, CH4 and NO2 at the rate of 0.34885 per kWh, 0.00062, and 0.00209 respectively. The calculation for cost of CO2 emitted can be stated as: ((U x R) / C) x P where U = kWh consumed per day; R = kgCO2 emitted per kWh; C = equivalency kg into tonnes; P = carbon price per tonne. The calculation for tonnes emitted per year is as above, but with the omission of P.

- CO_2e from increased food consumption. The global food system, from fertilizer manufacture to food storage and packaging, accounts for up to 33% of all anthropogenic GHG emissions (Vermeulen, 2012). For this reason, the amount of food that we eat, and the nature and provenance of that food is one of the critical issues of our time.

Any increase in food consumption resulting from occupational demands has to be factored into the overall GHG emissions of that occupation. Although ECTs operate with the assistance of an electric motor, they will not function without the input of pedal power, which comes from energy stored in the human body; this in turn comes from food which can be represented in terms of kilocalories.

After consulting with a leading expert at Bosch E-Bike Systems I concluded that in average ambient conditions 50% of the total energy required to propel a trike comes from electrical power and 50% comes from human energy. Battery usage was estimated at 0.48719 kWh (0.473 kWh per day less the residual amount 0.07095kWh). If the human energy used to cover the same distance also equals 0.487 kWh, and 1 kiloWatt hour = 860 kilocalories, total kilocalories used equals 419 kilocalories (860 x 0.487) per rider per day.

To identify the ratio between GHGs and kilocalories I used data from the Food Emissions section of CGIAR (CGIAR, 2018). Their figures show that farm-to-fork production for a 2,100 kilocalories-per-day diet generates an average 2.955 kg of CO_2e. This can also be expressed as 1 kilocalorie represents 0.001407 kg CO_2e. Since each rider burns an estimated 419 kilocalories to perform a day's work, the amount of CO_2e generated by each rider is 0.590 kg CO_2e per rider per day. Where K = kilocalories per trip/day; and C= kg CO_2e per kilocalorie, the kilogram emission rate per day (E) can be stated as: $E = K \times C$

The calculation for the number of tonnes of CO2e emitted per year (N) can be stated as: $N= ((K \times C) / T) \times D$ where K = kilocalories per trip/day; C= kg CO_2e per kilocalorie; T = equivalency kg into tonnes; D = days worked per year.

- Upstream emission costs: trikes. The emissions generated in the production of materials and components required in the making of a cargo trike are also quantifiable, though data are less precise than for a van. Unlike domestic bicycles, where the frames are often made of aluminum, cargo-trike frames and other major parts are made of heavy-duty steel in order to withstand much heavier use.

  Other materials found in ECTs — their motors and batteries— include plastic, nickel, copper, rubber, and aluminum. In the absence of a cradle-to-grave life cycle analysis of cargo trikes, data from analyses of domestic bikes made with steel frames can be used as a benchmark on which to make estimates of actual impacts on the environment. I assumed that a large proportion of these materials originate in mainland China or Taiwan from where they are typically shipped to Europe for conversion into parts and for assembly into the finished product.

A study conducted in China (Cherry, 2009) indicates that energy consumption related to emissions from domestic e-bike manufacturing processes is heavily reliant on the combustion of coal. Table 1 in that study indicates that GHG emissions for electric bikes are 0.603 tonnes of CO_2e and for non-electric they are 0.097 tonnes. The difference is almost certainly due to exceptionally high emissions associated with mining and smelting lead for the manufacture of the lead-acid battery for the e-bike. For this reason I used the 0.097 value as a baseline starting point. The average weight of the ECTs evaluated in this study was 103.5 kg (including box, motor and battery), 4.3 times heavier than the 24kg average for a domestic bike with motor and battery. Using weight as the factor for establishing equivalency of CO_2e emissions I upwardly adjusted the 0.097 baseline value to 0.418 kg CO_2e for the production of one cargo trike.

- Ecosystem costs: The acidification and eutrophication of terrestrial ecosystems associated with emissions from vans does not apply to trikes because there are no exhaust emissions from trikes.

Social Costs: Health

This section focuses on monetizing the costs of air pollution in terms of healthcare, productivity losses, and utility (welfare).

- PM2.5 and health: The methods used in this research to determine health costs were informed largely by reference to the methodology employed by the UK's Royal College of Physicians (RCP). They follow the 'impact pathway' approach, which tracks air pollution from its source and then describes its impacts on the population.

RCP uses European Commission analyses (Holland, 2014) to state that the total cost of air pollution in the UK in 2010 ranged from €20 billion - €56.2 billion (£17.8 billion - £50,018 billion) (RCP, 2016). The wide disparity in these values is due to differing methods for valuing life – one is based on 'loss of life expectancy', the other is based on deaths.

I modeled these cost values after calculating midpoints for the two versions of mortality from PM2.5 pollutants (€24,600+€38,000)/2. For ozone deaths I modeled the midpoint in the range €61-146 million. These values are only for the costs attributable to PM2.5 and ozone pollutants. Estimates for the cost of NOX were not found in the RCP report.

In 2002, traffic-exhaust emissions accounted for 25% of total UK primary PM10 emissions and 34% of primary PM2.5 (Ayres et al., 2009). Bearing in mind the rapid growth in total traffic and the much-increased percentage of diesel vehicles in the UK fleet since 2002 I assumed that the 34% value for PM2.5 from road transport still applies today, despite tighter regulations on emissions. In the model I adjusted RCP endpoint values downwards proportionately. Vans of all types represent a 15% share of total traffic on UK roads (SMMT, 2016b); I adjusted the transport share downwards to reflect this.

The UK Office of National Statistics indicates that the number of people reporting as van drivers in 2016 was 250,000 (ONS, 2017). Triangulating this figure with 3.89 million total vans on UK roads (DfT, 2017) suggests that one in 16 vans (6.25%) is a package-delivery van. However, industry experts pointed out that the employment figure includes a substantial but indeterminate number of drivers who are not delivering e-commerce parcels but are delivering A-B for miscellaneous commercial activity.

An alternative estimate for dedicated e-commerce parcel delivery vans was obtained from a report produced by the Royal Automobile Club (RAC). They calculated van numbers by triangulating total parcels delivered per annum with average number of parcels delivered per van day. They estimate that 110,000 vans are engaged in B2C and B2B parcel deliveries (Braithwaite, 2017). On the basis that B2C represents 68% of the e-commerce market, 75,000 vans (approximately one in 50 or 2% of all vans) are engaged in this activity. I used the RAC figures in the model.

The health costs of PM2.5 (C) incurred per van (Table 3) can be stated as: $C = (((H*T)*V)*P) / X$ where H = national costs as stated by RCP; T = transport sector % share of national cost; V = all vans in UK fleet; P = percentage of parcel vans to all vans; X = the number of parcel vans in operation. RCP showed values for seven endpoints: mortality, chronic bronchitis, bronchitis in children 6 – 12, minor restricted active days, work loss days, asthma symptom days in children, and hospital admissions.

- NO2 and health: Recent studies on the health impacts and costs of transport-generated emissions in the UK have been driven by the WHO's landmark 'Health risks of air pollution in Europe' project (WHO, 2013a). One of their main conclusions was that because many pollutants are highly correlated (temporally and/or spatially) it is difficult to distinguish between their effects in epidemiological studies. They noted a significant overlap between the

Table 3. The impact of PM2.5 from parcel delivery vans in the UK (2014).

HEALTH & SOCIAL COSTS			National Cost	Transport sector	All vans	Parcel vans	Share per van	Share per van
DIESEL VAN			**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**	**PM2.5**
Health costs			£m/year	£m/year	£m/year	£m/year	£m/year	£/year
Mortality			27,857.0	9,471.4	1,420.7	88.8	0.000355	355.18
Chronic bronchitis			939.0	319.2	47.9	3.0	1.2E-05	11.97
Bronchitis in children 6 - 12			46.0	15.6	2.3	0.1	5.87E-07	0.59
Minor restricted active days			2,570.3	873.9	131.1	8.2	3.28E-05	32.77
Work loss days			542.9	184.6	27.7	1.7	6.92E-06	6.92
Asthma symptom days in children			33.8	11.5	1.7	0.1	4.31E-07	0.43
Hospital admissions			24.9	8.5	1.3	0.1	3.18E-07	0.32
Totals			32,013.9	10,884.7	1,632.7	102.0	0.000408	£408
Social costs								
Congestion costs	1,359.85	1,387.05	1,414.79	1,443.09	1,471.95	1,501.39	1,531.42	1,562.05
Accident costs (non-health)	94.00	95.88	97.80	99.75	101.75	103.78	105.86	107.98
PM10								
Road damage costs	307.00	313.14	319.40	325.79	332.31	338.95	345.73	352.65

Sources: The RCP, SMMT, and the European Commission (aggregated by the author).

measurement of PM2.5and NO2. Combining a single-pollutant coefficient for NO2 and a single-pollutant coefficient for PM2.5 is likely to give an overestimate. For this reason they recommended the use of a coefficient of 1.025 (1.01-1.04). Because values for PM2.5 were already established in the Model, the correcting coefficient was applied to NO2 values using a 33% reduction of the coefficient, as recommended by the UK government's Parliamentary Committee on Air Quality (Comeap, 2015b). Using UK government data (Defra, 2015a, Table 4) on total national health costs as a base, I made conversions to produce figures for the transport sector, the van sector and an individual van using the same method and percentages used to model PM2.5 health costs.

Table 4. Health impact from NO2 emissions (Defra, 2015a).

	Central (2.5%)	Low (1%)	High (4%)
Annual equivalent attributable deaths	23,500	9,500	38,000
Annual Social Cost	£13.3bn	£5.3bn	£21.4bn

The Defra figures for the UK as a whole correlate closely with figures produced by a study undertaken on London (Walton, 2015b) which can be taken to represent approximately 20% of the UK population. The Walton study, which also used the WHO HRAPIE coefficient, estimated total health costs at a central value of £2.55 billion, closely correlating to Defra's equivalent figure for the UK as a whole on a 5:1 population ratio. The formula for modeling the van share of NO2 costs can be stated as: C = ((((H - R)*T)*V)*P) / X, where H = national costs; R = reduction of 33%; T = transport sector % share of national cost; V = all vans in UK fleet; P = percentage of parcel vans to all vans; X = the number of parcel vans in operation.

- Ozone and health: I modeled and quantified the damage to health from ground-level ozone generated by parcel delivery vans. Ozone can also affect wild plants and forests (Defra, 2017) and decrease the productivity of crops. Ideally, these effects should be factored into the environmental section of the Model, however, in the absence of quantifiable data they were not modeled.
- PM10 and health: According to NAEI, emissions of PM10 totaled 1.98 k/t in 2015. I modeled this figure with damage costs per tonne as recommended by Defra (Table 5) to quantify total health costs from PM10. I calculated NPV at 1.02 for 2015-2018.

Table 5. Air quality damage costs per tonne, 2015 prices (Defra, 2015b).

Particulate Matter (PM)	Transport average	£58,125	£45,510	£66,052
	Industry	£30,225	£23,665	£34,347
	Domestic	£33,713	£26,396	£38,311

Table 6 provides a summary of the percentage contribution of each sector for each pollutant in 2015. The table is shaded according to the overall contribution of that sector to the pollutant total. The transport sector is responsible for 48.3% of nitrous oxide emissions, the biggest single contributor of this gas.

Table 6. Source emission contributors by sector for England (2015) (NAEI 2018).

Sector	NH_3	CO	NO_X	NMVOC	PM_{10}	SO_2	Pb
Agriculture	77.6%	0.0%	0.0%	10.7%	8.8%	0.0%	0.0%
Energy Industries	0.0%	4.5%	22.4%	0.0%	4.1%	52.2%	5.7%
Fugitive	0.0%	0.3%	0.0%	13.5%	0.0%	2.2%	0.0%
Industrial Combustion	0.0%	30.0%	17.4%	2.8%	13.1%	21.0%	21.8%
Industrial Processes	1.2%	5.1%	0.0%	7.1%	15.9%	3.9%	56.7%
Residential, Commercial & Public Sector Combustion	0.0%	32.0%	9.5%	6.9%	32.8%	18.2%	9.2%
Solvent Processes	0.0%	0.0%	0.0%	52.3%	3.6%	0.0%	0.0%
Transport Sources	2.2%	26.3%	48.3%	5.4%	17.5%	1.8%	3.7%
Waste	9.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
Other sources	9.7%	1.8%	2.4%	1.4%	4.2%	0.9%	2.8%

Social Costs: Miscellaneous

I included costs of noise, congestion, accidents and road damage:

- Noise cost: Noise contributes not only to annoyance and sleep disturbance but can also lead to heart attacks, strokes, learning disabilities, hypertension, productivity losses, dementia and tinnitus. A report by the WHO identified environmental noise as the second largest environmental health risk in Europe, accounting for more than one million healthy years of life lost annually to ill health, disability or early death (WHO, 2011). That part of growing traffic volume resulting from online shopping and van deliveries is a likely cause of increased noise in last-mile environments.

  In the UK specifically it is estimated that the annual social cost of urban road noise in England is £7 to £10 billion, placing it at a similar magnitude to road accidents (£9 billion) (UK Gov, 2018). The Ricardo-AEA Handbook does not provide country-by-country costs for noise pollution, however European-wide figures for different modes of transport are given in the Handbook's Table 28 (MOVE, 2014). I used references for daytime noise emanating from dense urban traffic to calculate costs at the rate of €44 per 1000vkm. None of these costs are internalized.

- Congestion costs of vans: Roads in most European capital cities are congested with slow-moving traffic. Either there are too many vehicles in relation to road space, or road capacity is insufficient to meet demand from vehicles. London is one of those cities where it is largely impractical and uneconomic to increase road capacity.

  Traffic congestion costs consist of incremental delay, vehicle operating costs (fuel, tire and brake wear), air pollution emissions, time lost, and stress, all of which result from interference among vehicles in the traffic stream (Addison, 2016). Although a substantial part of the burden caused by traffic congestion is borne by motorists themselves and is thus counted as an operational cost, traffic congestion is also a cost imposed on non-motorists. The part that is involuntarily borne by non-motorists is a social cost.

Not to make the distinction between operational and social costs would be to risk double counting whereby, for example, the cost of the extra fuel incurred by delays caused by congestion is counted not only in van operating costs but also in congestion costs. As the ‘distance traveled’ values used in my ‘financial appraisal’ section included operating costs, I had to avoid duplicating the same costs under the congestion heading in the environmental costs section.

I used the updated version of the Ricardo-AEA Handbook to identify the social costs of congestion (MOVE, 2014). Ricardo-AEA states that the best practice estimation of congestion costs is based on speed-flow relations, value of time and demand elasticities. Referencing these metrics, Ricardo-AEA states a preference for the efficient marginal congestion cost (EMCC) interpretation over the market marginal congestion cost interpretation and recommends that only EMCCs are included in social cost calculations (MOVE, 2014).

Ricardo-AEA states that the best information currently available is the bundle of speed-flow relations of the FORGE model used in the National Transport Model of the UK (DFT, 2009). The FORGE model distinguishes between several types of areas and roads and states that the results for London "will not be considered", as they can be regarded as too specific. Instead, the results for “conurbations” (other large cities) are used as a proxy for typical metropolitan areas (MOVE, 2014).

Table 9 of the Handbook shows results for three road types – motorway, major roads and other roads in metropolitan, urban and rural areas. To approximate the van delivery scenario in London I used data for cars on ‘other roads’ in the metropolitan region (Table 7). Industry experts suggested I assume 95% of the driving was in ‘free-flow’ conditions, 3% in ‘near capacity’, and 2% in ‘over-capacity’. To that total I added 20% to account for the passenger car equivalence (PCE) value of 1.2 using SUVs as a proxy for vans with a short wheel-base (Adison, 2016) and converted the result into £ to reach a baseline value for the spreadsheet.

Table 7. Efficient marginal congestion costs in €ct per vkm, EU average, (2010).

Vehicle	Region	Road type	Free flow	Near capacity	Over capacity
			(€ct/vkm)	(€ct/vkm)	(€ct/vkm)
Car	Metropolitan	Motorway	0.0	26.8	61.5
		Main roads	0.9	141.3	181.3
		Other roads	2.5	159.5	242.6
	Urban	Main roads	0.6	48.7	75.8
		Other roads	2.5	139.4	230.5
	Rural	Motorway	0.0	13.4	30.8
		Main roads	0.4	18.3	60.7
		Other roads	0.2	42.0	139.2

Source: Table 9 from Ricardo-AEA Update of the Handbook on External Costs of Transport, (MOVE, 2014).

The calculation for congestion costs per van can be stated as: (((((K*X)*B) + ((K*Y)*C) + ((K*Z)*D))/100)*P)*R where K = vehicle kilometers per year; X represents percentage of Vkm at free flow rate; B represents free flow factor on ‘other roads’; Y represents percentage of Vkm at ‘near capacity’; C represents near capacity flow on other roads; Z represents percentage of Vkm at ‘over capacity’; D represents over capacity factor on other roads; P represents passenger car equivalence; R represents the exchange rate. For the baseline scenario I modeled the €ct per vkm at an NPV of 1.02 from 2010.

- Congestion costs for trikes: Congestion impacts tend to increase with size by increasing a vehicle's road space usage. The congestion costs of different vehicles are measured in terms of PCEs. In the absence of data on PCE values for cargo trikes, I used websites to obtain data on trike lengths and widths, and determined an average 'footprint' value of 2.2 sq. meters. I then compared this to corresponding measurements of short-wheel-base medium-size parcel delivery vans (10.3 sq. meters) also obtained from websites. The result showed the trike requires 4.68 times less road space than the van. On this basis I attributed to cargo trikes 4.68 times less in congestion costs in the spreadsheet Model.
- Accident costs: Accident costs for vans can be categorized either as operational or social. Accident costs in road transport are typically captured through risk-oriented insurance policies, the cost of which is modeled in the financial appraisals. Major costs internalized by accident insurance include: medical costs, production losses, material damage, and administrative costs. Not normally covered is so-called 'risk value', a proxy to estimate the pain, grief and suffering caused by traffic accidents (Lindberg, 2006). Additional costs include expected cost for the relatives and friends of the person exposed to risk, and the cost for society, mainly police, ambulance and state hospital costs.

  To identify marginal accident cost estimates I used the Ricardo-AEA Handbook (Table 12) and selected values for passenger cars on urban roads in Great Britain as a proxy for vans in London. This showed €0.2ct (£0.18) per vkm at 2010 prices. I adjusted this figure upwards by 100% to reflect the higher risk associated with operating a commercial van as distinct from a passenger car.

For trikes, I used the values for passenger cars on urban roads in Great Britain as a proxy for cargo trikes in London. This showed €0.2ct (£0.18) per vkm at 2010 prices. I doubled this figure to reflect the added risk associated with operating a commercial vehicle.

- Road damage costs: Vehicles damage road surfaces. Heavy vehicles damage road surfaces exponentially and more severely than light vehicles. The damage caused is reduced by increasing the number of axles. A truck with two rear axles (tandem) will cause less damage than a truck of the same weight with a single axle. The nine vans appraised in this study were single axle vehicles with an average weight of 1,950 kg. Thus, on a rigid surface, the average van would have an axle load of approximately 17.8 kN and a load equivalency factor of 0.0164 (the relationship between weight and damage is exponential, not linear) (PI, 2018).

  To translate this value into monetary costs, I used the Ricardo-AEA Handbook. This states that German evaluations are the most detailed in terms of differentiation of vehicle types and road types. They show that in 2010 the cost per kilometer traveled by light duty vehicles was €ct1.3 on roads other than motorways and other trunk roads. I modeled €ct1.3 at NPV 0.02 from 2010 (Table 8).

Table 8. Average variable infrastructure costs for Germany in €ct/vkm (2010).

Vehicle type	All roads	Motorways	Other trunk roads	Other roads
Mopeds and motorcycles	0.2	0.1	0.2	0.3
Passenger cars	0.6	0.3	0.3	0.9
Buses	2.2	0.9	1.5	2.9
LDV	0.8	0.3	0.5	1.3
HGV 3.5-12 tonnes	1.3	0.6	0.8	2.9
HGV 12-18 tonnes	4.1	1.9	2.7	20.8
HGV >18 tonnes	6.6	2.8	4.6	37.7
Average	0.9	0.6	0.5	1.4

Source: Ricardo-AEA Update of the Handbook on External Costs of Transport (2014).

In contrast, the average weight of an ECT is 103.5 kg, approximately 5% of the van. On this basis, the trike is 37,400 times less damaging to the road surface than a van. The cost is so small that I entered it as a zero value in the spreadsheet Model.

Table 9. Some typical load equivalency factors.

Axle Type (lbs)	**Axle Load**		**Load Equivalency Factor (from AASHTO, 1993)**	
	(kN)	**(lbs)**	**Flexible**	**Rigid**
Single axle	8.9	2,000	0.0003	0.0002
	44.5	10,000	0.118	0.082
	62.3	14,000	0.399	0.341
	80.0	18,000	1.000	1.000
	89.0	20,000	1.4	1.57
	133.4	30,000	7.9	8.28

Source: RoadTec Pavement Interactive by Pavia Systems (PI, 2018).

Revenue

It became clear at an early stage that there were two revenue streams for last-mile operators – assignment revenue and redeployment revenue. Assignment revenue is the revenue generated in delivering packages assigned for delivery in a given day. Evaluations for assignment revenue are based on a fixed fee per parcel charged by last-mile operators to clients such as such as UPS or DHL. Limitations on parcel dimensions and weight are agreed between the parties. The areas to be covered — usually defined by zip-codes — are also agreed, along with other terms such as delivery procedures, driver conduct, signatures, non-deliveries, returns and so forth.

Evaluations for the secondary revenue stream are based on surplus-time redeployment value – a source that enables last-mile operators to generate additional income by performing A-B and contract deliveries in the time left over after completing the day's assignment. The variables needed to model these revenue streams are defined below.

Independent Variables

I identified 24 factors or independent variables (Table 10) that would need to be quantified to derive 28 additional variables in order to determine financial viability for trikes and vans. Methods used to obtain data for the 24 independent variables are described below under the headings of Distance, Drops, Time, Area, Miscellaneous, Money, and Rates, along with explanations about function, relevance and context.

Table 10. Independent variables showing baseline values.

INDEPENDENT VARIABLES	Unit	TRIKE	VAN
Inter-stop distance	km	0.333	0.333
Return distance	km	1.00	1.00
Stem distance	km	1.00	1.00
Vehicle km. p/liter of diesel	vkm	n/a	10.22
Package drops p/stop	drop	1.14	1.14
Packages assigned to operator p/day	drop	90	90
Riding/driving time permitted p/day	hour	8	10
Time taken p/redeployment job	min	20	20
Transaction time p/stop	min	4.58	5.92
Vehicle days p/year	day	250	250
Cargo volume (capacity)	m^3	1.56	3.00
Micro depot area	m^2	37	37
Package size	m^3	0.01	0.01
Electricity purchased p/charge	kWh	0.5581	n/a
Speed of travel	km/h	22.73	26.07
Carbon price p/tonne	£	70.02	70.02
Fuel price p/kWh (electricity)	£	0.16	n/a
Fuel price p/liter (diesel)	£	n/a	1.03
Micro depot rent p/m2	£	275	275
Vehicle purchase price	£	8,092	16,308
Fee receivable p/package	£	2.25	2.25
Fee receivable p/redeployment job	£	10.00	10.00
Inflation rate	%	2.00	2.00
NPV discount rate	%	5.00	5.00

Source: Compiled by the author.

Distance

- Inter-stop distance/distance between stops: This metric expresses the average distance between one delivery stop and the next, and is synonymous with the density of the consignee population for a given route on a given day. Last-mile operators described it as highly variable with an average of 333 meters. I used this value for the baseline scenario (Table 10).
- Return distance: This metric indicates the distance from the final stop of the trip back to the distribution center and is important for trike operators for the same reason as the stem distance. Based on conversations with ECT operators, I surmised that the distance could be quantified as per the stem distance. The baseline value is shown in Table 10.
- Stem distance: This is the distance between the last-mile distribution center and the first stop. It is important both to ECT and van operators but more so for ECT operators because, with a lower parcel carrying capacity they may have to return to the depot to reload more frequently than van operators. For data on this metric I spoke with several last-mile operators and calculated an amalgamated figure as shown in Table 10.
- Vehicle kilometers p/liter: Performance data of vans are published by the Vehicle Certificate Agency (VCA) which is the UK Government's designated national authority responsible for reporting road vehicle fuel consumption and CO_2 emissions. VCA categorizes vans by engine size, fuel type, and transmission type. Manufacturers submit vehicles to the agency and pay a fee for fuel-consumption tests that are conducted in VCA laboratories.

The VCA reports its fuel-consumption findings in miles per gallon (MPG), distinguishing between urban and extra-urban driving. The VCA currently publishes data on approximately 500 small-size vans that are representative of nearly all vans available in the UK. I imported the VCA's van fuel data and then deleted electric and petrol vehicles because they are outside the scope of this thesis.

I also deleted the small number of vans with automatic transmission because, for reasons of fuel economy, delivery companies invariably choose vehicles with manual transmission (common knowledge). And I deleted the column relating specifically to 'extra-urban' MPG data, because this thesis is focused on the last-mile leg of the delivery chain, i.e. extra-urban data is out of scope. Then I deleted crew vans and combo vans, and I calculated that the median average MPG for the remaining 87 vans was 55.4.

However, representing MPG at 55.4 does not reflect actual real-life mileage. The preferred baseline value used in the spreadsheet model takes into account that the VCA data are only for the purpose of comparing one vehicle with another. There is overwhelming evidence that the VCA test (and tests by other government agencies in Europe and the USA) substantially overestimates MPG measurements.

The Washington-based International Council on Clean Transportation (ICCT) states that in the EU, the gap between official and real-world CO_2 emission values [*ergo* actual fuel consumption] grew from 9% in 2001 to 42% in 2015 (ICCT, 2016). This 2016 update is the latest in a series begun in 2013. It analyzes 13 data sources covering 15 years, six countries, and approximately one million cars. Sources other than ICCT also confirm the existence of a substantial gap between official and real-world figures (Get Real, 2017); (Archer, 2017); (Berry, 2010).

ICCT states the urgent need for improved test procedures. Two new procedures –the Worldwide Harmonized Light Vehicle Test Procedure (WLTP) and the Real Driving Emissions (RDE) test — are being introduced incrementally, but several years will elapse before all vans are tested.

In the absence of a better alternative for an upper threshold to represent maximum likely fuel consumption I deducted 42% from the VCA's mileage figures. Furthermore, I deducted an additional amount to reflect the effect of cargo load. The effect of load on fuel consumption (and CO_2 emissions) is an average increase of 5.9% for a van carrying 50% of its maximum load (EQUA, 2018). Thus, real-life actual kilometers per liter (km/pl) can be stated as follows: (M-A)*R or (55.4 - 47.9%) x 0.354 where M is MPG as stated by VCA, A represents adjustment for real-life usage, R is the conversion rate for mpg to km/pl (0.354). The value for the baseline scenario is in Table 15.

Drops

- Package drops per stop: The number of parcels delivered is not necessarily the same as the number of stops made to deliver them. At one extreme, every parcel in a given load will be delivered to a single destination in one stop. In the opposite extreme, each and every parcel in a given load is delivered to a different address.
  Legacy operators such as UPS use large vehicles and may deliver as many as 400 packages per vehicle per day. This high daily number of packages delivered is only

achievable because of bulk deliveries where dozens of packages may be delivered at one stop to a single business address.

The profile for delivery of B2C packages sent by online suppliers is different; the packages tend to be smaller, and usually there is only one parcel to be delivered per address. But operators said that even in the B2C space, multiple drops do occur. Typically, the ratio of double to single drops was one in seven, and the ratio of triple to single drops was one in 21. For the baseline scenario I used a value of 1.14 for drops per stop (24/21), as shown in Table 10.

- Packages assigned to operator per day: Unless otherwise stated, last-mile businesses are assumed to be subcontractors in this study. As such, they are typically in the hands of the 3PLs who decide on a day-to-day basis how many packages they will hand over to a particular last-mile business for delivery to a given postal district that day. After consulting with industry experts it emerged that an assignment of 90 packages per day would be a likely average number (Table 10).

Money

- Carbon price per tonne: The valuation of climate change costs per tonne of CO_2e is derived from the abatement cost approach advocated by Ricardo-AEA. It measures the cost per tonne at between €60 and €120 (MOVE, 2014). I converted these estimates to UK£ and used the central point value, as shown in Table 10.
- Fee receivable p/package: I obtained pricing details from operators and found an average figure for Table 10.

- Fee receivable per redeployment job: This refers to the average amount charged for delivery jobs performed in surplus time not related to assignment work. Table 10 shows the amount used in the baseline.
- Fuel price p/kWh: Despite the fact that ECTs use very little electricity per trip, I included this metric so that I could model the effects of substantial price increases on profitability (Table 10).
- Fuel price per liter: The pump price of fuel in the UK includes value added tax (VAT). In the spreadsheet calculations I deducted 20% from the pump price to reflect the fact that the VAT portion of the price can be reclaimed by registered businesses (Table 10).
- Inflation rate: Although inflation has not always been factored into cost-benefit analyses in recent years, I applied it in this study because inflation is once again on the rise and is likely to be an important factor going forward. I assumed that inflation would affect costs and revenue equally throughout the seven-year period under review and I applied a fixed rate of 2% per year (Table 10).
- Micro depot rent p/sq. meter: Standard warehouse rentals for old units in London range from £70 per m2 in Dagenham to £150 per m2 in West Drayton, plus business rates which average approximately £48 per m^2 (Colliers, 2018). But these prices are for large units that are way beyond the size required by the current generation of ECT operators. More realistic are the small self-storage units that can be found for £250 to £300 per m^2, including business rates. I contacted several agents and identified an average for use in Table 10.

- Vehicle purchase price: I searched the internet for prices of popular vehicles and reported my findings under ‘Purchase price for vans’, and ‘Purchase price for trikes’, elsewhere in this document. Table 10 shows the value used.
- Discount rate: To determine the appropriate rate I started with the current central bank rate of 2.9% and used the Fisher equation (LearnSignal, 2018) to calculate a discount rate that included a general inflation rate of 2% per year, as in: (1+i) = (1+r)*(1+h) where I = inflated discount factor; r = real/uninflated discount factor; h = inflation rate. Thus, 1.029*1.02 = 1.04958 and the inflated required discount rate is 0.04958 or a rounded 5%, both for the trike and the van financial appraisal.

Time

- Riding/driving time permitted per day: UK law states that employed drivers must not drive for more than 10 hours per day and must be given adequate rest (GOV.UK, 2016). This means that even if the van has the capacity to hold, for example, 200 packages, there may only be sufficient time to deliver half that number (or less) because the driver is not allowed to drive for more than 10 hours. ECT operators appear to be constrained by the same laws but are reluctant to ask their riders to ride the same number of hours as van drivers because of the fatigue factor. I aggregated responses received from industry experts. They are shown in Table 10.
- Time taken per redeployment job: This refers to the average amount of time taken to perform ad hoc/one-off or non time-sensitive contract jobs in time left over after completion of the current assignment. The value shown in Table 10 was calculated after consulting with operators.

- Transaction time: This has a major impact on stop/drop rates. It refers to the activities that have to be performed to effect the delivery of a package. I identified 10 discrete activities within the transaction phase and contacted operators for comments on the time values I had attached to each activity, ranging from low estimates for best-case scenarios, and high estimates for worst-case scenarios.

  Some operators said it was impossible to quantify worst-case scenarios; for example, for time taken to walk to the customer's door, because sometimes the address was only a few steps away, while at other times it might be several floors up a high-rise building accessible only by a slow lift. Similar comments spoke to the extra time taken to obtain a signature from a neighbor if the consignee was not at home at the time of delivery. Nevertheless, ignoring outliers, I aggregated the responses received (Table 11).

Table 11. Comparison between estimates for a range of transaction times.

Transaction Time for Trike			
(last mile/urban) **ACTIVITY**	**Low estimate**	**Central estimate**	**High estimate**
	seconds	seconds	seconds
find address	-	30	60
find parking spot	20	30	40
park vehicle	20	20	20
grab parcel	20	30	40
walk to door	20	50	80
ring bell/wait	20	25	30
handover	20	20	20
get signature	10	10	10
return to trike	20	50	80
mount vehicle	10	10	10
Total seconds	160	275	390
Total minutes	2.67	**4.58**	6.50

Transaction Time for Van			
(last mile/urban) **ACTIVITY**	**Low estimate**	**Central estimate**	**High estimate**
	seconds	seconds	seconds
find address	-	30	60
find parking spot	20	100	180
park vehicle	30	30	30
grab parcel	20	30	40
walk to door	20	50	80
ring bell/wait	20	25	30
handover	20	20	20
get signature	10	10	10
return to van	20	50	80
mount vehicle	10	10	10
Total seconds	170	355	540
Total minutes	2.83	**5.92**	9.00

Source: Aggregated from data provided by UK last-mile operators.

- Vehicle days per year: In calculating the number of vehicle days per year for this study I assumed a 5-day working week. I deducted 10 days closure per year for national holidays leaving 250 days as the annual working-day figure for vans and trikes (Table 10).

Volume / Area

- Cargo volume: Volume and payload factors determine the optimum choice for cargo trikes. Because I believed that volume would be a particularly critical factor in determining viability I decided to focus on big volume three-wheelers. From a list of 492 cargo bike manufacturers across 18 European countries (Kuppinger, 2017), I identified nine companies – Urban Arrow, BAYK, Cycles Maximus, Iceni Cycles, Evolo, Radkutsche, Radpower, eCargo Bikes and Maxpro – that make ECTs for last-mile parcel delivery operators. I found that 14 of their bikes (Table 12) were offered with containers ranging in size from $1m^3$ to $3m^3$, making them the largest on the market. Average capacity was $1.56m^3$ and I used this figure in the baseline scenario.

  The 'Deliver with Amazon' program identifies medium-size vans with a $5m^3$ capacity as the entry size for deliveries made on their behalf by sub-contractors (Amazon UK, 2018). However, the medium-size van is an inappropriate choice for last-mile deliveries because typically its capacity far exceeds the number of packages that can be delivered in the time legally allowed on-road per driver, per day. UK law states that drivers who are employed — as opposed to self-employed — are not permitted to drive for more than 10 hours per day. I obtained specifications for the 10 best-selling small vans in the UK (Table 13). The average load volume was 3m3.

Table 12. Trike box-volume internal measurements in m^3 (2018).

Manufacturer	Model	Wheels	Box Vol. m3
Veloform/BAYK	Veloform Delivery Cruiser	3	1.00
Urban Arrow	Tender 1500	3	1.50
Urban Arrow	Tender 2500	3	2.50
Radkutsche	Musketeer	3	1.34
Rad Power	RadBurro e-Trike	3	1.35
MaxPro	EcoCargo XL	3	1.71
MaxPro	BlueMate	3	1.00
Lovelo	Cargocycle V2	3	1.50
Iceni	Pickup Trike	3	1.50
Evolo	Z1	3	1.50
Evolo	Z2	3	2.00
ESA	T-Cargo	3	1.95
Cycles Maximus	Max Van (Traction Drive)	3	1.50
BAYK	Velotaxi Bring	3	1.50
		Mean average	**1.56**

Source: Various sources, including manufacturers' websites.

Table 13. The leading small-size vans in the UK (2018).

Brand	Model	List Price	Weight	Capacity
		£ (ex.VAT)	kg	m3
Fiat	Doblo Cargo	16,698	2,270	3.20
Vauxhall	Combo	16,308	2,350	2.80
Renault	Kangoo	15,046	1,950	3.00
Mercedes-Benz	Citan	16,858	1,395	3.10
Peugeot	Partner	15,006	1,399	3.00
Citroen	Berlingo	14,601	1,490	3.00
Nissan	NV200	14,913	2,000	3.47
Volkswagen	Caddy	17,355	2,800	3.20
Ford	Transit Connect	16,347	2,125	2.90
	Totals	16,308	1,975	**3.00**

Source: Data obtained from manufacturers' websites.

- Micro depot area: Contact with ECT operators indicated that the amount of space required to run a trike-operating business can vary from 9m^2 to 65m^2. The lower of these two figures might represent a share of a larger unit, or it could be a shipping container. Several operators said they had started by renting a self-storage unit measuring 200 sq.ft. or 18.58 m^2 — fine for bikes but cramped for trikes because of their larger 'footprint' Most trike users said that once they were established, they moved to premises with about 400 sq. ft. (37.16 m^2). An area of this size would have space for sorting packages, loading the trikes, storing the trikes, spares, accessories, storage of staff bikes, repair and maintenance of trikes, office, and a space for charging batteries. I used this figure in the baseline scenario (Table 10).

- Package size: The literature did not reveal data for average size of parcels delivered for online purchases. According to the Royal Mail – the UK's largest parcel delivery provider – the delivery of smaller items such as CDs and DVDs (media) is declining, while the delivery of larger items such as clothing and footwear is growing as consumers make more of these purchases online (Royal Mail, 2015). Retailer and consumer activities are also driving an increase in average parcel size. Consumers who want free delivery have to buy more items at once as e-retailers raise the threshold where free delivery kicks in. This can lead to purchases being consolidated in one larger package. I obtained data on parcel dimension averages from ECT operators and van delivery companies and calculated mean volume (Table 10).

Miscellaneous

- Electricity purchased per charge: This metric expresses the amount of electricity purchased from the grid to charge an ECT battery. The calculations are made in 'cost per charge' elsewhere in this document (Table 10).

- Speed of travel: This metric is influenced by congestion, traffic speed limits, and in the case of ECTs a speed limiter is built into the trike by law. Speed of travel operates on stops per hour which is the key determinant of the drop rate. The average travel speed of a male cyclist on a standard bike in the UK is stated as 25.61 km/h. For females it is 19.84km/h (Cycling Weekly, 2016). I assumed these values were for daylight hours including all levels of congestion. The mean central value was taken to be 22.725 km/h.

  The average speed for motorized vehicles in Q3 2016/17 for the 12 hours between 07:00 and 19:00 was 7.3 mph in central London and 16.2mph (26.1km/h) across greater London (TFL, 2017). For average delivery van speed I used the latter figure in the baseline scenario.

  To express speed in terms of meters traveled per second I used the following formula: (A * C) / D where A= average km/h; C = equivalency for conversion from km/h to meters p/hour; D = number of seconds in an hour. I divided the result into 100 and modeled the result for both modes.

  It was necessary to assess the impact of higher and lower than average congestion on travel speed. The literature indicated that there are two main methodologies for measuring congestion. One measures the amount of extra travel-time experienced by drivers and compares it in percentage terms to values found in uncongested conditions. The other method bases the comparison on average achievable speed over a given distance and time. I used a combination of both methods for five levels of congestion – ranging from free-flow down to near gridlock.

The legal speed limit for ECTs in the UK is 25 km/h. For vans in most parts of London it is 32 km/h. I used these values for the maximum speed achievable in free-flow conditions. For light congestion conditions I used the central value between average speed and free-flow speed for vans and ECTs. For heavy congestion I used the central value between average speed and near gridlock for vans, but for ECTs I assumed that reductions in speed would be less steep because of their ability to by-pass congestion. This assumption was corroborated in the literature (Lenz & Riehle, 2013). The value for speed of travel in the baseline scenario is shown in Table 14.

Table 14. The impact of congestion on travel speed.

Speed key	TRIKES	VANS
Congestion	km/h	km/h
Nr. freeflow	25.00	32.19
Light	23.86	29.13
Average	22.73	26.07
Heavy	19.32	15.54
Nr. gridlock	15.91	5.00

Derived Variables

Values for 35 variables derived from independent variables, and combinations of independent variables, reflected performance variations of ECTs and vans under different conditions (Table 15). Although headings are not given in the Table, the derived variables are grouped under: Distance, Drops, Money, Stops, Time, and Miscellaneous.

Distance

- Distance to be covered: This metric expresses the number of kilometers traveled by the trike or van to complete delivery of the packages assigned for a given day. Precedents comprise: Inter-stop distance, Stem distance, Return distance, Stops needed to complete current assignment, and Trips needed to complete assignment.

Table 15. Derived variables showing default performance data (Scenario 1).

DERIVED VARIABLES / Performance data	Unit	TRIKE	VAN
Distance to be covered to complete this assignment	vkm	28.3	28.3
Distance traveled this scenario p/yr	vkm	7,072	7,072
Distance traveled when time expires in this scenario	vkm	31	32
Drops achievable p/load (packages loadable)	drop	125	240
Drops needed to complete this assignment	drop	90	90
Drops that can be effected before time expires	drop	99	101
Packages assigned p/yr.	drop	22,500	22,500
Packages undelivered because time expires	drop	-	-
Packages delivered p/yr	drop	22,500	22,500
Packages undelivered p/yr in deficit situation	drop	-	-
Stops achievable p/load	stop	109	211
Stops needed to complete this assignment	stop	79	79
Stops that can be made before time expires	stop	87	89
Stops that cannot be made because time expires	stop	-	-
Inter-stop travel time needed p/stop this assignment	min.	0.88	0.77
Inter-stop travel time needed p/assignment	min.	69	61
Return time p/assignment	min.	2.64	2.30
Stem time p/assignment	min.	2.64	2.30
Time taken p/stop this assignment	min.	5.53	6.74
Time surplus after completing this assignment	min.	44	68
Time needed to complete this assignment	hr.	7.27	8.87
Time deficit this day	hr.	-	-
Time spent on-road this assignment	hr.	7.27	8.87
Time spent on-road p/yr.	hr.	1,818	2,219
Transaction time needed p/assignment	min.	362	467
Cargo volume less losses	m3	1.25	2.40
Diesel fuel used p/yr in this scenario	liter	-	692
Trips needed to complete this assignment	trip	1.00	1.00

- Distance traveled current scenario p/year: This describes the distance traveled under the conditions prevailing in a given scenario if it were to prevail for a whole year. Precedents comprise: Vehicle days per year, Distance to be covered to complete current assignment, Distance traveled when time expires in current scenario, and Hours spent on-road in current assignment.

- Distance traveled when time expires: This refers to the number of kilometers covered when the length of time permitted to ride/drive per day has been reached. Precedents comprise: Inter-stop distance, Stem Distance, Return distance, Stops that can be made before time expires, and Trips needed to complete current assignment.

Drops

- Drops achievable per load: This refers to the maximum number of packages that can be loaded into the van or trike cargo container. Precedents comprise: Package size, and Cargo volume less losses.
- Drops needed to complete assignment: This refers to the number of packages assigned for delivery on a given day. Precedents comprise: Package drops p/stop, and Stops needed to complete current assignment.
- Drops that can be effected before time expires: This describes the number of packages that can be delivered before the legal time limit expires on a given day. Precedents comprise: Package drops p/stop, and Stops that can be made before time expires.
- Packages assigned per year: This refers to the number of packages assigned annually if the number prevailing in the current scenario was repeated every working day throughout the year. Precedents comprise: Packages assigned p/day, and Vehicle days p/year.

- Packages that cannot be delivered before time expires: This defines the number of packages that were assigned for delivery on a given day but which could not be delivered that day because time ran out. Precedents comprise: Package drops p/stop, Stops that cannot be made because time expires, and Time deficit this day.
- Packages delivered per year: This refers to the number of packages assigned per year that would get delivered without exceeding time limits. Precedents comprise: Packages assigned p/year, and Packages undelivered p/year in deficit scenario.
- Packages undelivered per year in deficit scenario: This refers to the number of packages that would not get delivered if the current scenario prevailed every working day for the whole year. Precedents comprise: Vehicle days p/year, and Packages that cannot be delivered because time expires.

Money

- Break-even price (BEP): I used the break-even pricing method to establish the points at which the two transport modes break-even. This was calculated using the following formula: Break-even price = (Total fixed costs / Production unit volume) + Variable cost per unit, where variable cost per unit is variable costs / packages delivered. I developed two versions: one using financial costs only, the other using all costs. Table 10 shows the relevant values.
- Diesel fuel cost p/km: This refers to the retail cost of fuel consumed over one kilometer, less 20% representing Value Added Tax (VAT) reclaimable. Precedents comprise: Fuel price p/liter (diesel), and Vehicle km. p/liter (diesel).

- Electricity cost p/charge: This is grid electricity purchased by the trike operator from the local utility. Where K = cost per charge, the calculation can be stated as: $K = ((V*Ah)/1000) + L) * P$ where V = volts; Ah = amp hours; L = charging losses; P = electricity unit cost. Precedents comprise: 'Fuel price p/kWh (electricity)', and 'Electricity purchased p/charge'.
- Gross profit (GP): Gross profit is deemed to be revenue less costs before tax and interest. In accordance with the full-cost accounting framework that is fundamental to this thesis, environmental and social costs are combined with operating costs to produce a single figure for the total cost of doing business. Therefore the default definition of costs (C) in the context of profitability can be stated as: $C = O + E + S$ where O = operating costs; E = environmental costs, and S = social costs. GP is the foundation for NPV.
- Net present value (NPV): NPV is an internationally recognized tool for expressing the current value of future cash flows generated by capital investments [the higher the NPV, the more likely it is that the project will produce profits]. I calculated NPV using the Excel NPV function, which is based around two variable factors: the discount rate, and gross profit (GP) per year over the seven-year period. The method used to establish the discount rate is described under 'independent variables'.
- Revenue p/yr current assignment: This describes the revenue accrued if the current fee receivable and the number of packages currently assigned remain constant every working day for a whole year. Precedents are: Packages delivered per year, and Fee receivable per package.

- Revenue achieved p/hr on road: This represents the revenue generated per vehicle per hour on-road over one year. Precedents comprise: Revenue p/yr from assignment, and Hours spent on road p/yr.
- Surplus time redeployment value p/yr: If the 90 packages per day assignment is completed within the time limit for the vehicle, an amount of surplus time is generated. This can be monetized by having the vehicle take on additional work such as on-demand or local contract deliveries. The rate charged for this type of work was estimated after consultation with industry experts. This metric describes the monetary value of surplus time accrued if current values for independent variables are maintained every working day for the whole year. Precedents comprise: Fee receivable per redeployment job, Time taken per redeployment job, Vehicle days per year, and Time surplus after completing current assignment are shown in Tables 10 and 15.

Stops

- Stops achievable p/load: This metric represents the number of stops that can be made under the current scenario when the vehicle is fully loaded. Precedents comprise: Drops achievable p/load, and Package drops p/stop.
- Stops needed to complete assignment: This refers to the number of stops that need to be made in order to fulfill the current assignment. Precedents comprise: Package drops p/stop, and Drops needed to complete assignment.
- Stops that can be made before time expires: This refers to the number of stops that can be made before the amount of time permitted on-road per day is reached.

Precedents comprise: Time taken p/stop this assignment, and Riding/driving time permitted p/day.

- Stops that cannot be made because time expires: Precedents comprise: Stops needed to complete assignment, and Stops that can be made before time expires.

Time

- Inter-stop travel time needed p/stop this assignment: This refers to the amount of time taken for the vehicle to travel between one stop and the next in the conditions prevailing for the current assignment. Two precedents inform this metric: Inter-stop distance, and Speed of travel.
- Inter-stop travel time needed p/assignment: This represents the sum of the time taken traveling between stops in the current assignment. Precedents comprise: Stops needed to complete assignment, and Inter-stop travel time needed p/stop this assignment.
- Return time p/assignment: Just as there is a distance to be covered before the first stop, so there is a distance to be covered to get back to base after the last stop. Precedents comprise: Speed of travel, Return distance, and Trips needed to complete current assignment.
- Stem time allocated p/assignment: This refers to the amount of time that it takes the vehicle to travel from the distribution depot to the first stop of any trip. Precedents comprise: Speed of travel, Stem distance, and Trips needed to complete current assignment.

- Time taken p/stop this assignment: Precedents comprise: Inter-stop travel time needed p/stop this assignment, Transaction time p/stop, Stops needed to complete assignment, Stem time p/assignment, and Return time p/assignment.
- Time surplus after completing assignment: If the assignment is completed within the time legally permitted to be on-road, an amount of time is left over that can be used to perform additional work. I refer to this as 'redeployment time'. Precedents comprise: Riding/driving time permitted p/day, and Time needed to complete assignment.
- Time needed to complete assignment: This is total time needed to complete the current assignment. Precedents comprise: Inter-stop travel time needed p/assignment, Stem time p/assignment, Return time p/assignment, and Transaction time needed p/assignment.
- Time deficit this day: If the rider/driver cannot complete the current assignment in the time legally permitted, there is a time deficit. Precedents comprise: Riding/driving time permitted p/day, and Time needed to complete assignment.
- Time spent on road this assignment: This represents the total number of hours spent on-road for the current assignment. Precedents comprise: Riding/driving time permitted p/day, and Time needed to complete assignment.
- Time spent on road p/yr: This is the sum total of the amount of time spent on-road per calendar year. Precedents comprise: Vehicle days p/year, and Hours spent on-road this assignment.
- Transaction time needed p/assignment: This represents the sum of the amount of time taken to effect a transaction at the householder's address in the current assignment.

Table 11 itemizes what is involved in transaction time]. Precedents comprise: Transaction time p/stop, and Stops needed to complete assignment.

Miscellaneous

- Cargo volume less losses: This is an expression of gross capacity less capacity losses. The gaps between the units being packed into the cargo box and the inner surface of the box are referred to collectively as loading losses or packing losses (Gudehus & Kotzab, 2012). Additionally, the number of parcels deliverable per full load is compromised by the fact that, unless all the parcels in a given load are destined for a single address, they cannot be loaded solely with efficient space utilization in mind. This concept is referred to as 'sequencing losses'. Route planning dictates that parcels should be delivered in a sequence that maximizes efficiency in terms of rider time. In the absence of published data on packing losses or sequence losses I spoke with industry experts and deducted 20% from the sole precedent 'Cargo volume (capacity)'. Table 21 shows the value used.
- Diesel fuel used p/year: Precedents comprise: Vehicle km. p/liter of diesel and Distance traveled this scenario p/year.
- Trips needed to complete current assignment: At baseline values, both vehicles can complete the assignment by making one trip only. However, larger assignments may require more than one trip. Precedents comprise: Drops needed to complete assignment, and Drops achievable p/load.

Chapter III

Results

The results of this study are presented in three parts: Baseline Costs, Scenarios, and NPV Sensitivity Analysis. The Baseline Costs section summarizes how the baseline independent and derived variables determine different types of costs as calculated in the sections of the spreadsheet model. All data refer to costs for one van and one trike as described in the Methods chapter, for a seven-year period.

The Scenarios show how profitability and other results are affected by altering the values of key independent variables, starting with presentation of the Baseline model. The NPV Sensitivity Analysis shows the relative sensitivity of the financial, environmental and social appraisals to changes in key independent variables.

Baseline Costs

This section examines operational, environmental and social costs incurred in running a trike or a van business in the last-mile space over a seven-year period in London, using the full-cost accounting framework. Results are for the baseline model set of variables (Table 10).

Operational Costs

In Chapter II I outlined the methods used to obtain and calculate data on 20 operational cost variables that would provide the basis for the cost appraisals, one on trikes, the other on vans. Extracts of those spreadsheet appraisals are shown below in

Table 16, followed by an analysis of key features. Full versions of the spreadsheet are presented in Appendix 1.

Table 16. Spreadsheet showing overhead (fixed) costs and on-road variable costs.

OPERATING COSTS	TRIKES			VANS		
2018 - 2024	7-year Total	% of Total	Annual Average	7-yr Total	% of Total	Annual Average
Overhead Costs	£	%	£	£	%	£
Purchase cost of vehicle	10,510	3.50%	1,501	21,182	6.44%	3,026
Depreciation	8,092	2.70%	1,156	16,308	4.96%	2,330
Road use tax	-	0.00%	-	2,007	0.61%	287
Vehicle insurance (comprehensive)	3,531	1.18%	504	10,646	3.23%	1,521
Public & Employers' liability insurance	3,717	1.24%	611	2,100	0.64%	300
Goods in transit insurance	2,230	0.74%	319	677	0.21%	97
Bookkeeping/accounting/legal fees	7,434	2.48%	1,062	7,434	2.26%	1,062
Rental of premises	75,971	25.33%	10,853	75,971	23.08%	10,853
Servicing and MOT	714	0.24%	102	922	0.28%	132
Delivery management software rental	3,717	1.24%	531	3,717	1.13%	531
Rider's salary	158,573	52.88%	22,653	152,886	46.45%	21,841
National Insurance (NI)	13,289	4.43%	1,898	12,512	3.80%	1,787
Advertising and marketing	7,434	2.48%	1,062	7,434	2.26%	1,062
Total Overhead Costs	**£ 295,213**	-	**£42,173**	313,926	-	**£44,847**
On-Road Costs						
Fuel	141	0.05%	20	5,300	1.61%	757
Congestion charge	-	-	-	4,275	1.30%	611
Parking fines	-	-	-	2,899	0.88%	414
Brake pads / discs (fitted)	297	0.10%	42	1,242	0.38%	177
Tires	657	0.22%	94	1,264	0.38%	181
Repairs	2,550	0.85%	364	201	0.06%	29
Battery	1,023	0.34%	146	162	0.05%	23
Total On-Road Costs	4,669	-	667	15,180	-	2,169
Total Operating Costs	**£ 299,882**	100%	**£42,840**	329,106	100%	**£47,015**

On-road costs were 1.56% of overall operating costs for trikes, and 4.61% of on-road costs for vans. The main reason for the disparity is that fuel costs for the van were more than 37 times higher than for the trike – the van weighs approximately 20 times as much as the trike and uses a large amount of energy just to move itself, regardless of cargo weight. This result, also illustrated in Figure 6, highlights the inherent inefficiency of vans.

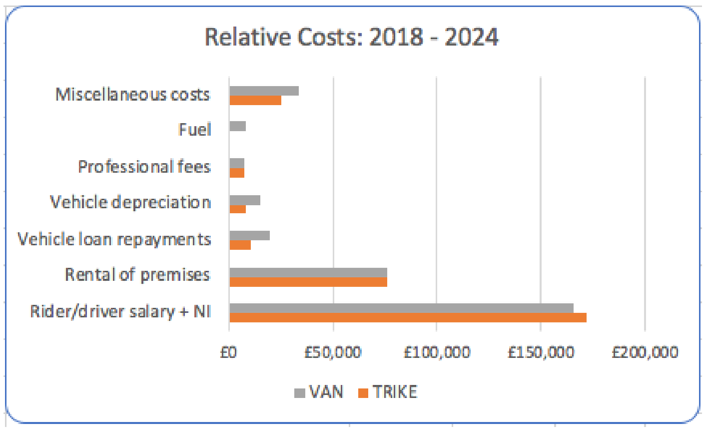

Figure 6. Relative costs of vans and trikes compared (2018-2024).

Comparison of the costs in the financial appraisal for each enterprise (Table 17) showed that delivering packages is a labor-intensive business, whether from a van or from a trike. In both modes, the salary of the rider/driver was shown to be the largest single expense.

Table 17. Highest cost elements in the financial appraisal of trikes and vans.

2018-2024	TRIKE		VAN	
	£	% of Total	£	% of Total
Rider/driver salary +NI	171,862	57.31%	165,398	50.26%
Rental of premises	75,971	25.33%	75,971	23.08%
Vehicle loan repayments	10,510	3.50%	21,182	6.44%
Vehicle depreciation	8,092	2.70%	16,308	4.96%
Professional fees	7,434	2.48%	7,434	2.26%
Fuel	141	0.05%	5,300	1.61%
Other costs	25,872	8.63%	37,513	11.40%
Total costs over 7 years	£299,882	100%	£329,106	100%

Salaries were followed by rental of premises, repayment of vehicle-purchase loan, depreciation, and professional fees for accountancy and legal advice. The cost of renting rural instead of urban premises is examined in the Discussion.

Environmental Costs

- Greenhouse gas emission costs (Table 18) and (Figure 7): The total cost of CO2e emissions from the van was almost 20 times higher than from the trike. Nitrous oxide emissions were 0.48% of total van emissions and zero for trikes. Methane emissions were insignificant and zero, respectively for vans and trikes.

Table 18. Environmental costs for trikes and vans, baseline scenario.

ENVIRONMENTAL COSTS	TRIKE			VAN		
Carbon price = £70.02 p/tonne	Yrs. 1-7 Total	% of Total	Annual Average	Yrs. 1 -7 Total	% of Total	Annual Average
GHG Emissions	£	%	£	£	%	£
Carbon Dioxide (CO2)	4.05	3.62%	0.58	1,491	69.57%	212.95
Methane (CH4)	0.01	0.01%	0.00	0	0.003%	0.01
Nitrous Oxide (N2O)	0.02	0.02%	0.00	10	0.48%	1.45
CO2e from increased food consumption	76.76	68.57%	10.97	-	-	-
Total GHG Costs	£ 81	72.21%	£ 12	1,501	70.05%	£ 214
Upstream Costs						
CO2 from production processes	31.11	27.79%	4.44	587.48	27.39%	83.93
Miscellaneous costs						
Ecosystem costs	-	-	-	51.47	2.56%	7.35
Total Environmental Costs	£ 112	100%	£ 16	£ 2,140	100%	£ 306

Emission costs resulting from the production, storage, distribution and retailing of the extra food consumed by riders to propel the trike accounted for nearly 70% of total emission costs by the trike. This finding is examined in the discussion. Although last-mile van drivers also have a largely non-sedentary routine, no evidence was found in the literature to suggest that they required a higher intake of food.

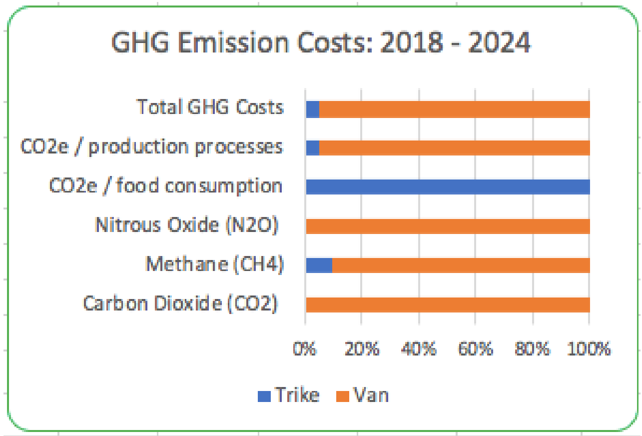

Figure 7. Greenhouse gas emission cost results for trikes and vans.

- Upstream costs: After GHG emissions, the next highest contribution to total emission costs for the trike was from the processes involved in the manufacture of the trike, the cargo box and drive unit (Scope 3). These represented 27.8% of overall trike emissions. This figure equaled less than 19% of the upstream emission costs (£587.48) incurred in manufacturing the van.

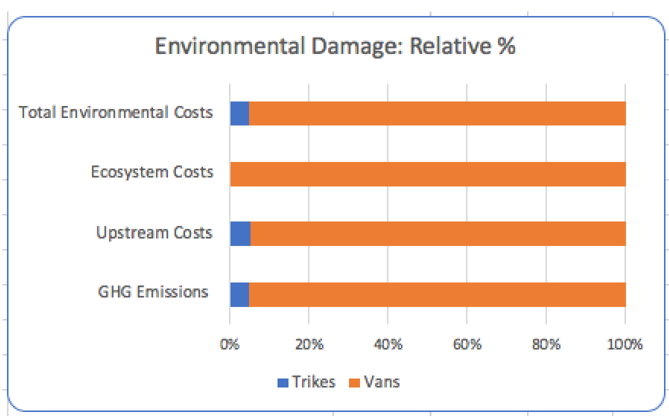

Figure 8. Relative environmental damage by cost in percentage terms.

- Ecosystem costs: Costs caused by the trike were zero, and for the van they were insignificant at £7.35 per year. Added to other environmental costs itemized in Table 18, it can be said that with total environmental costs of £16 per year it would take 19 trikes to produce the same environmental damage as one van.

Social Costs

Damage to human health from fine particulate matter (PM2.5), coarse particulate matter (PM10), ozone and nitrous oxide (NO2) from trikes was zero (Table 19).

Table 19. Social costs for trikes and vans.

SOCIAL COSTS		
(p/vehicle p/year) (2018-24)	TRIKE	VAN
	£	£
Health Costs from PM2.5 Damage		
Mortality	0	500
Infant mortality	0	10
Chronic bronchitis	0	48
Bronchitis in children 6 - 12	0	2
Hospital admissions	0	1
Restricted activity days	0	130
Asthma symptom days in children	0	2
Working days lost	0	28
Total Health Costs from PM2.5	0	**721**
Health Costs from PM10 Damage		
Mortality	0	**346**
Health Costs from Ozone Damage	0	
Mortality (valued against life expectancy)	0	1.50
Hospital admissions	0	0.11
Minor restricted activity days	0	3.10
Total Health Costs from ozone damage	0	**4.70**
Health Costs from NO2 Damage		
Mortality	0	422
Total Health Costs	0	**1,493**
Miscellaneous costs		
Congestion costs	206	1,129
Accident costs	27	31
Road damage costs	0	87
Total Miscellaneous Costs	233	1,247
Total Social Costs	**£ 233**	**£ 2,740**

For vans, damage to human health from particulate matter, nitrous oxide and ozone averaged £1,493 per year, or £10,453 per van over the seven-year working life of the vehicle. The largest single source of damage to human health was PM2.5 – fine particulate matter – at £721 per year representing more than 50% of total damage to public health in an average year.

Costs associated with premature death (mortality) caused by PM2.5 amounted to £500 per van. Mortality from PM10 totaled £346, and from NO2 it amounted to £422 per van. Thus, the total cost in human life (mortality) associated with toxic emissions from vans averaged £1,279 per van, per year.

PM10 and NO2 each accounted for approximately 25% of health costs while damage from PM2.5 was about 50% (Figure 9). Ozone was an insignificant factor with an annual average cost of £4.70.

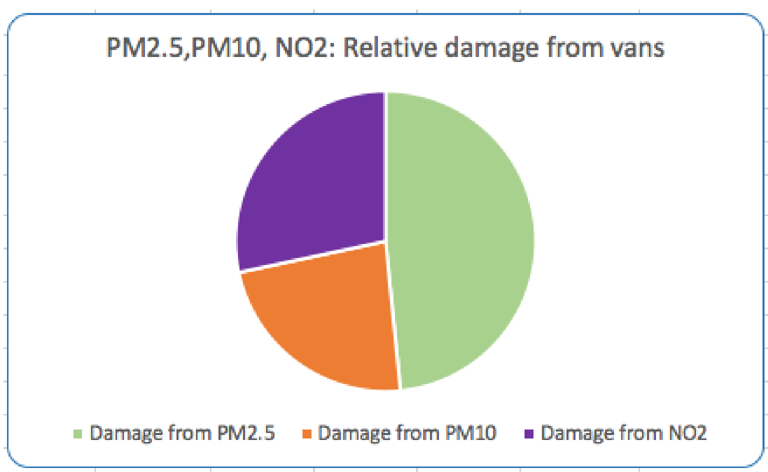

Figure 9. Van emission health-cost percentages by type.

- Congestion caused by trikes showed an average cost of £206 per year. Congestion caused by the van totaled £1,129, making the values for this metric higher than for any other external cost in the study. For example, the cost of congestion for the van over the 7-year period was £7,905 compared with the next highest value which was £5,044 for PM2.5. The significance of congestion in the overall cost picture is examined in the Discussion.
- Social costs averaged £2,740 per year or £19,182 over the lifetime of the van (Table 18). The impact of trikes over the same length of time averaged £233 per year, i.e. vans are 82 times more damaging than vans in terms of social costs. In terms of health costs alone, vans are 1,493 times more damaging to human health than trikes.

Table 20. Summary of all costs (2018-2024).

ALL COSTS	TRIKE		VAN	
2018 - 2024	7-year Total	Annual Average	7-year Total	Annual Average
	£	£	£	£
Overhead costs	295,213	42,173	313,926	44,847
On-Road costs	4,669	667	15,180	2,169
GHG costs	81	12	1,501	214
Upstream costs	31	4	587	84
Ecosystem costs	-	-	51	7
PM2.5 costs	-	-	5,044	721
PM10 costs	-	-	2,424	346
Ozone costs	-	-	33	5
NO2 costs	-	-	2,953	422
Congestion costs	1,441	206	7,905	1,129
Accident costs	187	27	215	31
Road damage costs	-	-	608	87
Total costs	£301,623	£ 43,089	£350,428	£ 50,061

- Avoided costs: Total costs avoided – net costs not incurred by society – if trikes were to replace vans to make last-mile deliveries was estimated to average £2,639 per year over the seven-year period under review (Table 21).

Table 21. Costs avoided by adopting trikes to replace vans.

AVOIDED COSTS	TRIKE	VAN	AVOIDED
(environmental & social)	Average	Average	Average
2018 - 2024	costs p/yr	costs p/yr	costs p/yr
	£	£	£
GHG costs	12	214	202
Upstream costs	4	84	80
Ecosystem costs	-	7	7
PM2.5 costs	-	721	721
PM10 costs	-	346	346
Ozone costs	-	5	5
NO2 costs	-	422	422
Congestion costs	206	1,129	923
Accident costs	27	31	4
Road damage costs	-	87	87
Total avoided			£ 2,797

Scenarios

The values shown in Table 10 are the baseline values for this study and were generated from equations and formulae described in the Methods section. The variables and corresponding values seen in Table 10 are the 'levers' that largely determine the values in Table 15 and in the costs spreadsheet (Table 16).

A major part of the study was to alter the values in Table 10 in order to see how such changes influence performance-outcomes and profitability for trike and van operations. Some 11 different scenarios were deemed to be significant in the context of the study.

Scenario 1: The Baseline / Default Scenario

Running the model at the default values for the independent variables in Table 10 produced the results shown in Table 15 where the derived variables – the performance metrics upon which the independent variables operate – are listed, along with default performance data.

- Revenue: Revenue in this and the other 10 scenarios described below is subject to 2% inflation over the period 2018-2024. Thus, the year 1 delivery fee of £2.25 for assignment revenue becomes an average annual fee of £2.39 when inflation is included. Based on delivery of 90 parcels per day and using the inflated fee of £2.39 per package over 250 days, assignment revenue average per year was shown to total £59,573 for trikes and £62,730 for vans (Table 22).

  The same method was used to calculate average annual redeployment revenue over the seven-year period. The trike was able to complete its 90-package per day assignment with 44 minutes to spare (Table 15), which converts into potential deployment revenue of £5,807 per year. For the van, the redeployment value was £8,964 per year from a 68-minute per day time surplus.

Table 22. Revenue 2018-2024 (Scenario 1).

TRIKE REVENUE	2018	2019	2020	2021	2022	2023	2024	7-yr Total	Av. p/yr
Assignment revenue	£50,625	51,638	52,670	53,724	54,798	55,894	57,012	n/a	53,766
Redeployment revenue	£ 5,468	5,578	5,689	5,803	5,919	6,037	6,158	40,652	5,807
Total Revenue	£56,093	57,215	58,359	59,527	60,717	61,931	63,170	417,013	59,573

VAN REVENUE	2018	2019	2020	2021	2022	2023	2024	7-yr Total	Av. p/yr
Assignment revenue	£50,625	51,638	52,670	53,724	54,798	55,894	57,012	n/a	53,766
Redeployment revenue	£ 8,440	8,609	8,781	8,957	9,136	9,319	9,505	62,749	8,964
Total Revenue	£59,065	60,247	61,452	62,681	63,934	65,213	66,517	439,109	62,730

- Profitability: Results for the seven-year period (Table 23) showed that operating trikes is more profitable than operating vans. Total costs for the trike were approximately 15% lower, and the trike returned gross profit and NPV approximately 30% higher than the van (Table 23).

Table 23. Profitability at default values (Scenario 1).

PROFITABILITY (average p/year) (2018-24)	TRIKE	VAN
Assignment revenue	53,766	53,766
Redeployment revenue	5,807	8,964
Operating costs	42,840	47,015
Environmental costs	16	306
Social costs	233	2,740
Total costs	43,089	50,061
Gross profit	16,484	12,669
Break-even price (BEP)	1.92	2.22
NPV	£ 95,035	£ 72,904

At an average fee of £2.39 per package over the seven years under review, both modes made a profit in the last mile, but NPV for the trike was approximately 30% higher than for the van.

- Break-even price. Using default values, the trike broke-even at £1.92, and the van at £2.22 (Table 23).

Scenario 2: Changes in Fees Receivable.

Clearly, changing fee levels while keeping all other variables unchanged would result in higher revenue, but by how much would it impact NPV? Table 24 shows the effect of different fee levels on gross profit and NPV. At all fee levels tested, the trike returned higher gross profit and higher NPV than the van.

Figure 10. Total revenue, costs, gross profit and NPV (Scenario 1).

Table 24. Gross profit and NPV at different fee levels (Scenario 2).

Fee Receivable	Gross Profit	Gross Profit	NPV	NPV
2018-2024	TRIKE	VAN	TRIKE	VAN
£ 1.80	5,731	1,916	33,053	10,922
£ 1.85	6,926	3,110	39,940	17,809
£ 1.90	8,121	4,305	46,827	24,696
£ 1.95	9,316	5,500	53,714	31,583
£ 2.00	10,510	6,695	60,601	38,469
£ 2.05	11,705	7,890	67,488	45,356
£ 2.10	12,900	9,084	74,375	52,243
£ 2.15	14,095	10,279	81,262	59,130
£ 2.20	15,290	11,474	88,148	66,017
£ 2.25	16,484	12,669	95,035	72,904
£ 2.30	17,679	13,863	101,922	79,791
£ 2.35	18,874	15,058	108,809	86,678
£ 2.40	20,069	16,253	115,696	93,565
£ 2.45	21,263	17,448	122,583	100,451
£ 2.50	22,458	18,643	129,470	107,338
£ 2.55	23,653	19,837	136,357	114,225
£ 2.60	24,848	21,032	143,244	121,112
£ 2.65	26,043	22,227	150,131	127,999
£ 2.70	27,237	23,422	157,017	134,886

Scenario 3: Changes in Package Size.

Default figures had indicated that with an average size of 0.01 m3 –the size of a men's shoe-box– the trike operator was able to effect delivery of the default assignment of 90 parcels a day with 44 minutes to spare (Table 15). How would an increase in parcel size affect the independent variables and profitability?

Increasing average parcel size by a factor of 10 to 0.1m3 reduced the number of packages loadable onto the trike from 125 to 12 (Table 25), but by undertaking 7.2 trips the 90-parcel assignment could still be completed within the time limit. However, the distance that had to be covered by the trike increased from 28.29 km to 40.71 km because of the extra distance traveled in performing six extra stem and return segments.

The number of packages loadable onto the van fell from 240 to 24. It was able to complete the assignment in 3.8 trips with 55 minutes to spare. It too had to travel a greater distance (33.79 kilometers) than in the default scenario (28.29 kilometers, which would push operating costs up.

Assignment revenue for the trike was unchanged, while redeployment revenue fell from £5,807 to£1,454 if this scenario were to pertain for a full year (Table 26) representing a drop of 75.0%. Operating costs increased marginally from £42,840 to £42,882 because of increased mileage resulting from seven stem and seven return elements. Gross profit fell 27.3% as did NPV (Table 26).

For the van, increased mileage from four stem and four return segments impacted fuel consumption and operating costs, as well as environmental and social costs. Together, these extra costs contributed to a fall of 16.7% in gross profit and NPV. The van is a clear winner in this scenario; the loser is the environment and human health.

Table 25. Impact of 10-fold increase in package size on performance metrics.

DERIVED VARIABLES / Performance data	Unit	TRIKE	VAN
Distance to be covered to complete this assignment	vkm	40.7	33.8
Distance traveled this scenario p/yr	vkm	10,178	8,447
Distance traveled when time expires in this scenario	vkm	41	36
Drops achievable p/load (packages loadable)	drop	12	24
Drops needed to complete this assignment	drop	90	90
Drops that can be effected before time expires	drop	92	99
Packages assigned p/yr.	drop	22,500	22,500
Packages undelivered because time expires	drop	-	-
Packages delivered p/yr	drop	22,500	22,500
Packages undelivered p/yr in deficit situation	drop	-	-
Stops achievable p/load	stop	11	21
Stops needed to complete this assignment	stop	79	79
Stops that can be made before time expires	stop	81	87
Stops that cannot be made because time expires	stop	-	-
Inter-stop travel time needed p/stop this assignment	min.	0.88	0.77
Inter-stop travel time needed p/assignment	min.	69	61
Return time p/assignment	min.	19.04	8.63
Stem time p/assignment	min.	19.04	8.63
Time taken p/stop this assignment	min.	5.94	6.91
Time surplus after completing this assignment	min.	11	55
Time needed to complete this assignment	hr.	7.82	9.09
Time deficit this day	hr.	-	-
Time spent on-road this assignment	hr.	7.82	9.09
Time spent on-road p/yr.	hr.	1,954	2,271
Transaction time needed p/assignment	min.	362	467
Cargo volume less losses	m3	1.25	2.40
Diesel fuel used p/yr in this scenario	liter	-	827
Trips needed to complete this assignment	trip	7.21	3.75

Table 26. Financial impacts of increasing package size to 0.1 m3 (Scenario 3).

PARCEL SIZE: Results when size increases from 0.01m3 to 0.10m3								
Yearly averages 2018-2024	TRIKE				VAN			
	0.01m3	0.1m3	£ change	% change	0.01m3	0.1m3	£ change	% change
Assignment Revenue	53,766	53,766	-	-	53,766	53,766	-	-
Redeployment revenue	5,807	1,454	(4,353)	(74.96)	8,964	7,284	(1,680)	(18.74)
Operating costs	42,840	42,882	42	0.10	47,015	47,162	147	0.31
Environmental costs	16	16	0	-	306	351	45	14.71
Social costs	233	335	102	43.78	2,740	2,983	242	8.83
Total costs	43,089	43,332	243	0.56	50,061	50,496	435	0.87
Gross profit	16,484	11,987	(4,497)	(27.28)	12,669	10,554	(2,115)	(16.69)
NPV	£95,035	£69,115	(25,920)	**(27.28)**	£ 72,904	£60,713	(12,191)	**(16.69)**

Scenario 4: Changes in Speed of Travel.

Under worst-case traffic conditions (Table 27), the trike was able to take shortcuts, bypass much of the congestion, and operate at an average speed of 15.91 km/h in delivering all 90 parcels assigned with 12 minutes to spare. Under the same conditions, van speed was reduced to walking pace or an average 5 km/h, and it would take nearly 13.45 hours to deliver the consigned number of 90 parcels, exceeding permissible driving time by 3 hours 27 minutes. Staying within legal time limits, the van would only be able to deliver 67 parcels p/day leaving 23 packages per day undelivered (5,678 p/year), thus

Table 27. Performance values under worst travel conditions (Scenario 4).

DERIVED VARIABLES / Performance data	Unit	TRIKE	VAN
Distance to be covered to complete this assignment	vkm	28.3	28.3
Distance traveled this scenario p/yr	vkm	7,072	5,387
Distance traveled when time expires in this scenario	vkm	29	22
Drops achievable p/load (packages loadable)	drop	125	240
Drops needed to complete this assignment	drop	90	90
Drops that can be effected before time expires	drop	92	67
Packages assigned p/yr.	drop	22,500	22,500
Packages undelivered because time expires	drop	-	23
Packages delivered p/yr	drop	22,500	16,732
Packages undelivered p/yr in deficit situation	drop	-	5,768
Stops achievable p/load	stop	109	211
Stops needed to complete this assignment	stop	79	79
Stops that can be made before time expires	stop	81	59
Stops that cannot be made because time expires	stop	-	20
Inter-stop travel time needed p/stop this assignment	min.	1.26	4.00
Inter-stop travel time needed p/assignment	min.	99	315
Return time p/assignment	min.	3.77	12.00
Stem time p/assignment	min.	3.77	12.00
Time taken p/stop this assignment	min.	5.93	10.22
Time surplus after completing this assignment	min.	12	-
Time needed to complete this assignment	hr.	7.80	13.45
Time deficit this day	hr.	-	3.45
Time spent on-road this assignment	hr.	7.80	10.00
Time spent on-road p/yr.	hr.	1,951	2,500
Transaction time needed p/assignment	min.	362	467
Cargo volume less losses	m3	1.25	2.40
Diesel fuel used p/yr in this scenario	liter	-	527
Trips needed to complete this assignment	trip	1.00	1.00

risking the loss of the contract. The biggest single problem for the van is that inter-stop travel time increases from 0.77 minutes to 4 minutes per stop.

Table 28 shows that revenue for the trike fell from £59,573 to £55,324 because the operator only gets paid for packages actually delivered. This resulted in NPV falling by 26%. Results for the van were much more marked, with gross profit falling from £12,690 to negative £9,550, and NPV plummeting by 175% to negative £55,168. Under these conditions the van would need to charge £2.96 per package in order to break-even. The trike could continue to charge £1.92 per package and still break-even.

Table 28. Financial results for trike and van in gridlocked traffic (Scenario 4).

PROFITABILITY	SCENARIO 4		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	53,766	39,982	53,766	53,766	-	(13,783)
Redeployment revenue	1,558	-	5,807	8,964	(4,250)	(8,964)
Operating costs	42,840	46,835	42,840	47,015	-	(180)
Environmental costs	16	255	16	306	-	(51)
Social costs	233	2,443	233	2,740	-	(297)
Total costs	43,089	49,533	43,089	50,061	-	(529)
Gross profit	12,235	(9,550)	16,484	12,669	(4,250)	(22,219)
Break-even price (BEP)	1.92	2.96	1.92	2.22	-	0.74
NPV	**£70,541**	**-£55,168**	**£95,035**	**£72,904**	**-£24,495**	**-£ 128,072**

Under the best traffic conditions with the least congestion (Table 29), the van ran at an average speed of 32.19 km/h. Stem- and return-time each fell to 1.86 minutes, while inter-stop travel time fell to 37.2 seconds, enabling the van to complete the consigned number of deliveries in 8 hours 38 minutes.

Under the same ‘near-freeflow’ conditions the trike was able to travel at no more than 25km/h, constrained by the pedelec law that limits top speed. Nevertheless, time

Table 29. Performance values for near freeflow travel conditions (Scenario 4).

PERFORMANCE VALUES at nr. FREEFLOW TRAFFIC	Unit	TRIKE	VAN
Inter-stop travel time needed p/stop this assignment	min.	0.80	0.62
Inter-stop travel time needed p/assignment	min.	63	49
Return time p/assignment	min.	2.40	1.86
Stem time p/assignment	min.	2.40	1.86
Time taken p/stop this assignment	min.	5.44	6.59
Time surplus after completing this assignment	min.	51	80
Time needed to complete this assignment	hr.	7.16	8.67
Time deficit this day	hr.	-	-
Time spent on-road this assignment	hr.	7.16	8.67
Time spent on-road p/yr.	hr.	1,789	2,167
Transaction time needed p/assignment	min.	362	467
Cargo volume less losses	m3	1.25	2.40
Diesel fuel used p/yr in this scenario	liter	n/a	692
Trips needed to complete current assignment	trip	1.0	1.0

performance improved and it was able to effect its consigned 90 deliveries per day with 51 minutes to spare.

Table 30 shows that because of increased redeployment revenue, total van revenue increased to £64,373, gross profit went up to £14,312 and NPV to £82,376. Trike revenue increased to £60,474, gross profit went up to £17,384 and NPV to £100,224.

Table 30. Profitability at best possible travel speed (Scenario 4b).

PROFITABILITY	SCENARIO 4b		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	53,766	53,766	53,766	53,766	-	-
Redeployment revenue	6,708	10,607	5,807	8,964	900	1,643
Operating costs	42,840	47,015	42,840	47,015	-	-
Environmental costs	16	306	16	306	-	-
Social costs	233	2,740	233	2,740	-	-
Total costs	43,089	50,061	43,089	50,061	-	-
Gross profit	17,384	14,312	16,484	12,669	900	1,643
Break-even price (BEP)	1.92	2.22	1.92	2.22	-	-
NPV	**£100,224**	**£82,376**	**£95,035**	**£72,904**	**£ 5,189**	**£ 9,472**

Scenario 5: Changes in Stem and Return Distances.

When stem-distance and return-distance were doubled from the baseline value to 2 kilometers, both vehicles were still able to complete the 90-package assignment with time to spare, 38 minutes for the trike and 63 minutes for the van. Not until the distances were increased to 10km (Table 31) did the trike begin to run into time deficit.

For the same 10km distance the van was able to complete the assignment with 26 minutes to spare, and was even able to complete the assignment with time to spare when stem and return distances were increased to 16km. Thereafter it too ran into time deficits.

Table 31. Performance data for 10km stem and return times (Scenario 5).

DERIVED VARIABLES / Performance data	Unit	TRIKE	VAN
Distance to be covered to complete this assignment	vkm	46.3	46.3
Distance traveled this scenario p/yr	vkm	11,572	11,572
Distance traveled when time expires in this scenario	vkm	46	47
Drops achievable p/load (packages loadable)	drop	125	240
Drops needed to complete this assignment	drop	90	90
Drops that can be effected before time expires	drop	89	94
Packages assigned p/yr.	drop	22,500	22,500
Packages undelivered because time expires	drop	1	-
Packages delivered p/yr	drop	22,325	22,500
Packages undelivered p/yr in deficit situation	drop	175	-
Stops achievable p/load	stop	109	211
Stops needed to complete this assignment	stop	79	79
Stops that can be made before time expires	stop	78	83
Stops that cannot be made because time expires	stop	1	-
Inter-stop travel time needed p/stop this assignment	min.	0.88	0.77
Inter-stop travel time needed p/assignment	min.	69	61
Return time p/assignment	min.	26.40	23.01
Stem time p/assignment	min.	26.40	23.01
Time taken p/stop this assignment	min.	6.13	7.27
Time surplus after completing this assignment	min.	-	26
Time needed to complete this assignment	hr.	8.06	9.57
Time deficit this day	hr.	0.06	-
Time spent on-road this assignment	hr.	8.00	9.57
Time spent on-road p/yr.	hr.	2,000	2,391
Transaction time needed p/assignment	min.	362	467
Cargo volume less losses	m3	1.25	2.40
Diesel fuel used p/yr in this scenario	liter	-	1,133
Trips needed to complete this assignment	trip	1.00	1.00

Deployment revenue for the trike was reduced from £5,807 to zero, and for the van it goes down by £5,500. Operating costs increase noticeably for the van because of increased fuel consumption, and for both modes there is a marked increase in social and environmental costs per year because of the increased emissions from longer distances traveled. NPV for the trike fell from £95,035 to £57,949. Van NPV fell by £39,864 to £33,040.

Table 32. Effect of increasing stem and return distances to 10km (Scenario 5).

PROFITABILITY (average p/year) (2018-24)	SCENARIO 5		DEFAULT		CHANGE + / -	
	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	53,347	53,766	53,766	53,766	(419)	-
Redeployment revenue	-	3,464	5,807	8,964	(5,807)	(5,500)
Operating costs	42,900	47,497	42,840	47,015	60	482
Environmental costs	16	447	16	306	-	141
Social costs	381	3,534	233	2,740	148	793
Total costs	43,297	51,478	43,089	50,061	208	1,416
Gross profit	10,050	5,753	16,484	12,669	(6,434)	(6,916)
Break-even price (BEP)	1.94	2.29	1.92	2.22	0	0.06
NPV	**£ 57,949**	**£33,040**	**£95,035**	**£72,904**	**-£37,086**	**-£ 39,864**

Scenario 6: Changes in Distance Between Stops.

Running the model at increments of 10% from the baseline distance of 330 meters between stops had little impact on the trike until a distance of 545 meters was reached. At that point the total distance that had to be traveled per day to complete the assignment rose from approximately 28 to 45 kilometers per day, or 4,184 kilometers per year (Table 33). The trike was still able to complete delivery of its assigned 90 packages (all bar 20 per year) but the additional time taken to accomplish the task led to a drop in time surplus available for redeployment work.

Inroads were also made into surplus time for the van, but because of its ability to travel at a faster speed between stops, the increased distance to be traveled had less of an impact than on trikes and the van was able to complete the assignment in a single trip with 29 minutes to spare and the opportunity for productive redeployment.

The advantage held over the bike by the van in Scenario 6 conditions only prevails because the van is on-road for 10 hours compared with eight hours for the trike. Were the trike to be ridden for the same number of hours as the van, the advantage would be reversed, and the trike would have a significant opportunity for productive redeployment.

Table 33. Performance data for inter-stop distance of 545 meters (Scenario 6).

DERIVED VARIABLES / Performance data	Unit	TRIKE	VAN
Distance to be covered to complete this assignment	vkm	45.0	45.0
Distance traveled this scenario p/yr	vkm	11,257	11,257
Distance traveled when time expires in this scenario	vkm	45	47
Drops achievable p/load (packages loadable)	drop	125	240
Drops needed to complete this assignment	drop	90	90
Drops that can be effected before time expires	drop	90	95
Packages assigned p/yr.	drop	22,500	22,500
Packages undelivered because time expires	drop	0	-
Packages delivered p/yr	drop	22,480	22,500
Packages undelivered p/yr in deficit situation	drop	20	-
Stops achievable p/load	stop	109	211
Stops needed to complete this assignment	stop	79	79
Stops that can be made before time expires	stop	79	83
Stops that cannot be made because time expires	stop	0	-
Inter-stop travel time needed p/stop this assignment	min.	1.44	1.25
Inter-stop travel time needed p/assignment	min.	114	99
Return time p/assignment	min.	2.64	2.30
Stem time p/assignment	min.	2.64	2.30
Time taken p/stop this assignment	min.	6.09	7.23
Time surplus after completing this assignment	min.	-	29
Time needed to complete this assignment	hr.	8.01	9.52
Time deficit this day	hr.	0.01	-
Time spent on-road this assignment	hr.	8.00	9.52
Time spent on-road p/yr.	hr.	2,000	2,379
Transaction time needed p/assignment	min.	362	467
Cargo volume less losses	m3	1.25	2.40
Diesel fuel used p/yr in this scenario	liter	-	1,102
Trips needed to complete this assignment	trip	1.00	1.00

Table 34 shows that trike redeployment revenue dropped from £5,807 to zero - as it did in Scenario 5 - and van revenue from redeployment fell by £5,114 to £3,850. Costs increased, and NPV decreased by a large amount.

Table 34. Profitability when inter-stop distance rises to 545 meters (Scenario 6).

PROFITABILITY	SCENARIO 6		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	53,717	53,766	53,766	53,766	(49)	-
Redeployment revenue	-	3,850	5,807	8,964	(5,807)	(5,114)
Operating costs	42,896	47,463	42,840	47,015	56	448
Environmental costs	16	437	16	306	-	131
Social costs	370	3,478	233	2,740	138	738
Total costs	43,282	51,378	43,089	50,061	193	1,317
Gross profit	10,435	6,238	16,484	12,669	(6,049)	(6,431)
Break-even price (BEP)	1.93	2.28	1.92	2.22	0.01	0.06
NPV	**£ 60,167**	**£35,837**	**£95,035**	**£72,904**	**-£34,868**	**-£ 37,067**

When the distance between stops was doubled from 333 to 666 meters (Table 35) the trike ran 26 minutes over the legal time limit, was only able to deliver 85 parcels and its NPV plummeted to £44,091. At the same distance, van NPV fell to £14,681.

Table 35. Results when inter-stop distance was doubled (Scenario 6).

PROFITABILITY	SCENARIO 6b		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	51,038	53,766	53,766	53,766	(2,727)	-
Redeployment revenue	-	932	5,807	8,964	(5,807)	(8,032)
Operating costs	42,928	47,719	42,840	47,015	87	704
Environmental costs	16	512	16	306	-	206
Social costs	449	3,899	233	2,740	216	1,159
Total costs	43,392	52,130	43,089	50,061	303	2,069
Gross profit	7,646	2,568	16,484	12,669	(8,838)	(10,101)
Break-even price (BEP)	2.03	2.32	1.92	2.22	0.12	0.09
NPV	**£ 44,091**	**£14,681**	**£95,035**	**£72,904**	**-£ 50,945**	**-£ 58,222**

Scenario 7: Changes in Transaction Time.

Increasing transaction time for both modes by 10% had no effect on the number of packages that could be delivered. However, a 20% increase put both modes into time deficit, and the number of deliveries made per day fell (Table 36).

Table 36. Impact of increasing transaction time by 20% (Scenario 7).

DERIVED VARIABLES / Performance data	Unit	TRIKE	VAN
Distance to be covered to complete this assignment	vkm	28.3	28.3
Distance traveled this scenario p/yr	vkm	7,072	7,072
Distance traveled when time expires in this scenario	vkm	27	27
Drops achievable p/load (packages loadable)	drop	125	240
Drops needed to complete this assignment	drop	90	90
Drops that can be effected before time expires	drop	85	86
Packages assigned p/yr.	drop	22,500	22,500
Packages undelivered because time expires	drop	5	4
Packages delivered p/yr	drop	21,236	21,567
Packages undelivered p/yr in deficit situation	drop	1,264	933
Stops achievable p/load	stop	109	211
Stops needed to complete this assignment	stop	79	79
Stops that can be made before time expires	stop	75	76
Stops that cannot be made because time expires	stop	4	3
Inter-stop travel time needed p/stop this assignment	min.	0.88	0.77
Inter-stop travel time needed p/assignment	min.	69	61
Return time p/assignment	min.	2.64	2.30
Stem time p/assignment	min.	2.64	2.30
Time taken p/stop this assignment	min.	6.44	7.93
Time surplus after completing this assignment	min.	-	-
Time needed to complete this assignment	hr.	8.48	10.43
Time deficit this day	hr.	0.48	0.43

Table 37. Profitability when transaction time increases by 20% (Scenario 7).

PROFITABILITY	SCENARIO 7		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	50,745	51,537	53,766	53,766	(3,020)	(2,229)
Redeployment revenue	-	-	5,807	8,964	(5,807)	(8,964)
Operating costs	42,840	47,015	42,840	47,015	-	-
Environmental costs	16	306	16	306	-	-
Social costs	233	2,740	233	2,740	-	-
Total costs	43,089	50,061	43,089	50,061	-	-
Gross profit	7,656	1,476	16,484	12,669	(8,828)	(11,193)
Break-even price (BEP)	2.03	2.32	1.92	2.22	0.11	0.10
NPV	£44,151	£ 8,386	£95,035	£72,904	-£ 50,885	-£ 64,518

Redeployment revenue for both modes falls to zero, resulting in a significant fall in NPV; for the trike it fell to £44,151 (Table 37), and for the van it fell to £8,386.

I also ran the model to simulate reductions in transaction time. A 10% reduction from the baseline times of 4.58 and 5.92 minutes led to marked increases in surplus time and redeployment revenue resulting in NPV increases of 29.1% for the trike and 49.1% for the van. It is clear from these results that transaction time is a key component in determining the viability of both modes.

Scenario 8: Changes in the Number of Parcels Assigned.

It should be noted that the last-mile operator is unlikely to have control over the number of packages assigned on a given day. Although parameters (minima and maxima) are agreed in advance, the precise number will vary. The baseline number used in this study is 90. When the number of packages assigned per day is reduced to 80 (Table 38), distance traveled falls by 730 kilometers per year, and total costs fall by 0.08% for the trike and by 0.46% for the van (reflecting the relative difference in ratios of variable to fixed costs).

Although assignment revenue fell (Table 39), redeployment revenue increased, and this led to slightly higher overall revenue, along with slightly higher NPV values. Results for this scenario reflect the fact that redeployment revenue is more valuable than assignment revenue in terms of time, and brings into question the availability of the contract and A-B work necessary to generate redeployment revenue. This is a critical area for operators. Those without contract work are at a serious disadvantage.

Table 38. Results when number of packages assigned is reduced (Scenario 8).

DERIVED VARIABLES / Performance data	Unit	TRIKE	VAN
Distance to be covered to complete this assignment	vkm	25.4	25.4
Distance traveled this scenario p/yr	vkm	6,342	6,342
Distance traveled when time expires in this scenario	vkm	31	32
Drops achievable p/load (packages loadable)	drop	125	240
Drops needed to complete this assignment	drop	80	80
Drops that can be effected before time expires	drop	99	101
Packages assigned p/yr.	drop	20,000	20,000
Packages undelivered because time expires	drop	-	-
Packages delivered p/yr	drop	20,000	20,000
Packages undelivered p/yr in deficit situation	drop	-	-
Stops achievable p/load	stop	109	211
Stops needed to complete this assignment	stop	70	70
Stops that can be made before time expires	stop	87	89
Stops that cannot be made because time expires	stop	-	-
Inter-stop travel time needed p/stop this assignment	min.	0.88	0.77
Inter-stop travel time needed p/assignment	min.	62	54
Return time p/assignment	min.	2.64	2.30
Stem time p/assignment	min.	2.64	2.30
Time taken p/stop this assignment	min.	5.53	6.75
Time surplus after completing this assignment	min.	92	126
Time needed to complete this assignment	hr.	6.47	7.90
Time deficit this day	hr.	-	-
Time spent on-road this assignment	hr.	6.47	7.90
Time spent on-road p/yr.	hr.	1,618	1,974
Transaction time needed p/assignment	min.	321	415
Cargo volume less losses	m3	1.25	2.40
Diesel fuel used p/yr in this scenario	liter	-	621
Trips needed to complete this assignment	trip	1.00	1.00

Table 39. Results when packages assigned declined to 80 per day (Scenario 8).

PROFITABILITY	SCENARIO 8		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	47,792	47,792	53,766	53,766	(5,974)	(5,974)
Redeployment revenue	12,165	16,751	5,807	8,964	6,357	7,786
Operating costs	42,831	46,937	42,840	47,015	(10)	(78)
Environmental costs	16	283	16	306	-	(23)
Social costs	209	2,612	233	2,740	(24)	(129)
Total costs	43,055	49,831	43,089	50,061	(34)	(230)
Gross profit	16,901	14,711	16,484	12,669	417	2,042
Break-even price (BEP)	2.15	2.49	1.92	2.22	0.24	0.27
NPV	£ 97,438	£ 84,676	£95,035	£72,904	£ 2,403	£ 11,772

In contrast, when the number of packages assigned was increased from 90 to 100 per day, the model showed that the trike was able to deliver up to 99 packages before time expired, while the van maxed out at 101 per day before it too ran out of time. Both modes showed decreases in time surplus and a reduction in redeployment revenue, along with significant decreases in NPV due to the alteration in the ratio between the two revenue streams (Table 40).

Table 40. Results when packages assigned were increased to 100 per day.

PROFITABILITY	SCENARIO 8		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	59,229	59,740	53,766	53,766	5,463	5,974
Redeployment revenue	-	1,178	5,807	8,964	(5,807)	(7,786)
Operating costs	42,850	47,093	42,840	47,015	10	78
Environmental costs	16	329	16	306	-	23
Social costs	257	2,869	233	2,740	24	129
Total costs	43,123	50,291	43,089	50,061	34	230
Gross profit	16,106	10,626	16,484	12,669	(378)	(2,042)
Break-even price (BEP)	1.74	2.01	1.92	2.22	(0.18)	(0.21)
NPV	**£92,856**	**£ 61,132**	**£95,035**	**£72,904**	**-£ 2,179**	**-£ 11,772**

Break-even price for both modes dropped. In the case of the trike, the increase in packages assigned meant that it could break-even with a price of £1.74 charged per delivery, whilst the van would have to charge £2.01 (Table 40).

Scenario 9: Changes in Package Drops per Stop.

An increase in the ratio of stops made to the number of packages delivered might occur in locations where, for example, there are multiple households at a given address such as a condominium or a university college.

A 10% increase over the baseline value of 1.14 packages per stop led to a reduction in distance traveled to complete the assignment, a reduction in overall transaction time, and a marked increase in surplus time, 83 minutes as opposed to 44 minutes for the trike, and 116 minutes as opposed to 68 minutes for the van (Table 41).

Table 41. Changing number of packages delivered per stop (Scenario 9).

DERIVED VARIABLES / Performance data	Unit	TRIKE	VAN
Distance to be covered to complete this assignment	vkm	25.9	25.9
Distance traveled this scenario p/yr	vkm	6,475	6,475
Distance traveled when time expires in this scenario	vkm	31	32
Drops achievable p/load (packages loadable)	drop	125	240
Drops needed to complete this assignment	drop	90	90
Drops that can be effected before time expires	drop	109	111
Packages assigned p/yr.	drop	22,500	22,500
Packages undelivered because time expires	drop	-	-
Packages delivered p/yr	drop	22,500	22,500
Packages undelivered p/yr in deficit situation	drop	-	-
Stops achievable p/load	stop	100	191
Stops needed to complete this assignment	stop	72	72
Stops that can be made before time expires	stop	87	89
Stops that cannot be made because time expires	stop	-	-
Inter-stop travel time needed p/stop this assignment	min.	0.88	0.77
Inter-stop travel time needed p/assignment	min.	63	55
Return time p/assignment	min.	2.64	2.30
Stem time p/assignment	min.	2.64	2.30
Time taken p/stop this assignment	min.	5.53	6.75
Time surplus after completing this assignment	min.	83	116
Time needed to complete this assignment	hr.	6.62	8.07
Time deficit this day	hr.	-	-
Time spent on-road this assignment	hr.	6.62	8.07
Time spent on-road p/yr.	hr.	1,654	2,019
Transaction time needed p/assignment	min.	329	425
Cargo volume less losses	m3	1.25	2.40
Diesel fuel used p/yr in this scenario	liter	-	634
Trips needed to complete this assignment	trip	1.00	1.00

Consequently, redeployment revenue showed marked increases (Table 42) for both modes - particularly for the trike - costs declined slightly, and NPV increased 31.7% for the trike, and 51.9% for the van.

Table 42. Financial impact of 10% increase in package drop ratio (Scenario 9).

PROFITABILITY	SCENARIO 9		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	53,766	53,766	53,766	53,766	-	-
Redeployment revenue	11,009	15,335	5,807	8,964	5,201	6,371
Operating costs	42,832	46,951	42,840	47,015	(8)	(64)
Environmental costs	16	287	16	306	-	(19)
Social costs	213	2,635	233	2,740	(20)	(105)
Total costs	43,061	49,873	43,089	50,061	(28)	(188)
Gross profit	21,713	19,227	16,484	12,669	5,229	6,559
Break-even price (BEP)	1.91	2.22	1.92	2.22	(0.00)	(0.01)
NPV	**£ 125,175**	**£ 110,709**	**£95,035**	**£72,904**	**£ 30,140**	**£ 37,805**

Scenario 10: Changes in Riding/Driving Time.

Increasing the length of the working day per rider is not possible without changing the law. However, it was noted that the law relates to the rider, not to the trike. Thus, employing two part-time riders, each to ride one shift of five hours, generated the potential for as many on-road hours for the trike as for the van, and – it was assumed – at no additional cost. With a 10-hour working day, the trike was able to complete the baseline assignment with 2 hours 44 minutes to spare, quadrupling the surplus time in the baseline scenario (Scenario 1). This generated redeployment revenue of £21,738 per year and NPV of £186,861, an increase of 96.6% in NPV (Table 43).

Table 43. Results when on-road working hours are equalized at 10 per day.

PROFITABILITY	SCENARIO 10		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	53,766	53,766	53,766	53,766	-	-
Redeployment revenue	21,738	8,964	5,807	8,964	15,931	-
Operating costs	42,840	47,015	42,840	47,015	-	-
Environmental costs	16	306	16	306	-	-
Social costs	233	2,740	233	2,740	-	-
Total costs	43,089	50,061	43,089	50,061	-	-
Gross profit	32,415	12,669	16,484	12,669	15,931	-
Break-even price (BEP)	1.92	2.22	1.92	2.22	-	-
NPV	**£ 186,861**	**£ 72,904**	**£95,035**	**£72,904**	**£ 91,825**	**£ -**

Scenario 11: Changes in Electricity and Diesel Prices.

When electricity prices were doubled from £0.16 per kWh (Table 44), there was an insignificant impact (+ 0.05%) on operating costs for the trike. When diesel-fuel prices were doubled to £2.06 per liter the impact on van operating costs was +1.61%. Van NPV dropped by 5.99%. Conversely, when diesel fuel price was halved, van NPV increased by 2.99%.

Table 44. The impact of increased diesel and electricity prices (Scenario 11).

PROFITABILITY	SCENARIO 11		DEFAULT		CHANGE + / -	
(average p/year) (2018-24)	TRIKE	VAN	TRIKE	VAN	TRIKE	VAN
Assignment revenue	53,766	53,766	53,766	53,766	-	-
Redeployment revenue	5,807	8,964	5,807	8,964	-	-
Operating costs	42,861	47,772	42,840	47,015	20	757
Environmental costs	17	306	16	306	1	-
Social costs	233	2,740	233	2,740	-	-
Total costs	43,110	50,818	43,089	50,061	21	757
Gross profit	16,464	11,912	16,484	12,669	(21)	(757)
Break-even price (BEP)	1.92	2.26	1.92	2.22	0.00	0.03
NPV	**£ 94,919**	**£ 68,540**	**£95,035**	**£72,904**	**-£ 117**	**-£ 4,364**

Sensitivity Analysis

In order to readily see which independent variables had the greatest impact on gross profit and NPV I constructed a sensitivity analysis table. Using the baseline value for each independent variable as the central point I calculated what the NPV would be if the baseline value was increased or decreased by 25%. Subtracting one from the other produced a spread value for each of the variables tested.

Fee receivable per package, vehicle days per year, and packages assigned per day were the three dominant variables in terms of trike NPV sensitivity, accounting for a total of 70.95% of total spread (Table 45). The table for vans produced similar results, as shown in Table 46.

Table 45. NPV sensitivity spread for trikes.

TRIKE	NPV Sensitivity	+25%	-25%	Spread	Spread
Rank	Variable	NPV	NPV	NPV	% of Total
		£	£	£	%
1	Riding/driving time permitted p/day	186,861	7,696	179,165	19.28
2	Vehicle days p/year	180,379	9,691	170,688	18.36
3	Fee receivable per package	172,513	17,558	154,955	16.67
4	Package drops p/stop	161,343	7,985	153,358	16.50
5	Transaction time	34,110	164,206	130,096	14.00
6	Inflation rate	97,406	41,005	56,401	6.07
7	Speed of travel	106,464	75,988	30,476	3.28
8	Distance between stops (density)	81,323	108,748	27,425	2.95
9	Discount trate	90,777	99,605	8,828	0.95
10	Average # packages assigned p/day	93,284	100,442	7,158	0.77
11	Micro depot rent	79,396	72,904	6,492	0.70
12	Vehicle purchase price	93,363	96,708	3,345	0.36
13	Stem distance	94,514	95,557	1,043	0.11
14	Carbon price	95,032	95,039	7	0.00
15	Max cargo volume (capacity)	95,035	95,035	-	-
16	Average size of packages	95,035	95,035	-	-

The legally permitted amount of time on the road was the most sensitive variable for both modes of transport. Other variables which also took a double-digit percentage share of total spread included: vehicle days per year, fee receivable per package delivered, package drops per stop, and transaction time. Rate of inflation showed higher sensitivity in the case of the van and this was likely because of the higher purchase price of the vehicle compared with the trike and also because of higher operating costs.

It had been assumed that density – based on the combined distance between stops- would be among the top variables in terms of sensitivity. However, this was not the case,

Table 46. NPV sensitivity spread for vans.

VAN	NPV Sensitivity	+25%	-25%	Spread	Spread
Rank	Variable	NPV	NPV	NPV	% of Total
		£	£	£	%
1	Riding/driving time permitted p/day	187,685	(24,928)	212,613	17.75
2	Package drops p/stop	156,068	(27,737)	183,805	15.35
3	Vehicle days p/year	160,102	(14,294)	174,396	14.56
4	Inflation rate	187,200	22,070	165,130	13.79
5	Transaction time	(2,305)	162,313	164,618	13.74
6	Fee receivable per package	150,381	(4,574)	154,955	12.94
7	Average # packages assigned p/day	59,609	99,381	39,772	3.32
8	Micro depot rent	57,265	88,543	31,278	2.61
9	Distance between stops (density)	58,358	87,450	29,092	2.43
10	Speed of travel	82,868	56,297	26,571	2.22
11	Discount trate	69,620	76,428	6,808	0.57
12	Vehicle purchase price	69,534	76,274	6,740	0.56
13	Stem distance	72,351	73,457	1,106	0.09
14	Carbon price	72,474	73,334	860	0.07
15	Max cargo volume (capacity)	72,904	72,904	-	-
16	Average size of packages	72,904	72,904	-	-

and this variable appeared in the middle for both modes. Even more surprising was that average size of parcels assigned, and also cargo volume, were the bottom two variables for both modes. It had been assumed they would be in the top five. The bottom five variables were the same for both vehicles (Tables 45 & 46).

Table 47 shows the relative importance of the three main cost categories to NPV for both modes and highlights the significance of social costs to operating the van. This table also confirms that NPV sensitivity is not greatly impacted by environmental costs.

Table 47. Sensitivity spread by cost groups.

NPV Sensitivity Spread by Cost Category					
TRIKE	Baseline value	Baseline + 25%	Baseline - 25%	Spread total	% of Total Spread
	£	NPV	NPV	NPV	%
Operating costs	42,840	53,550	40,163	13,388	99.46
Social costs	233	291	218	73	0.54
Environmental costs	16	20	15	5	0.04

NPV Sensitivity Spread by Cost Category					
VAN	Baseline value	Baseline + 25%	Baseline - 25%	Spread total	% of Total Spread
	£	NPV	NPV	NPV	%
Operating costs	47,015	58,769	44,077	14,692	94.49
Social costs	2,740	3,425	2,569	856	5.51
Environmental costs	306	382	287	96	0.61

Chapter IV

Discussion

The results obtained from the financial appraisal answered the main research question. Gross profit and net present value (NPV) for the trike significantly surpass those of the van, making the operation of a trike business financially viable and more profitable than operating a van for delivering small packages in the last-mile space in London, even when the cost of a transfer hub is not covered or subsidized by a third party. These results stand regardless of whether traditional or full-cost accounting methods are used. Add some numbers of %s here to demonstrate scope of difference

Selected Results

Predictably, environmental costs for the trike were low, £16 per year per trike compared with £306 for the van (Table 23). What had not been expected was that the proportion of trike environmental costs attributable to food production and distribution to provide the human energy needed to propel the trikes would be nearly 70% of their total environmental footprint. Although the monetary value of food emissions is relatively low, it is expected that greater significance will be attached to it as increases in temperature caused by global warming move towards 1.5ºC from pre-industrial levels.

Although the van's environmental footprint cost is nearly 20 times higher than for the trike it is, nevertheless, lower than had been supposed. The reason for this is that European Union directives around permissible GHG emissions from road vehicles has resulted in technological improvements in diesel engines and a net reduction in CO2e emissions per vehicle since 2015. Despite this, CO2e emissions for the transport sector as a whole continue to rise inexorably because of the increase in new vehicle registrations, not only in London, but worldwide.

It should also be noted that even though environmental costs are lower than had been supposed, they have a significant impact on NPV. Table 20 shows that trike NPV is higher than van NPV by more than 30% at default values.

As expected, time variables proved to be among the most sensitive. Top of the NPV sensitivity tables both for the trike and for the van was 'riding/driving time permitted per day', which I also refer to as 'on-road time'. As stated in the Results section, the law prohibits employees from driving a van for more than 10 hours per day. Although there appears to be no legislation covering trike operators, they tend to limit on-road time to eight hours per rider, and that is the baseline default value for this study. However, there is nothing to stop a trike operator from employing two riders part-time, each riding a five hour shift per day. Thus, it could be argued that this study should have used 10 hours as the default value in the baseline scenario. The case for not doing so is that none of the operators contacted by the author said that they were employing part-timers. However, Table 43 shows that when trike on-road time was increased to 10 hours per day, NPV rose to £186, 861. This is 2.56 times higher than NPV for the van and suggests that trike operators may benefit substantially from exploring the option of employing more part-time riders and working two shifts per trike.

Another time metric, 'vehicle days per year' was also shown to be a critical factor. UK operators reported that predominantly they were working five days per week and for a total of 250 days per year. In contrast, according to the European Cycle Logistics

Federation (ECLF Survey, 2016), most operators on the continent are working six days a week or 300 days per year.

Transaction time values turned out to be somewhere between what I had expected and what appeared in the results. An increase of 10% had no effect on either mode, but a 20% increase put both into time deficit, as package deliveries were reduced from 90 to 85 for the trike and to 86 for the van (Table 36). Most of the metrics measured in the study do not directly reflect the performance of the rider. For example, decisions about cargo volume, micro depot area, and vehicle purchase price are in the hands of the operator. In contrast, transaction time depends very much on the knowledge, experience and skill of the rider. For this reason, it is probably more susceptible to variation than any other metric measured in this study.

For the baseline scenario, I attempted to capture the average time spent on the transaction phase, but it should be noted that the values used — 4.58 minutes for the trike and 5.92 for the van — may vary substantially depending on the rider. This may sound important because this phase accounts for 83% and 88% respectively of total time spent on the road. However, it still only amounts to 14% and 13.74% of total spread in the sensitivity table (Tables 45 and 46).

Package drops per stop were shown to be a major determinant for trike and van NPV. A high ratio of drops to stops is likely to be found in districts where there is a relatively high number of apartment blocks, colleges or communal residential buildings such as in Oxford, Cambridge, Edinburgh and other university towns and cities. Potential investors in last-mile operations may benefit from noting that this metric appears to be more important, than the 'distance between stops' metric.

It was a surprise to find that the fee charged per parcel delivered proved to be less sensitive than I had supposed for both modes of transport. I am confident that the baseline fee of £2.25 (£2.39 inflated) is the correct value to have used in this study; however, it has to be acknowledged that on the grounds of "commercial sensitivity" some industry sources were reluctant to divulge specific figures. This may represent a limitation on the absolute certainty of some financial results. What is certain is that break-even figures based on the £2.25 figure indicate there is room for trike operators to reduce the fee charged, remain competitive with the van, and still make a better return on investment.

One of the most surprising results was that changes in average package-size (Scenario 3) did not make a bigger impact on trike GP and NPV. I had assumed that this factor would be among the three most sensitive variables. In fact it emerged as the least dominant (Table 26) for both modes. This is likely because the ability of the trike to make repeat trips and still remain within the legal on-road time limit is much greater than I had assumed. For example, when parcel size is increased 10 fold to 0.1m3 the trike makes 8 trips and still finishes the assignment with 11 minutes to spare; NPV falls by 27.27% compared with only a 16.72% drop for the van, but the point is that the trike can complete the assignment within the allotted time.

Much less surprising was the disproportionately detrimental effect of traffic congestion on van profits and NPV. The fact that 'speed of travel' does not rank higher in the sensitivity rankings (Tables 45 and 46) is misleading. This is because the sensitivity spread is only +/- 25%, whereas the model showed that van speed falls from 26 km/h to 5 km/h — a fall of some 500% (Scenario 4) — NPV plummets by 175%. Under the same conditions trike NPV also drops but only by 26%. This is important because the last mile is getting more congested over time and all the indicators are that congestion will continue to increase. Electric vans will not move the dial one way or the other with regard to congestion.

The low sensitivity spread for stem time and return time was not what I had assumed, not only for intuitive reasons, but also because a leading last-mile operator had confided that for his business this metric was important. My results showed that in baseline conditions it was not until stem time was increased to 10km that it started to generate a time deficit for the trike. Re-running the model with a more realistic 3km stem time had very little impact on overall trip time, GP or NPV.

Even in combination with increases in other metrics such as speed of travel or average package-size, stem time had only a modest impact on overall results. The implication of this is that locating the distribution center slightly further away from the first stop on the route may not be as damaging to viability and profitability as first thought. This applies to both trike and van operations.

Similarly, the average distance between stops — which can be translated into 'stop density' — was another metric that had less of an impact than I had supposed. Intuitively speaking, this would seem to be a very sensitive metric because of the multiplier effect on increased distance. However, the results showed that even when the distance is increased by 25% (Tables 44 and 45) the shift in NPV is no more than 3% for either the trike or the van. [It is important to note that the spreads shown in the sensitivity table are percentages of a whole, and are thus highly relative].

Another variable that only took a single digit share of the overall sensitivity spread was 'number of parcels assigned'. The results showed that the profit window for trikes was wider and stayed open 'longer' for trikes than for vans. For example, it was not until the number of parcels fell from 90 to 73 per day that trike NPV began to turn negative, whereas negative NPV for the van started at 84 packages per day. Bearing in mind that both modes started to run out of time at about 100 parcels per day, I observed that the trike remains NPV positive over a longer range of deliveries than the van, 26 packages for the trike, 17 for the van. This indicates that the trike business model is more robust with regard to packages assigned per day.

Another metric that highlights the robustness of the trike business model is 'price of fuel'. As policy-makers seek new ways to deter the use of fossil fuel going forward, it seems likely that they will increase tax on diesel. Even without such an increase, diesel prices have a proportionately much greater impact on van NPV than electricity prices have on trike NPV, something like 25:1. When prices are doubled, van NPV is reduced, but it remains a relatively low cost component of total costs, and less important than I had supposed. Other noteworthy results are discussed below.

Redeployment. It was noted that in some scenarios, the amount of time left over after completing the 90-package per day assignment was substantial. For example, when transaction time for the trike was reduced by 30%, the amount of time left over for unspecified local deliveries was more than two hours, or one quarter of the working day.

Another example is package drops per stop; although the results showed that an increase of 25% had only an insignificant effect on NPV, it boosted redeployment value by a factor of 5.8. Anomalies such as these bolster the argument that redeployment should have been excluded from the default baseline for this study. However, to have done so would have been to exclude a metric that is highly relevant to overall profitability. Although it can be said that the inclusion of redeployment dilutes the focus of the core of the study (deliveries on behalf of 3PL legacy operators in the age of online shopping) it makes for a much more true-to-life picture than would otherwise be obtained. *Distribution center location.* Technically, results for locating the distribution base in a rural area are outside the scope of a study focused on last-mile deliveries. However, I ran the model to provide data for interested parties; the data are in this section and not in Results because they are not part of the main study.

Locating the van business in a rural area and reducing the rental paid for premises by 80% from £275 down to £55 per m2 had a major impact on costs and boosted its NPV to £69,375. When the same rental reduction was applied to trike operations, NPV rose to £110,586. However, these gains were offset by the concomitant increase in stem- and return-distance which I estimated to be 25 kilometers for each, adding a total of 50 kilometers to every trip. Van NPV went down to £26,953 and trike NPV fell to £62,038 (Table 48).

The model showed that locating the van's operating base 25 kilometers further out than the trike base more than doubled the environmental damage caused by the van, as well as increasing health and social costs by 77%.

The overall effect (Table 49) was that the van ran into a time deficit of 43 minutes. Over a period of one year, this would leave 1,503 parcels undelivered.

Table 48. Impact of location on costs, gross profit and NPV of van.

RURAL LOCATION: FINANCIAL RESULTS		
VANS:	Yearly averages: 2018 - 2024	£
Revenue		47,243
Internal costs		37,616
Environmental costs		647
Health & social costs		4,573
Total costs		42,836
Gross profit (revenue less costs)		4,407
NPV (Van)		£ 26,953

Table 49. Impact of rural location on derived variables.

RURAL LOCATION: RESULTS	Unit	TRIKE	VAN
Max cargo volume less losses	m3	1.25	2.40
Max drops achievable p/load	drop	125	240
Max stops achievable p/load	stop	109	211
Drops needed to complete assignment	drop	90	90
Stops needed to complete assignment	stop	79	79
Trips needed to complete assignment	trip	1.0	1.0
Inter-stop travel time needed p/stop this assignment	min.	0.88	0.77
Inter-stop travel time needed p/assignment	min.	69	61
Stem time allocated p/assignment	min.	65.99	57.54
Return time allocated p/assignment	min.	65.99	57.54
Transaction time needed p/assignment	min.	362	467
Total time needed to complete assignment	hr.	9.38	10.72
Time taken p/stop this assignment	min.	7.13	8.14
Stops that can be made before time expires	stop	67	74
Drops that can be effected before time expires	drop	77	84
Distance to be covered to complete this assignment	vkm	76	76
Time surplus after completing assignment	min.	-	-
Packages assigned p/yr.	drop	22,500	22,500
Packages delivered p/yr	drop	19,184	20,997
Revenue p/yr. from assignment	£	43,165	47,243
Surplus time redeployment value p/yr.	£	-	-
Distance traveled this scenario p/yr	vkm	18,104	19,072
Packages undelivered p/yr in deficit scenario	drop	3,316	1,503

Traditional accounting vs. full-cost accounting. It is clear that the van is at an even greater disadvantage compared with the trike when full-cost methods are applied.

Traditional cost-accounting methods do not reflect total costs and are unsustainable in the long term. Nevertheless, they can be useful for comparison purposes. Using baseline values and ignoring external costs, the trike returns average NPV almost 70% higher than for the van (Table 50). The main area in which the trike outscores the van is variable costs, such as fuel, the London congestion charge, and parking fines. Van variables are more than three times higher than trike variables, a higher figure than I had assumed and one that is attributable mostly to extremely low propulsion costs for the trike, and the high price of van diesel. These figures don't sound right until the role of human energy is brought into the picture. Suffice it to say that variables have a key role in determining break-even points, and enable the trike to outperform the van in baseline conditions.

Table 50. Profit and NPV results using traditional cost-accounting methods.

Using Traditional accounting methods		
EXCLUDING external costs	**TRIKES**	**VANS**
2018 - 2024	£	£
Revenue	50,625	50,625
Overhead costs	39,865	42,540
Variable costs	628	2,042
Total operating costs	40,493	44,582
Gross profit	10,132	6,043
NPV	**£ 61,952**	**£ 36,953**

The trike enterprise also had higher fixed costs. Although the most expensive items such as rental of premises, salaries, and payments to professional advisers are similar for both modes, expenses such as purchasing the vehicle, depreciation and insurance mean that van overheads are greater than trike overheads by 5.3%.

Overall, traditional accounting methods indicate that trike costs are almost 10% less than van costs at the baseline values modeled. This is not as great a difference as I had assumed. The main reason for this is that because the highest fixed costs are disproportionately high, other costs carry proportionately less weight. Using baseline values and full-cost accounting the financial appraisal showed that van NPV suffers more than trike NPV because of the inclusion of environmental and social costs (Table 51).

Table 51. NPV compared by traditional and triple bottom line methods.

NPV by Accounting Method	Trike NPV	Van NPV
	£	£
Traditional accounting	61,952	36,953
Triple Bottom Line accounting	60,599	19,387

Conclusions

This study used values for 24 independent variables to produce a baseline scenario that showed performance results for 28 derived variables categorized under the headings of distance, drops/packages, money, stops, time, and miscellaneous.

These baseline results showed that even though the van was able to achieve higher speed of travel, the trike was able to find a parking spot more quickly, effect the delivery and return to base in less time than the van.

The results also revealed that although the van had the capacity to make more stops and deliver nearly twice as many packages as the trike, it could not capitalize on these advantages because of time constraints limiting to 10 the number of hours that could be driven legally by any one driver per day.

Moreover, the baseline results showed that although the van could generate higher total revenue per year than the trike, this failed to produce the expected profit and NPV figures, both of which measurements were substantially higher for the trike.

The study did not stop at the baseline. It explored 10 scenarios in which the baseline variables were given new values, each producing a new set of results measuring the performance of the trike against the van.

In some of these scenarios, the van performed relatively well. For example, when the distribution center was moved 25 kilometers out of London, the model indicated that the van's superior top speed enabled it to get a head-start to the first stop of the day. But, when the extra environmental and social costs were added to the increased operating costs incurred in traveling the longer distance, the van once again lagged behind the trike. In fact, there was not one single instance in which the van came close to the trike in terms of gross profit or NPV. Only by inputting unrealistic values to the independent variables is it possible to create scenarios that make the van business model seem superior to that of the trike.

The evidence presented in this study makes it clear that even though environmental costs are lower than anticipated for the van, social costs are high, and together they have a significant impact on NPV. This means that investing in the van business model is not only antisocial, it is also likely to be financially risky.

> In conclusion, the trike is not only viable, it is more profitable than the van, less damaging to the environment, and much less damaging to human health and society as a whole. National and local authorities may wish to take these findings 'on board' and frame policies that encourage the establishment of trike businesses going forward.

Appendix 1 Full Financial and Social Appraisals for Trikes and Vans

Table 52. Financial appraisal for operating costs of trikes.

OPERATING COSTS										
TRIKES	Year 1	2	3	4	5	6	7	7-year	% of	Annual
	2018	2019	2020	2021	2022	2023	2024	Total	Total	Average
Overhead Costs	£	£	£	£	£	£	£	£	%	£
Purchase cost of trike(s) @£8,092	1,501	1,501	1,501	1,501	1,501	1,501	1,501	10,510	3.50%	1,501
Depreciation	1,156	1,156	1,156	1,156	1,156	1,156	1,156	8,092	2.70%	1,156
Road use tax (VED) (not required)	-	-	-	-	-	-	-	-	0.00%	-
Vehicle insurance (comprehensive)	475	485	494	504	514	524	535	3,531	1.18%	504
Public & Employers' liability insurance	500	510	520	531	541	552	563	3,717	1.24%	611
Goods in transit insurance	300	306	312	318	325	331	338	2,230	0.74%	319
Bookkeeping/accounting/legal fees	1,000	1,020	1,040	1,061	1,082	1,104	1,126	7,434	2.48%	1,062
Rental of premises	10,219	10,423	10,632	10,844	11,061	11,283	11,508	75,971	25.33%	10,853
Servicing (MOT not required)	96	98	100	102	104	106	108	714	0.24%	102
Delivery management software rental	500	510	520	531	541	552	563	3,717	1.24%	531
Rider's salary	21,330	21,757	22,192	22,636	23,088	23,550	24,021	158,573	52.88%	22,653
National Insurance (NI)	1,787	1,823	1,860	1,897	1,935	1,974	2,013	13,289	4.43%	1,898
Advertising and marketing	1,000	1,020	1,040	1,061	1,082	1,104	1,126	7,434	2.48%	1,062
Total Overhead Costs	£ 39,865	40,609	41,368	42,142	42,932	43,738	44,559	295,213	-	42,173
On-Road Costs										
Fuel (electricity)	19	19	20	20	21	21	21	141	0.05%	20
Congestion charge	-	-	-	-	-	-	-	-	-	-
Parking fines	-	-	-	-	-	-	-	-	-	-
Brake pads / discs (fitted)	40	41	42	42	43	44	45	297	0.10%	42
Tires	88	90	92	94	96	98	100	657	0.22%	94
Repairs	343	350	357	364	371	379	386	2,550	0.85%	364
Battery	138	140	143	146	149	152	155	1,023	0.34%	146
Total On-Road Costs	£ 628	641	653	666	680	693	707	4,669	-	667
Total Operating Costs	£ 40,493	41,250	42,022	42,809	43,612	44,431	45,266	299,882	100%	42,840

Table 53. Financial appraisal of operating costs for vans.

OPERATING COSTS										
VANS	Year 1 2018	2 2019	3 2020	4 2021	5 2022	6 2023	7 2024	7-yr Total	% of Total	Annual Average
Overhead Costs	£	£	£	£	£	£	£	£	%	£
Purchase cost of van(s) @ £16,308	3,026	3,026	3,026	3,026	3,026	3,026	3,026	21,182	6.44%	3,026
Depreciation	2,330	2,330	2,330	2,330	2,330	2,330	2,330	16,308	4.96%	2,330
Road use tax (VED)	270	275	281	287	292	298	304	2,007	0.61%	287
Vehicle insurance (comprehensive)	1,432	1,461	1,490	1,520	1,550	1,581	1,613	10,646	3.23%	1,521
Public & Employers' liability insurance	300	306	312	318	325	331	338	2,100	0.64%	300
Goods in transit insurance	91	93	95	97	99	100	102	677	0.21%	97
Bookkeeping/accounting/legal fees	1,000	1,020	1,040	1,061	1,082	1,104	1,126	7,434	2.26%	1,062
Rental of premises	10,219	10,423	10,632	10,844	11,061	11,283	11,508	75,971	23.08%	10,853
Servicing & MoT	124	126	129	132	134	137	140	922	0.28%	132
Delivery management software rental	500	510	520	531	541	552	563	3,717	1.13%	531
Driver's salary	20,565	20,976	21,396	21,824	22,260	22,705	23,160	152,886	46.45%	21,841
National Insurance (NI)	1,683	1,717	1,751	1,786	1,822	1,858	1,895	12,512	3.80%	1,787
Advertising and marketing	1,000	1,020	1,040	1,061	1,082	1,104	1,126	7,434	2.26%	1,062
Total Overhead Costs	42,540	43,283	44,042	44,816	45,605	46,410	47,231	313,926	-	44,847
On-Road Costs										
Diesel fuel	713	727	742	757	772	787	803	5,300	1.61%	757
Congestion charge	575	587	598	610	622	635	648	4,275	1.30%	611
Parking fines	390	398	406	414	422	431	439	2,899	0.88%	414
Brake pads & discs	167	170	174	177	181	184	188	1,242	0.38%	177
Tires	170	173	177	180	184	188	191	1,264	0.38%	181
Repairs	27	28	28	29	29	30	30	201	0.06%	29
Battery	22	22	23	23	24	24	25	162	0.05%	23
Total On-Road Costs	2,042	2,083	2,124	2,167	2,210	2,254	2,300	15,180	-	2,169
Total Operating Costs	£ 44,582	45,366	46,166	46,983	47,815	48,664	49,530	329,106	100%	47,015

Table 54. Environmental costs for trikes and vans.

ENVIRONMENTAL COSTS										
TRIKES	Year 1	2	3	4	5	6	7	7-yr	% of	Annual
	2018	2019	2020	2021	2022	2023	2024	Total	Total	Average
GHG Emissions (electricity)	£	£	£	£	£	£	£	£	%	£
Carbon Dioxide (CO2)	0.545	0.556	0.567	0.579	0.590	0.602	0.614	**4.05**	3.62%	0.58
Methane (CH4)	0.001	0.001	0.001	0.001	0.001	0.001	0.001	**0.01**	0.01%	0.00
Nitrous Oxide (N2O)	0.003	0.003	0.003	0.003	0.004	0.004	0.004	**0.02**	0.02%	0.00
CO2e from increased food consumption	10.33	10.532	10.743	10.957	11.177	11.400	11.628	**76.76**	68.57%	10.97
Total GHG Costs	10.88	11.09	11.31	11.54	11.77	12.01	12.25	**80.85**	72.21%	**11.55**
Upstream Costs										
CO2 from production processes	4.18	4.27	4.35	4.44	4.53	4.62	4.71	**31.11**	27.79%	**4.44**
Miscellaneous costs										
Ecosystem costs	-	-	-	-	-	-	-	-	-	-
Total Environmental Costs	£ 15.06	£15.36	£ 15.67	£15.98	£ 16.30	£ 16.63	£ 16.96	**112**	100.00%	16

ENVIRONMENTAL COSTS										
VANS	Year 1	2	3	4	5	6	7	7-yr	% of	Annual
	2018	2019	2020	2021	2022	2023	2024	Total	Total	Average
GHG Emissions (tailpipe)	£	£	£	£	£	£	£	£	%	£
Carbon dioxide (CO2) Defra tables	201	205	209	213	217	221	226	**1,491**	69.66%	213
Methane (CH4)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**0.05**	0.0025%	0.01
Nitrous oxide (N2O)	1.37	1.40	1.42	1.45	1.48	1.51	1.54	**10.18**	0.48%	1.45
CO2e from increased food consumption	-	-	-	-	-	-	-	-	-	-
Total GHG Costs	202	206	210	214	219	223	227	**1,501**	70.14%	**214**
Upstream Costs										
CO2 from production processes	79.02	80.60	82.22	83.86	85.54	87.25	88.99	**587.48**	27.45%	83.93
Miscellaneous costs										
Ecosystem costs	6.92	7.06	7.20	7.35	7.49	7.64	7.80	**51.47**	2.41%	7.35
Total Environmental Costs	£ 288	£ 294	£ 299	£ 305	£ 312	£ 318	£ 324	**2,140**	100.00%	306

Table 55. Social costs for trikes.

SOCIAL COSTS										
TRIKES	Year 1 2018	2 2019	3 2020	4 2021	5 2022	6 2023	7 2024	7-yr Total	% of Total	Annual Average
Health Costs from PM2.5 Damage	**£**	**£**	**£**	**£**	**£**	**£**	**£**	**£**	**%**	**£**
Mortality	-	-	-	-	-	-	-	-	-	-
Infant mortality	-	-	-	-	-	-	-	-	-	-
Chronic bronchitis	-	-	-	-	-	-	-	-	-	-
Bronchitis in children 6 - 12	-	-	-	-	-	-	-	-	-	-
Hospital admissions	-	-	-	-	-	-	-	-	-	-
Restricted activity days	-	-	-	-	-	-	-	-	-	-
Asthma symptom days in children	-	-	-	-	-	-	-	-	-	-
Working days lost	-	-	-	-	-	-	-	-	-	-
Total Health Costs from PM2.5	-	-	-	-	-	-	-	-	-	-
Health Costs from PM10 Damage	-	-	-	-	-	-	-	-	-	-
Mortality	-	-	-	-	-	-	-	-	-	-
Health Costs from Ozone Damage	-	-	-	-	-	-	-	-	-	-
Mortality (valued against life expectancy)	-	-	-	-	-	-	-	-	-	-
Hospital admissions	-	-	-	-	-	-	-	-	-	-
Minor restricted activity days	-	-	-	-	-	-	-	-	-	-
Total Health Costs from ozone damage	-	-	-	-	-	-	-	-	-	-
Health Costs from NO2 Damage	-	-	-	-	-	-	-	-	-	-
Mortality	-	-	-	-	-	-	-	-	-	-
Total Health Costs	-	-	-	-	-	-	-	-	-	-
Miscellaneous social costs										-
Congestion costs	194	198	202	206	210	214	218	**1,441**	88.51%	**206**
Accident costs	25	26	26	27	27	28	28	**187**	11.49%	**27**
Road damage costs	-	-	-	-	-	-	-	-	-	-
Total Miscellaneous Costs	219	223	228	232	237	242	247	1,628	-	233
Total Social Costs	£ 219	223	228	232	237	242	247	1,628	100.00%	**233**

Table 56. Social costs for vans.

SOCIAL COSTS										
VANS	Year 1 2018	2 2019	3 2020	4 2021	5 2022	6 2023	7 2024	7-yr Total	% of Total	Annual Average
Health Costs from PM2.5 Damage	£	£	£	£	£	£	£	£	%	£
Mortality (valued against life expectancy)	470.56	479.97	489.57	499.36	509.35	519.54	529.93	3,498	18.24%	500
Infant mortality	9.65	9.84	10.04	10.24	10.45	10.65	10.87	72	0.37%	10
Chronic bronchitis	44.84	45.74	46.65	47.58	48.54	49.51	50.50	333	1.74%	48
Bronchitis in children 6 - 12	1.96	2.00	2.04	2.08	2.12	2.16	2.21	15	0.08%	2.08
Hospital admissions	1.19	1.21	1.24	1.26	1.29	1.31	1.34	9	0.05%	1.26
Restricted activity days	122.74	125.19	127.70	130.25	132.86	135.51	138.23	912	4.76%	130
Asthma symptom days in children	1.62	1.65	1.69	1.72	1.75	1.79	1.82	12	0.06%	1.72
Working days lost	25.93	26.45	26.98	27.52	28.07	28.63	29.20	193	1.00%	28
Total Health Costs from PM2.5	678	692	706	720	734	749	764	**5,044**	26.30%	721
Health Costs from PM10 Damage										
Mortality	326.00	332.52	339.17	345.95	352.87	359.93	367.13	**2,424**	12.63%	346
Health Costs from Ozone Damage										
Mortality (valued against life expectancy)	1.41	1.44	1.47	1.50	1.53	1.56	1.59	10	0.05%	1.50
Hospital admissions	0.10	0.10	0.10	0.11	0.11	0.11	0.11	1	0.00%	0.11
Minor restricted activity days	2.92	2.98	3.04	3.10	3.16	3.22	3.29	22	0.11%	3.10
Total Health Costs from ozone damage	4.43	4.52	4.61	4.70	4.80	4.89	4.99	**33**	0.17%	4.70
Health Costs from NO2 Damage										
Mortality	397	405	413	421	430	438	447	**2,953**	15.39%	422
Total Health Costs	1,406	1,434	1,463	1,492	1,522	1,552	1,583	10,453	54.49%	1,493
Micellaneous social costs										
Congestion costs	1,063	1,085	1,106	1,128	1,151	1,174	1,198	**7,905**	41.21%	1,129
Accident costs (non-health)	28.95	30	30	31	31	32	33	215	1.12%	31
Road damage costs	81.83	83	85	87	89	90	92	608	3.17%	87
Total Miscellaneous costs	1,174	1,198	1,222	1,246	1,271	1,296	1,322	8,729	45.51%	1,247
Total Social Costs	£ 2,580	£2,632	£ 2,684	£2,738	£ 2,793	£ 2,849	£ 2,906	19,182	100.00%	**2,740**

Appendix 2

Transaction Time Values

Table 57. Baseline values for the ‘transaction time’ metric.

Transaction Time		**TRIKE**	
(last mile/urban) **ACTIVITY**	**Low estimate**	**Central estimate**	**High estimate**
	seconds	seconds	seconds
find address	-	30	60
find parking spot	20	30	40
park vehicle	20	20	20
grab parcel	20	30	40
walk to door	20	50	80
ring bell/wait	20	25	30
handover	20	20	20
get signature	10	10	10
return to trike	20	50	80
mount vehicle	10	10	10
Total seconds	160	275	390
Total minutes	2.67	**4.58**	6.50

Transaction Time		**VAN**	
(last mile/urban) **ACTIVITY**	**Low estimate**	**Central estimate**	**High estimate**
	seconds	seconds	seconds
find address	-	30	60
find parking spot	20	100	180
park vehicle	30	30	30
grab parcel	20	30	40
walk to door	20	50	80
ring bell/wait	20	25	30
handover	20	20	20
get signature	10	10	10
return to van	20	50	80
mount vehicle	10	10	10
Total seconds	170	355	540
Total minutes	2.83	**5.92**	9.00

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