Sustainable Logistics: Towards the Development of Environmentally Conscious Supply Chains

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Abstract

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There is mounting concern over the recent rise in man-made greenhouse gas (GHG) emissions which are changing the earth’s climate. This concern has resulted in increased scrutiny over GHG emitting supply chain operations. The Green or Sustainable Supply Chain is an approach which seeks to minimise a product’s ecological footprint, and is an extremely broad area of study which has identified logistics as a key determent in designing an environmentally conscious supply chain. As such, this study focuses on one aspect of sustainable supply chain design; green or sustainable logistics, and its development in Ireland.

To support companies in sustainable logistics practices, new developments in standards, tools and methodologies have materialised. These developments have grown considerably in the past number of years with a number of parallel streams of work emerging. With this in mind the first aspect of this thesis is to provide the reader with an overview and analysis of these standards, methodologies and tools currently available to companies for the implementation of sustainable supply chains. At present in Ireland there is also little or no information available on the readiness of companies to adapt to more environmentally friendly behaviour in logistics and supply chain management. Therefore, the attitudes to and knowledge of sustainable logistics among companies and their preparedness to implement sustainable logistics methods are also tested using a survey.

This survey showed that the link between environmental and monetary savings appears skewed by companies, who tend to assume that environmental savings only come with an increased cost to their operations. To this end, a quantitative analysis study to provide insight into the trade-off between environmental impact and cost/service levels in a supply chain was developed. This simulation model analysis was carried out on a three tier supply chain, which compared different transport strategies on environmental impact, cost and supply chain performance. This simulation study, while being case specific (electronic sector), provides insights into the trade-off between environmental impacts, cost and service level in a realistic supply chain setting.
Declaration

I hereby declare that this thesis is entirely my own work, and has not been submitted for any other awards at this or any other academic establishment. Where use has been made of the work of other people it has been fully acknowledged and referenced.

Signed: ________________________________

Paul Ryan

Date: __________________________
Acknowledgement

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1 Introduction

1.1 Introduction

"There is now a scientific consensus that global warming is happening, that it is directly related to man-made greenhouse gas emissions, and that we have little time remaining to stabilise and reduce these emissions if we are to avoid devastating impacts on our planet." (Department of the Environment Heritage & Local Government Ireland 2007)

The ideas of sustainable development originate from the 1987 Brundtland Report (ACE 2004), also known as “Our Common Future”. This report alerted the world to the urgency of making progress toward economic development that could be sustained without depleting natural resources or harming the environment. Over recent years Ireland’s per capita greenhouse gas (GHG) emissions have risen to be one of the highest in Europe. This rise in emissions is in no small part attributable to the 165% increase in transport emissions in the period 1990 to 2006, a figure more than 137% higher than the EEA-32 average (EEA 2009). The focus of this thesis is on the development of environmentally conscious supply chains in Ireland through studying the harmful impact that logistical activities have on the environment. With this in mind the following section will define the Green or Sustainable Supply Chain and introduce the concept of Sustainable Logistics.

1.2 Definitions

There are many different definitions in the literature for Supply Chain Management (SCM). However all these definitions are slight adaptations of
each other. One such definition as presented by Christopher (1998) is, “supply chain management involves the management of upstream and downstream relationships with suppliers and customers to deliver superior customer value at less cost to the supply chain as a whole”. Supply chains have been shown to be high contributors to the carbon footprint of most goods (Van Hoek 2001), with Eyefortransport (2008) claiming that up to 75% of a company’s carbon footprint is derived from supply chain activities. The study of the impact of supply chains on the environment is relatively new and a rapidly growing research area. The Green or Sustainable Supply Chain is an approach which seeks to minimise a product or service’s ecological footprint (BearingPoint 2008). The concept covers all the phases of a product’s life cycle, from the extraction of raw materials through the design, production and distribution phases, to the use of the product by consumers and their eventual disposal of same (see Figure 1-1 (BearingPoint 2008)).

Figure 1-1; Elements to sustainable (green) supply chains, adapted from BearingPoint (2008)

The scope of green supply chain management practices implementation ranging from green purchasing to integrated life-cycle management for supply chains flowing from supplier, through to manufacturer, customer, and
closing the loop with reverse logistics. Similar to the concept of supply chain management, the boundary of green supply chain management is dependent on the researcher/practitioner goals and the problems at hand, e.g., should it be just the procurement stage or the full logistics channel that is to be investigated? (Zhu et al. 2008).

However, irrespective of the focus of a particular researcher/practitioner in defining the green supply chain, there is one central core objective in all related efforts. This involves adding the ‘green’ component to supply chain management by addressing the influence and relationships between supply chain management and the natural environment, its purpose being to minimise a product or services’ ecological impact, Srivastava (2008).

BearingPoint (2008) define the main research areas of green supply chains as:

1) **Green Design**: Green Design can be described as an approach which seeks to reduce a product’s environmental impact throughout its complete lifecycle through the design of the product.

2) **Green Sourcing**: is where environmental criteria are included in the decision making process when sourcing products or services. In the literature it is often also referred to as green procurement.

3) **Green Manufacturing**: has the goal of reducing the environmental impact of the manufacturing function in supply chains through the reduction of the environmental impact of the use of materials and energy.

4) **Green Logistics**: has the aim of meeting cost targets and customer service levels with reduced pollution from the transport, warehousing, inventory management and distribution function in the supply chain.

5) **Reverse Logistics**: represents all operations related to the reuse of products and materials. It is a vital component of green supply chains providing a means for products/materials to be returned from the user to the producer in order to be recycled, reused or reconditioned.
While a products entire environmental lifecycle is not currently regulated by a statuary body, the WEEE and RoHS compliances measures are directives which were implemented in an attempt to “green” the design of a product. This lack of a regulatory body may reduce the innovation of new emerging green technologies. The WEEE and RoHS directives have enabled produces to rethink their material and processes that they use. This change was ultimately driven by consumer behaviour in which producers are now paying for the external environmental costs which until previously, the consumer was burdened with.

From the above description of green supply chains it can be seen that it is an extremely broad area of study. This study focuses on one aspect: green logistics, which is also referred to as sustainable logistics, a term which will be used in the remainder of the thesis. The following section will document the changing effect that GHGs have on the environment through global warming and outline the initiatives which the United Nations are imposing to subdue these changes.

### 1.3 Global Warming

In simple terms the greenhouse effect is the rise in temperature that the earth experiences due to greenhouse gasses trapping energy from the sun, (EPA 2006). The Stern (2006) report on climate change outlines that it is now “widely accepted” that if no action is taken on reducing GHG emissions, and in particular Carbon Dioxide (CO₂) emissions that based on current trends in the next 50 years or so, a 2-3°C increase in global temperature can be predicted, causing disastrous effects in the areas of:

- **Food sources** 150 to 550 million people at risk of hunger
- **Water** 1 to 4 billion people suffering water shortages
- **Health** 40 to 60 million people exposed to malaria in Africa
- **Land** Up to 170 million people affected by coastal flooding
• **Environment**  Up to 50% extinction of species

Ireland’s National Climate Change Strategy 2007 - 2012 report states that continued emissions of greenhouse gases at or above current rates would result in greater changes to the global climate system over this century than those observed to date. If atmospheric concentrations of greenhouse gas had been stabilised at 2000 levels, warming and sea level rise would continue at least until the end of this century due to the timescales associated with climate processes and feedback. Key projections include (Department of the Environment Heritage & Local Government Ireland 2007):

- A temperature increase of 0.2ºC per decade for the next two decades with a warming of 1.8–4.0ºC by 2100 (the full uncertainty range is 1.1-6.4ºC). This is expected to be greatest over land and across most northern latitudes
- Global average sea level rise in the ranges 18-38cm for the low emissions scenario and 26-59cm for the high emissions scenario. These may be underestimates due to the fact that the models do not include the full effects of changes in ice sheet flow
- Sea ice is projected to shrink with summer sea ice in the Arctic disappearing in some projections by the end of the century
- It is very likely that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent and likely that future tropical cyclones will become more intense
- Precipitation decreases are likely in most subtropical regions with increases very likely in high latitudes, and
- Increasing atmospheric carbon dioxide concentrations lead to increasing acidification of the ocean
1.3.1 Environmental Compliance

The Kyoto Protocol is an agreement under the United Nations Framework Convention on Climate Change (UNFCCC), to which 186 countries are parties. It states that “industrialised countries must reduce their harmful GHG emissions to 5.5% above 1990 emission levels”. 1990 has been chosen as a base year for comparison for all countries (Europa 2002). Allowing for economic development or decline in member states, the EU have agreed a “Burden Sharing” agreement in which emissions are seen as an EU-wide total. In Ireland’s case, the country’s large scale development since 1990 has been noted, with Ireland’s overall emissions target amended to +13% above its 1990 emission levels.

In 2005, Ireland’s emissions were monitored at 25.4% above 1990 (its base year), which is 12.4% above its EU target (EEA 2006). Therefore, if Ireland is to meet its commitments to the Kyoto agreement, emissions must be reduced by at least this percentage (25.4 - 13 = 12.4 %) before 2012, or face the penalties of non-compliance.

Figure 1-2; Trends in sectoral emissions (1990 - 2005) (EPA 2007)*

* * The Department of Transport Ireland (2009) estimate that over 30% of transport emissions in Ireland come from freight transport. This figure is indicated on Figure 1-2 by a red strike across the columns of the emissions from the transport sector.
Figure 1-2 shows the increase/decrease in CO$_2$ emissions across all sectors from 1990 – 2005 along with the distance (in Kilo-tonnes CO$_2$ equivalent) away from Ireland’s Kyoto target. Note emissions in transport increasing, compared to other sectors.

This section has identified how increases in transport emissions in Ireland are effecting both global GHG emissions and Ireland’s Kyoto Protocol emission targets. With this in mind the following section will look at the relationship between transport (logistics) and the environment.

1.4 Logistics and the Environment

Logistics is concerned with the efficient flow of raw materials, of work in process inventory, and of finished goods from supplier to customer. In addition to transportation, logistics entails inventory control, warehousing, materials handling, order processing, and related information activities involved in the flow of products. How these activities are managed and organized determines the quantity and quality of transportation demanded and the nature of the commercial relationships between shippers and transportation service providers, (Regan et al. 2000).

Freight transportation by road is the “dominant mode of freight transport in many economies due mainly to the flexibility and speed that the movement of freight by road offers when compared to railway, inland waterway or sea transport”, (Mason and Lalwani 2004). This is particularly true for Ireland as 90% of freight traffic occurs on the road, (Ryan et al. 2003). In freight transport the burning of petrol and diesel fuels in internal combustion engines leads to the chemical by-product of Nitrous Oxide (N$_2$O), Methane (CH$_4$) and most importantly CO$_2$. Transport in Ireland is a major contributing factor to Ireland’s overall emissions, accounting for a 20.8% share of total emissions in 2007, 97% of which is from road transport (EPA 2008).
Figure 1-3, shows the trends in transport emissions between 1990 and 2006 for a selection of EU countries where the EEA-32 country average was an increase of 28%. It is notable that a 21% decrease in Bulgaria’s transport emissions has occurred in a time of economic instability and a decline in population for the country. Alternatively, Ireland’s 168% increase in transport emissions has occurred in conjunction with a population and economic development boom over the time same time period, (www.google.com/publicdata).

Aronsson (2006) further highlights how environmental problems have received increased attention during the last decade with a major source of environmental problems arising from transportation. Aronsson also notes how transportation is expected to grow even faster than the general growth of GNP in the industrialised world. With this in mind, the following section will look at the recent growth of freight transport in Ireland, which has grown in line with the increases in transport based emissions over recent years.
1.4.1 Industrial Road Transport in Ireland

As highlighted by Tenekcioglu (2004), certain modes of transportation, such as rail and maritime transport are considered “green modes” because their effects are less detrimental to the environment. These modes produce less pollution, less noise and account for fewer accidents. However, the relatively short distances and lack of suitable infrastructure in Ireland offset any advantages which could be gained by using intermodal freight transport. This is confirmed by a 2008 survey of transport service providers in Ireland who claim they foresee a decline in the use of rail for freight in future (InterTradeIreland 2008). Adding to the difficulties of transport in Ireland, Forfas (1996) notes how Ireland’s peripheral location results in transportation costs being higher than those in more favourable locations.

Goods movement on Irish roads is also increasing. Over the period 1996 to 2006 the Central Statistics Office (CSO) in Ireland documented increases in the following average number of (CSO 2007):

- Goods vehicles (163%)
- Vehicle kilometres travelled by goods vehicles (115%)
- Tonnes of goods transported (254%)
- Tonne-kilometres travelled (180%).

Fuel consumption by the road freight sector in Ireland increased by 264% over the period 1990 to 2005 (Department of Transport Ireland 2008). According to the same study, “Typically around a third of vehicle-kilometres are sub-optimal depending on length of haul, type of vehicle, industrial sector and the nature of the delivery operation”.

Being a relatively small island nation on the periphery of Europe, there are many complications arising from transportation in Ireland. The adoption of more efficient and sustainable transport operations will be advantageous to Ireland’s transport users, providers and the environment. This opinion is echoed by InterTradeIreland (2008) who state;
“Efficient freight transport is essential to the economy and to the quality of life across the island of Ireland. Economic growth generates increasing demand for freight transport. Goods have to be moved freely, reliably, efficiently to meet business needs, while minimising the impact on safety, on other transport users and on the environment.”

1.5 Sustainable Logistics and Logistics – Past Studies

Recent logistics and supply chain orientated studies in Ireland have been carried out by InterTradeIreland (2008), Sweeney et al. (2008) and The Department of Transport Ireland (2008). The IntertadeIreland (2008) study identifies how Irish companies rank inadequate infrastructure, fuel prices, peripherally and traffic congestion as the most serious issues faced by transport providers on the island of Ireland. While in Sweeney et al. (2008), the current level of diffusion of SCM among companies in Ireland is measured. The results suggest a need for more widespread adoption of SCM among Irish firms.


- The importance of the movement of goods to Ireland’s economy;
- Recognition that movement of goods by road will remain the principle mode;
- The need to reduce the environmental impact of heavy goods vehicles and light duty vans.

Results from two international surveys on supply chain and the environment have been recently published. “2008 Supply Chain Monitor
‘How mature is the Green Supply Chain?”’, (BearingPoint 2008); and “Logistics and Transport Industry Environmental Survey. Transport Intelligence” (Kewill 2008). The Kewill (2008) survey, which was targeted at logisticians, surveyed 450 respondents from around the world. They claim it represented the “full spectrum of the logistics sector” as well as manufacturers and retailers (Kewill 2008). In this survey, respondents were seen to take a very pragmatic view to environmental issues recognising that green and business issues must be balanced. Logistics service providers and customers were shown to recognise the importance of the environment to the long term development of their companies. Respondents also identified how the transportation elements of the supply chain were the main focus for companies implementing green strategies; this was largely due to rising oil prices.

The BearingPoint (2008) survey attained 600 respondent views on the emerging trends in the development of green supply chains. The survey documented how environmental matters are gaining consideration among companies, pushed by four main drivers, which are:

1) Regulation;
2) Brand image;
3) Innovation; and
4) Cost reduction.

The BearingPoint (2008) survey also identified how differing levels of involvement in green supply chain strategies exits between countries, citing the lack of information as the biggest obstacle in its development. However, as with the Kewill (2008) survey, it is in logistics operations where most companies implemented green supply chain strategies.
1.5.1 Sustainable Logistics in Ireland

From an industrial standpoint, Simons and Mason (2003) observed that companies are coming under increasing pressure not just to deliver profit improvement but also to do business in a responsible manner, being mindful of their activities’ impact on society and the environment. Being able to demonstrate improved environmental performance and to weave environmental and ethical considerations into their business decision-making processes is becoming mainstream. In order to do this, from a logistical standpoint, companies in Ireland need to either:

- Push for more localised sourcing of suppliers;
- Supplies / products need to be transported by less polluting means (i.e. rail or water);
- Or the method for transportation of supplies / products needs to become more efficient.

As mentioned earlier, less polluting modes of transport (i.e. rail or inland waterways) are not suitable for inland transportation in Ireland. In addition to this, Comhar (2008) state that “because of the population densities and distributions in Ireland, road freight distribution will remain the most practical method for many locations in Ireland”. However, in a somewhat conflicting view, the Department of Transport Ireland (2009) report “Smarter travel a Sustainable Transport Future” welcomes the potential of rail freight as having the ability to reduce emissions in the Irish goods transport system.

With the projected introduction of carbon taxes, rising fuel costs and requirements for more environmentally friendly products, creating sustainability in logistical operations is an advantage for any company or country. Unfortunately in Ireland, as reported by Comhar (2008), there appears to be few monetary or moral incentives at present for the logistics sector to employ such sustainable practices. As identified earlier on in the chapter, a change in consumer behaviour will ultimately drive environmental
change, and as such monetary incentives could only act as a transient measure until there is sufficient public awareness to drive an environmental change towards more sustainable practices in transport.

In addition also appears to be a certain lack of knowledge and conflicting views at present regarding the implementation sustainable practice within the logistics and supply chain sector in Ireland.

### 1.6 Problem Statement

There is growing concern over rising man-made GHG emissions, which are changing in the Earth’s climate. This concern has resulted in an increased scrutiny over GHG emitting supply chain operations. With this in mind there is currently a move towards the development of environmentally conscious supply chains. This developing body of research has identified logistics as a key deterrent in designing an environmentally conscious supply chain. Ireland is particularly affected by this link between logistical activities and the environment. Ireland has one of the highest per capita GHG emission rates, coupled with the highest increase in transport based emissions in the EU over the past fifteen years.

Sustainable logistics in Ireland is as yet in its infancy and is currently an under researched area. Conflicting views on the development of sustainable practices in logistics and its potential in the Irish system further highlight its under researched state. Research into a move towards a more sustainable approach to logistical functions in Ireland will support the development of environmentally conscious supply chain design and operation. This move towards a more consumer friendly green supply chain design will help Ireland to both, meet its Kyoto emission targets and remain an attractive country to multinational foreign direct investment.
1.7 Research Objectives

As previously mentioned, sustainable logistics is a key element in the development of environmentally conscious/green supply chain design and international research into this area is emerging and developing quickly. In order to support Irish companies in developing environmentally conscious supply chains through sustainable logistics, this thesis sets out to fulfil three interrelated objectives, including:

- Creating a snapshot of the current developments in implementing sustainable/green/environmentally conscious supply chains through a desktop study.
- Understanding the current situation as regards sustainable logistics in Ireland, with specific emphasis on the Mid-West region in Ireland. By using survey analysis, the attitudes to and knowledge of sustainable logistics among companies and their preparedness to implement sustainable logistics methods are tested.
- To undertake a quantitative analysis study to provide insight into the trade-off between environmental impact and cost/service levels in a supply chain when operating using different transport strategies. This analysis was motivated by
  - Results from the survey (see objective 2) which showed that companies are reluctant to implement more environmentally friendly options if additional costs might be incurred;
  - To provide insight to practitioners into how advanced analysis methods (approaches that are currently appearing on the market) can compliment more standard analysis methods (i.e. Life Cycle Assessment LCA) in developing more sustainable strategies in the operation of a supply chain.
2 Standards, Tools and Methodologies for Sustainable Supply Chain Development

2.1 Introduction

Chapter 1 introduced the emerging concept of the green/sustainable supply chain. Sustainable supply chain implementation requires standards to allow measurement of environmental impact and methodologies and support tools to allow adoption of environment practices. This sector is a new and emerging field and currently without a standard framework to allow it to be established as a standard business practice. Recent developments such the recently published specification "PAS 2050 - Assessing the life cycle greenhouse gas emissions of goods and services" (BSI 2008), are providing the momentum to have environmental management of supply chains become a de facto business practice.

The purpose of this chapter is provide an overview of standards, tools and methodologies currently available for the implementation of sustainable supply chains. Section 2.2 details the standards in environmental monitoring and discusses the two most prominently used standards in industry. Section 2.3 then presents an analysis of the environmental monitoring tools, and their underlying methodologies that utilise these developing environmental standards. At the end of this chapter, conclusions are drawn on industry’s acceptance of these standards and the perceived shortcomings in the tools presented.
2.2 Standards

One of the main difficulties associated with the area of green supply chains and the integration of its environmental aspects with business activity, is the ambiguity surrounding its structures, constructs and definitions. The trade-offs between economic and environmental goals makes environmental management a challenging and multidimensional problem. In an attempt to reduce this ambiguity and to streamline the area’s development a number of standards have been designed and developed over a period of time. As with the definition of the area associated with green supply chain management there are also considerable differences of opinion when it comes to standards in the area.

This lack of understanding is apparent when studying the literature. The Carbon Trust (2008) for example identify that as of 2006, there was no standard approach to measuring a product’s carbon footprint, let alone a credible way to communicate them to consumers. This lack of a standard base level for measurement is evident throughout all carbon footprinting techniques.

However there are some ecological footprinting techniques techniques in particular entropy and exergy* that utilise a base level for comparing measurements. (Susani et al 2006). When studying entropy and exergy, measurements and results are taken relative to a given level rather than on a defined scale. This concept may be useful when developing standards and gaining an understanding of the measurement concepts in the carbon footprinting domain.

* Entropy and Exergy are thermodynamics concepts that measure the energy (in heat) that changes between one system and to the next. In short, the exergy in a given system is always destroyed when a process involves a temperature change. This destruction is proportional to the entropy of the increase of the system together with its surroundings Cangel and Boles (2008)
One body of work in the area of standardisation has been the development of what is termed environmental management systems (EMS). Guidelines and instruments in the form of EMSs have been developed to assist businesses in reviewing their environmental impact in a business context. As illustrated by Schaltegger et al. (2003), implementing a defined set of standards helps businesses in analyzing, controlling and reducing their environmental impacts. Definition of an environmental policy ensures that environmental goals are made operational and equally considered. Additionally, internal and external auditing processes verify the implementation of a functioning EMS.

### 2.2.1 Environmental Management Systems

The following extract from the National Standards Authority of Ireland (NSAI 2009), outlines in relative terms the main background to the EMS standards and the ways in which they are implemented.

*Environmental issues and the need for protection of the environment is the focus of increasing concern and over the past number of years governments, businesses and the public are demanding a reasonable and effective response. The “Earth Summits” of world leaders in Rio de Janeiro and Kyoto brought much attention to these issues and encouraged tangible steps towards sustainable development which would allow for continued economic prosperity without compromising future generations. Many companies and organisations have responded positively to the challenge to contribute to economic development and prosperity in a way that respects the environment. They are actively implementing economically viable programs that reduce the adverse environmental impacts of their operations and that result in sustained benefits for all parties.*

*Environmental Management Systems (EMS) standards have been developed as tools to allow the management of organisations to*
better identify, manage and control their activities that can impact the environment.

By a systematic analysis of the aspects of an organisation’s operations, and by quantifying the impacts on the environment of these aspects, the organisation can respond in a planned and co-ordinated way. Defining clear goals and objectives in relation to environmental performance gives direction to the organisation by reducing waste and energy use, substitution of non-renewable resources, risk avoidance, good citizenship and image enhancement. This contributes to increased stakeholder confidence, competitive advantage and long term viability (NSAI 2009).

Although there is a range of EMSs, in practice the EU-issued EMAS and the international standard series ISO 14000 are the most frequently applied EMSs.

### 2.2.1.1 Features of EMS standards

Environmental management system standards were developed in the early 1990s in several countries. The first standard was approved by the British Standards Institution (BSI) in 1992 and became a model for the ISO standard 14001, which was elaborated on in the years 1991-1996. The European "Eco-Management and Audit Scheme" (EMAS) was adopted in 1993 (EEB 2003).

ISO 14000 specifies a set of measures to be incorporated into a company's management system aimed at dealing with environmental aspects in a systematic way including the following major elements:

1) Definition of an environmental policy including performance objectives;
2) Assessment of environmental aspects;
3) Identification of legal obligations;
4) Establishing an environmental management programme;
5) Definition of procedures to achieve the objectives;
6) Monitoring of the system and improvement.

The European EMAS scheme is based on the international standard but contains additional requirements:

1) Initial environmental review;
2) Independent verification;
3) An accreditation system for verifiers;
4) Validated environmental statements;
5) Employee involvement.

2.2.2 Industrial Carbon Footprinting Standards and Methodologies

A carbon footprint is “The total set of greenhouse gas emissions caused directly and indirectly by an [individual, event, organisation, product] expressed as CO$_2$” (Carbon Trust 2007).

One of the major impediments for carbon footprinting is the lack of standards associated with the methods of analysis, in combination with a lack of standardisation of greenhouse gas (GHG) emission factors for calculation.

Again, as was the case with the environmental management systems a number of different standards have been developed by independent bodies, on both a national and international scale. The two more dominant carbon footprinting standards presently are the ISO 14040/4 and the PAS 2050. The ISO 14040/4 standard has been in existence since 1997, with the PAS 2050 published in late 2008. The PAS 2050 standard builds on existing life cycle assessment (LCA) methods (discussed in the following section) established through ISO 14040/4.
2.2.2.1 ISO 14040/4

ISO standard 14040 describes the principles and framework for LCA. It provides an overview of the practice and its applications and limitations. It does not describe the LCA technique in detail, nor does it specify methodologies for the individual components of the LCA (goal and scope definition, inventory, impact assessment, and interpretation). Because the standard must be applicable to many industrial and consumer sectors, it is rather general. Nonetheless, it includes a comprehensive set of terms and definitions, the methodological framework for each of the four components, reporting considerations, approaches for critical review, and an appendix describing the application of LCA. ISO standard 14044 specifies requirements and provides guidelines for LCA. It is designed for the preparation, conduct, and critical review of life-cycle inventory analysis and provides guidance on the impact assessment and interpretation phases of LCA and on the nature and quality of data collected, (Elcock 2007).

2.2.2.2 Publicly Available Specification (PAS) 2050

The British Standards Institute (BSI) developed the Publicly Available Specification (PAS) 2050 as a method for measuring the embodied GHG emissions from goods and services. As part of the development of this standard, the BSI analysed GHG product emissions in general. From this report they highlight the fact that a substantial element of GHG product emissions can be attributed to the transport and storage of goods and services (logistics).

BSI Standards Solutions (BSI 2008) has led the development, since June 2007, of the PAS method for measuring the embodied GHG emissions from goods and services at the request of DEFRA (Department for Environment, Food and Rural Affairs) and the Carbon Trust in the UK. The PAS document
provides a workable standardisation process, providing a benchmark for future development aimed at reducing GHG emissions.

**Aim:** Similar to the concept of measuring “Emergy”, the PAS method for measuring embodied GHG emissions of goods and services will enable organisations, e.g. business, to effectively measure the climate change related impacts of their goods and services with a view to using this information to improve the climate change related performance of these.

**Scope:** PAS specifies requirements for the assessment of the GHG emissions associated with the life cycle of goods and services. This PAS is applicable to organizations assessing the life cycle GHG emissions of goods and services across their life cycle.

**Measurement method:**

1) Applies to all goods and services with consideration given to how and whether it may need customising for specific product groups, e.g. food, buildings, electronics, etc.

2) Considers all lifecycle stages along the supply/value chain of a product (goods and/or services), i.e. from raw materials to end of life

3) Includes the six GHGs identified under the Kyoto protocol

4) Could be used by all sizes and types of organisations

### 2.3 Tools

There is a vast array of tools available in the environmental modelling area. These range from tools which have been designed to calculate an individual’s carbon footprint, to household calculators, business calculators, to total supply chain calculators.

* Embodied energy of emergy is the available energy that was used in the work of making a product. Measured in a monetary value (Em$), emergy is used to find the sum total of the energy necessary for the entire product lifecycle, Odum (1996).
The range of developers of these tools includes individual organisations, organisational networks, environmental agencies, national and international bodies and research institutes.

The tools which have most relevance to this study can be categorised into three broad areas, this includes, life cycle analysis, static modelling and supply chain environmental modelling. In addition to these three areas is the carbon accounting tools. These carbon accounting tools are prerequisites to the three areas and are used to allocate carbon emissions to specific activities in question in order to build up its overall carbon footprint.

### 2.3.1 Carbon Accounting Tools

The carbon footprint of a specific product includes the total carbon output from the product, i.e. raw material extraction, manufacturing, distribution, retailing, consumption, disposal and recycling (Carbon Trust 2006). A company’s full carbon footprint covers three main areas:

1) Direct emissions from activities the company controls, such as heating and energy use used in manufacturing or processing;

2) Emissions from electricity use;

3) Indirect emissions from products or services, (i.e. the sourcing of products and their eventual disposal or reuse).

The Carbon Trust (2007) defines five steps which must be used for the calculation of a carbon footprint:

1) Define the methodology – use consistent conversion factors, and a reliable method of calculation;

2) Specify the boundary and Scope of the coverage – which and what emissions are included, how far up and down the supply chain to calculate;

3) Collect emissions data and calculate the footprint – accuracy relies on calculating the correct data;
4) Verify the results – verification from a third party to add credibility;
5) Disclose the footprint – make all the above information available for review.

There are many carbon calculation tools available over the internet; with many of these focused specifically on the individual or household carbon footprinting level. Carbon calculating tools already in use typically calculate household energy including transportation, examples of which include:

- “Act on CO2” – Available from http://actonco2.direct.gov.uk/index.html;
- “The Footprinter” – Available from http://www.footprinter.co.uk/site/CO2_Test.html;

In the Irish case, Repak also state through their website that they are “working with international consultants on the development of a carbon calculator for Irish businesses in relation to their product supply chain”; however, no update has been provided on this since late 2007.

2.3.2 Life Cycle Analysis

Life Cycle Analysis is a methodological tool that applies life cycle thinking in a quantitative way on environmental analysis of activities related to processes or products (goods and services). A central characteristic of life cycle analysis is the holistic focus on products or processes and their functions, considering upstream and downstream activities.

The European Commission (2007) define the life cycle concept as follows: A LCA of a product includes all the production processes and services associated with the product through its life cycle, from the extraction of raw materials through production of the materials which are used in the manufacture of the product, over the use of the products life, to
its recycling and/or ultimate disposal of some of its constituents. Such a complete life cycle is also often name “cradle to grave” or even in the case of the full recycling of the product “cradle to cradle”. Transportation, storage, retail, and other activities between the life cycle stages are included where relevant. This life cycle of a product is hence identical to the complete supply-chain of the product plus its use and end-of-life treatment.

Shown in Figure 2-1 are the standard elements which make up the measurement of a product’s life cycle emissions. As evident from this figure, transport and logistics make up a large portion of the life cycle of a product or service.

Figure 2-1; Life cycle analysis (adapted from BSI (2008))
LCA is not without its critics and the majority of this criticism is encapsulated in the comparatives that are required in order to develop definitive results. These comparatives can exist between the calculation of the environmental output(s) of differing processes and process types to the comparatives between the impact(s) on different environmental elements. Such comparative issues include for example (as described by GDRC (2009)):

1) How can one compare heavy energy demand with heavy water use: which imposes greater environmental burden? 

2) How should the use of non-renewable mineral resources like oil or gas (the ingredients of plastics) be compared with the production of softwoods for paper? 

3) How should the combined impacts of the land filling of wastes (air and groundwater pollution, transport impacts etc) be compared with those produced by the burning of wastes for energy production (predominantly emissions to air)?

Some studies attempt to aggregate the various impacts into clearly defined categories, for example, the possible impact on the ozone layer, or the contribution to acid rain. Others go still further and try to add the aggregated figures to arrive at a single 'score' for the product or process being evaluated. It is doubtful whether such simplification will be of general benefit. Reliable methods for aggregating figures generated by LCA, and using them to compare the life cycle impacts of different products, do not yet exist.

In addition, many LCAs have reached different and sometimes contradictory conclusions about similar products. Comparisons are rarely easy because of the different assumptions that are used, for example in the case of food packaging, about the size and form of container, the production and distribution system used, and the forms and type of energy assumed.

Gaudreault et al. (2009) notes that transparent and comprehensive LCA decision criteria should not only be defined, but also carefully interpreted by
the decision-making panel from the early stages and throughout the
decision process in order to greatly improve the quality of the outcome. This
difficulty is rooted in the multi dimensional nature of the outcomes. In this
regard, the author suggests that some LCA problems may require the use of
a Multi Criteria Decision Making (MCDM)* framework for the implementation
of LCA

2.3.3 Environmental Modelling

There are number of environmental modelling tools available, which have
been designed for supply chain operations, and many more being devised
and developed by both industry and academia on an ongoing basis.

From the research carried out in this study, it was found that the
majority of these modelling tools can be best described as static in nature.
Static models are models that have direct relationships between activities
and carbon output and do not have the capacity to change over time. These
models are typically spreadsheet or database driven.

2.3.3.1 Static Modelling

One such set of tools has been developed by the Greenhouse Gas
Protocol Initiative (2008). These tools have been specifically developed for a
number of different industrial areas. The tools have been developed using
Microsoft Excel, which equates industrial activities with environmental
impacts using a defined set of emission factors. The default emission factors
used are averages based on the most extensive data sets available and they

Multi criteria decision making (MCDM) is a branch of decision making which is faced with making
numerous and conflicting evaluations. MCDM aims at highlighting the conflicts and deriving a way to
come up with a comparative and transparent process. MCDM problems are usually expressed in a matrix
format with each MCDM problem being associated with attributes often referred to as “goals” or
“decision criteria” and are assigned a weight of importance. Triantaphyllou (2000)
are largely identical to those used by the Intergovernmental Panel on Climate Change (IPCC). However, organisations have the capacity to substitute these emissions factors with their own if necessary. A screen shot of one the transport element of one of these tools is shown in Figure 2-2.

![Figure 2-2; GHG protocol environmental modelling tool](image)

### 2.3.3.2 Supply Chain Mapping

A second set of tools have been developed around the concept of supply chain mapping, which is sometimes also referred to as value stream mapping (VSM). This supply chain mapping is not a new concept and is a technique which is used in lean manufacturing to map the flow of material and data, and associated time requirements from initial supplier to end customer for a given business process. In most instances it is used to define improvement areas and sources of waste. Building on this lean technique,
Braithwaite and Knivett (2008) developed a supply chain mapping technique in Microsoft Excel for estimating and visualising the carbon intensity of products as they move from source to consumption. This model has been developed for the Australian wine industry focusing on the transportation of wine to the UK. This model has taken the traditional costing mechanism from this mapping exercise and replaced it with carbon emissions outputs. The carbon emissions used in this model have been devised specifically for each of the elements of this example, with all elements then being normalised to the carbon \([\text{CO}_2]\) per unit of output/consumption.

Braithwaite and Knivett (2008) discuss the primitive and somewhat unreliable nature of this mapping technique, describing it as a prototype for further analysis. While critiquing their own static supply chain analysis, Braithwaite and Knivett (2008) note the difficulty in this type of modelling, stating three requirements for further analysis:

1) A requirement to access and catalogue reliable carbon emissions data from the different activities that make up the supply chain;
2) The model should be refined to incorporate supply chain cost along side the carbon assessment to support the decision making process about when and where business might carry higher cost to reduce carbon emissions;
3) The modelling should be enhanced to allow the creation and retention of scenarios, allowing comparison and hence supporting decision making.

### 2.3.3.3 Commercial Tools

**SEAT – Supply Chain Environmental Analysis/Optimisation Tool:** The SEAT is an interactive software tool from CleanMetrics. Details of the tool’s functions are limited and information provided hereafter has been extracted from the company website (CleanMetrics 2009). The tool can be used to quantify and improve the environmental performance of supply
chains. It allows users to easily model supply chain elements – including transportation, storage, and production – from an energy and carbon-dioxide emissions perspective, and provides methods to analyse, report, and explore improvements to supply chain environmental performance.

The tool can be used for detailed analysis of existing supply chains, "what-if" experiments, and comparisons of alternative supply chain configurations. Optional optimization modules are available for minimizing transport fuel consumption in supply/distribution networks, and for determining the best transport modes and shipping sizes throughout a supply chain. The tool can operate in variety of applications, such as (CleanMetrics 2009):

1) Achieving overall cost savings from reduced energy use in supply chains;
2) Meeting greenhouse gas emission reduction targets;
3) Emission calculations for use in offsetting carbon footprints;
4) Carbon footprint analysis for eco-labelling of consumer products;
5) Detailed corporate reporting of energy use and emissions.

![CleanMetrics CarbonScope](image-url)
Details of the tools' abilities to carry out the above functions are limited. Figure 2-3 shows a recent screen shot of a sister tool CarbonScope™ in which a limited input data base is available. Although user access to the tool is restricted, the literature regarding the tools serves as a basis for type of environmental analysis tool available in the market. This tool is also valuable as a reference to the environmental simulation model proposed in this thesis.

**CarbonView:** CarbonView is a supply chain footprinting tool from Supply Chain Consulting ([http://www.supply-chain.com.au/](http://www.supply-chain.com.au/)). Details of the tools' abilities are as described on the above referenced source. The CarbonView tool allows companies to optimise its supply chain by focusing on financial and carbon emission metrics. The tool can help companies achieve reductions in costs and carbon emissions, from within the organisation and across the supply chain. The tool uses static footprinting to provide its carbon footprint at a point in time. The tool develops “static ecological and carbon footprint data for products, processes, the entire organisation, or the extended supply chain”. Using LCA databases to provide the ecological and carbon data, the tool is able to analyse and report on their static carbon footprint.

### 2.3.3.4 Other Tools

The SEAT and the CarbonView tools are indicative of a number of tools that are coming to the market presently. In many cases these tools are provided by consultancy companies and are sold as part of a service offering. Other providers that have developed tools in this area are:

1) **ILOG:** ILOG has released a Carbon Footprint extension to its LogicNet Plus XE supply-chain application. The software can map out several scenarios to assess the cost of, for example, adding new
distribution facilities in various locations, then factor in different modes of transporting goods and the impact that the various configurations would have on service. It can also estimate the carbon impact of changes to the supply-chain network by computing the total carbon emissions associated with the new distribution facilities, plants, and modes of transportation used between various points (ILOG 2009).

2) **Aravo Sustain**: Aravo SIM provides a framework for managing supplier information within enterprise resource planning (ERP) and eProcurement applications such as Oracle, SAP and Ariba. Organizations can obtain, analyze and manage sustainability data, such as supplier and factory regulatory compliance, toxic substances monitoring, carbon footprinting and labour practices (Aravo 2009).

3) **IBM**: IBM has unveiled a tool designed to allow firms to calculate and reduce costs and carbon dioxide emissions in their supply chains, leading to reduced environmental impact and greater efficiency. Supply Chain Network Optimisation Workbench (SNOW) uses mathematical algorithms to delve deeper into a company's overall supply chain logistics, ultimately helping clients take stock of their various distribution centres (IBM 2009).

4) **Freight Management Inc.**: Freight Management Inc. has introduced a new offering dubbed “OptiGreen.” The OptiGreen Program is built around the company’s new software. “Distribution Pollution Solution,” which FMI says can calculate carbon emissions between departure and arrival then recommend alternate shipping strategies, methods or routes to lower those carbon emissions.

### 2.4 Conclusions

This chapter has documented the vast array of tools, techniques and standards which attempt to encapsulate the supply chain in an
environmental context. The fact that the area has expanded so rapidly has meant that a number of parallel tracks have been followed, particularly in the area of standardisation of carbon measurement and reporting techniques. This has led to certain fragmentation, overlaps and contradictions in the reporting on the environmental impacts of product and service supply chains. However, these discrepancies and overlaps are beginning to reduce, particular in relation to the underpinning standards, with the ISO 14000/4 and the PAS 2050 becoming to be accepted standards. With respect to the carbon accounting tools more work is required to create similar accepted standards. At present many carbon accounting mechanisms are used, and in some cases the results from these different mechanisms are in contradiction of each other. In general, this can lead to disenchantment from the public and scepticism with respect to the outputs from these techniques.

In addition, some of these tools and techniques attempt to introduce the multi-objectives of economic versus environmental costs. However, many of these tools and techniques simply attempt to measure/model the environmental impact of a particular supply chain as it is presently constructed. Little or no attempt has been made in many cases to introduce the trade-off concept of economic versus environmental cost of supply chain design. As is the case in most organisations, a good business case must be made to instigate change. With the exception of legislature directives, supply chain redesign in an environmental context will be driven by economic concerns. This economic element and its dynamic relationship with environmental change are presently underrepresented in the majority of work in this area. Chapter 4 will address this situation by means of a quantitative analysis study carried out with the primary purpose of providing insight into the trade-off between environmental impact and cost/service levels in a supply chain when operating using different transport strategies.
3 Field Study Analysis

3.1 Introduction

Sustainable logistics in Ireland is as yet in its infancy and is currently an under researched area. As it stands, there is also scant information on the attitudes of Irish companies to adopt such sustainable supply chain measurement practices, as discussed in the previous chapter. Accordingly, the design, implementation and results from a questionnaire based survey with the purpose of:

(i) Ascertaining the level of awareness of sustainable logistics in companies and

(ii) To evaluate the preparedness of companies in adopting sustainable logistics operations strategies are presented in this chapter.

Methods for creating sustainability in logistical operations in Ireland have been recently outlined by the (2008) Department of Transport Ireland document titled, 2020 Vision - Sustainable Travel and Transport: Public Consultation Document. They include:

- Increasing load factors
- Choosing the optimum type of vehicle;
- Optimising the entire transportation chain from origin to final delivery, ‘just in time’ delivery;
- Use of telematics and intelligent transport systems (ITS);
- Tackling underutilisation and empty running.

The Department of Transport document supports the requirements for further research into these areas, highlighting the inadequate information currently available into the adoption of sustainable logistics in Ireland. There is also little or no information available on the readiness of companies in
Ireland to adapt to more environmentally friendly behaviour in logistics and supply chain management. This is in contrast to other countries, most especially the UK.

Section 3.2 gives a background to previous studies into the environmental effects of logistics from the U.K. and Europe. These studies, along with an overview of previous logistical survey analysis, outlined in Section 3.3 form the basis for the development of the specific questions tested in the questionnaire. As the methodology for the development of the questionnaire, (i.e. respondent sample size, administration techniques) is of significant importance; Section 3.4 will document the physical design and implementation methodology of the questionnaire. The questionnaire results, presented in Section 3.5, establishes a point of reference for environmental studies of logistics in Ireland by assessing the awareness of sustainable logistics among companies, and giving a snapshot of the current state of logistics in the Mid-West Region.

3.2 Background

Chapter 2 reviewed the literature surrounding the tools and methodologies used in sustainable supply chain implementation. In doing so, a strong link is noticeable between the creation of sustainability, and the increases in operational efficiency that the supply chain or logistics management tools provide. For example, the commercial tools discussed in Chapters 2.3.3.3 and 2.3.3.4 which are designed for sustainable supply chain implementation emphasise the reduction of costs and increases in efficiency as means to reduce supply chain emissions.

With this in mind, the following section will document the emerging research on the creation of sustainable logistics through both increasing the operational efficiency in freight transport and lean optimisation. Many government and industry funded initiatives on tackling rising fuel costs and
GHG emissions from freight transport exist throughout the U.K. and Europe. Examples of the projects relevant to sustainable logistics in Ireland include:

- **ITeLS;** “Integrating Transport and e-Commerce in Logistics Supply Chains”. This 3 year collaborative research programme was sponsored the EPSRC. The project was aimed at sustainable freight distribution and has recently concluded with many research papers available at [http://www.itels.org.uk/](http://www.itels.org.uk/)

- **Green Logistics;** This active project “provides research into the sustainability of logistics systems and supply chains”. The project aims to minimise the external costs of logistical operations which they categorise as “climate change, air pollution, noise, vibration and accidents”. By examining and reducing these external costs the project aims to achieve a more sustainable balance between economic, environmental and social aspects of logistics. The study is co-ordinated by the Institute of Transport studies at the University of Leeds. More information is available at [http://www.greenlogistics.org/](http://www.greenlogistics.org/)

- **Freight Best Practice.** This U.K. government funded project offers free information for the freight industry covering topics such as saving fuel, developing skills, equipment and systems, operational efficiency and performance management. more information available at [http://www.freightbestpractice.org.uk/](http://www.freightbestpractice.org.uk/)

- **McCLOSM;** “Mass Customised Collaborative Logistics for Sustainable Manufacturers”. This is a three year industry linked research project coordinated by Cardiff University. The project is centred on the theme of sustainable logistics and more information is available at [http://www.cuimrc.cf.ac.uk/McCLOSM](http://www.cuimrc.cf.ac.uk/McCLOSM)

- **ETTAR;** “Environmental Technologies, Training and Awareness-Raising” This E.U. funded project has been established to identify and assess training needs, methods and activities for the wider use of environmental technologies in the transportation sector. More information is available at [http://www.ettar.eu/](http://www.ettar.eu/)
• **EyeForTransport;** Is a provider of logistics and transportation information, services and products. These include news updates, conferences, market research and industry reports. More information is available at [http://www.eyefortransport.com/channel/green](http://www.eyefortransport.com/channel/green)

These projects provide a wide range of information on logistical matters and the literature in the remainder of this section has been adapted from these resources.

### 3.2.1 Increasing Efficiency in Logistics Operations

Freight Transport provides the link in the supply chain between echelons that enable products to be available to the customer in the right place at the right time, (Potter and Lalwani 2005). In reviewing the literature, many authors e.g. (Potter and Lalwani (2005); Mason and Lalwani (2006)), refer to the difficulty in integrating freight transport into supply chains as the fixed verses flexible dilemma. This difficulty arises as the innate competitiveness of any supply chain is in its inherent flexibility, i.e. its ability to react to the constant, immediate and unforeseen changes that occur in modern day manufacturing. While in complete contrast to this, successful transport management is built on obtaining fixed and full loads on pre-planned time frames.

To overcome this fixed verses flexible dilemma Potter and Lalwani (2005) cite the integration of transport into supply chain operations and the use of advancements in information communication technology (ICT) as important frameworks. Potter and Lalwani analyse two main themes in the importance of integrating transport in the supply chain:

1) Minimisation of costs – analysing transport as a commodity;
2) Transport should meet the demands of the supply chain, regardless of what they are.
Cubitt (2002) outlines five ways in which cost minimisation can be achieved (see Table 3-1). The aim is to create economies of scale and maximise asset (tractor, trailer, drivers etc.) utilisation. Table 3-1 also catalogues the five main themes for the integration of transport into the supply chain as outlined by Potter and Lalwani (2005). On analysis of Table 3-1, the collaboration of transport services, minimisation of wastes in transport and the use of ICT are strong recurring themes. To this end, the remainder of this section will review these main themes in view to their analysis in an Irish context in Section 3.5.

<table>
<thead>
<tr>
<th>No.</th>
<th>Rule</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reducing the number of hauliers</td>
<td>Increasing the volume of product shipped with each haulier</td>
</tr>
<tr>
<td>2</td>
<td>Transport cost visibility</td>
<td>Agreeing rates on the basis of the haulier moving a fixed volume</td>
</tr>
<tr>
<td>3</td>
<td>Reduce administration costs</td>
<td>Linked to reducing hauliers as there are fewer companies to deal with</td>
</tr>
<tr>
<td>4</td>
<td>Maximise equipment use</td>
<td>Optimally routing vehicles as well as ensuring the right vehicle is allocated to each flow</td>
</tr>
<tr>
<td>5</td>
<td>Consolidate shipments</td>
<td>Creating a full vehicle load by mixing products from different orders/ customers</td>
</tr>
</tbody>
</table>

Five ways to Better Integrate Transport into Supply Chains

<table>
<thead>
<tr>
<th>No.</th>
<th>Rule</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Co-ordinated distribution network mgt</td>
<td>To provide flexibility in deliveries</td>
</tr>
<tr>
<td>2</td>
<td>Transport cost visibility</td>
<td>Holistically manage all costs, including production, inventory, obsolescence and lost sales</td>
</tr>
<tr>
<td>3</td>
<td>Exploitation of ICT</td>
<td>Simultaneous management of vast amounts of information</td>
</tr>
<tr>
<td>4</td>
<td>Collaborative relationships</td>
<td>Utilise a two way relationship between transport and the supply chain</td>
</tr>
<tr>
<td>5</td>
<td>Information feedback</td>
<td>Use information from transport to influence supply chain decisions and behaviour</td>
</tr>
</tbody>
</table>

Table 3-1; Integrating transport into the supply chain

3.2.2 Collaborative Transport Networks

If implemented correctly the utilisation of a collaborative transportation network among companies in the Mid-West Region is a possible method of
increasing efficiency and reducing emissions from transportation. According to Horvath (2001), “The driving force of effective SCM is collaboration”. Strategic SCM demands collaboration among all participants in the value chain, whatever their size, function, or relative position.

As highlighted by Mason and Lalwani (2005), collaboration can be “complicated and highly sensitive”, while Barrat (2004) identifies trust as a major factor in the implementation of collaborative transportation networks. Barrat adds, “It requires external and internal trust, mutual information exchange, communication and understanding, openness and honesty”. Mason and Lalwani (2005) argue that collaboration can occur in 3 states, conscious, semi conscious, or in an unconscious state. He describes the states as:

- **Conscious** – Classical collaboration; a deliberate mutual exchange occurring where both parties are aware of the others actions in working together to deliver an improved value proposition.
- **Semi-Conscious** – Joint management of an interface process might occur and be backed by strategic agreement, but in its operation be managed by only one party. (e.g. Vendor Managed Inventory/Transport)
- **Unconscious** – Two parties working together to deliver value but are unaware of the others roles in the process. In most cases collaboration is overseen by a supervising agency i.e. 4PL provider.

Section 3.5.3.3 assesses the possibilities and usefulness of setting up a collaborative transport network in the Mid-West Region of Ireland. Following on the theme of waste minimisation the following section looks at elimination wastes in transport, through lean optimisation.
3.2.3 **Tackling “wastes” in Freight Transport**

Lean supply chain management is a technique that analyses ways to eliminate wastes in the production process, thus increasing efficiency. In a 2006 paper on Supply Chain Management, Mason and Lalwani (2006) identify some hidden wastes in transport and logistics management which “eventually have to be paid for by supply chain customers”. These wastes include:

- Slow vehicle turnaround times;
- Low back-haul levels;
- Low fill rates;
- Duplicated administration;
- Poor fleet utilisation.

The minimisation of these wastes is central to improving the efficiency of logistics in Ireland. Unfortunately, limited data currently exists on this subject in Ireland. Mason and Lalwani (2006) highlight that recent developments in ICT now have the ability to analyse and reduce these “wastes”, through efficient use of supply chain and logistics management tools. With this in mind, the ICT tools in logistics management are introduced in the following section.

3.2.4 **ICT in Logistics Management**

Sections 3.2.1, 3.2.2 and 3.2.3 have highlighted the importance placed on utilising ICT for efficient supply chain operation. The uptake in developments of ICT, and overall ICT literacy of companies in Ireland is an important step towards increasing overall efficiency of the logistics and supply chain sector. Shown below are the a list of the ICT driven tools for the logistics software management sector compiled from a desktop survey carried out by Byrne et al. (2005), six categories were identified:
• Transport Management Systems (TMS);
• Enterprise Resource Planning (ERP) systems;
• Customer Relationship Management (CRM);
• Supplier Relationship Management (SRM);
• Warehouse Management Systems (WMS);
• Supply Chain Planning, Execution and Analysis.

Byrne et al. (2005) notes “most of the tools surveyed exist as stand-alone packages, i.e. Transport planning tools, contract management tools, and some of the categories surveyed exist as stand alone packages or suites, i.e. ERP”

<table>
<thead>
<tr>
<th>Category of Software</th>
<th>Functions</th>
<th>Tools / Modules / Features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transport Management Systems (TMS)</strong></td>
<td>• Transport Planning / Optimisation</td>
<td>• Vehicle Routing/Scheduling</td>
</tr>
<tr>
<td></td>
<td>• Transport Monitoring</td>
<td>• Transport Planning tools</td>
</tr>
<tr>
<td></td>
<td>• Vehicle Routing/Scheduling</td>
<td>• Global Positioning / Fleet Monitoring</td>
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<td></td>
<td>• Web Track and Trace (of consignments)</td>
<td>• Web Track and Trace (of consignments)</td>
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<tr>
<td></td>
<td>• Electronic Proof of Delivery (e-POD)</td>
<td>• Electronic Proof of Delivery (e-POD)</td>
</tr>
<tr>
<td></td>
<td>• Distribution Network Optimization</td>
<td>• Distribution Network Optimization</td>
</tr>
<tr>
<td><strong>Warehouse Management Systems (WMS)</strong></td>
<td>• Receipts Put-away</td>
<td>• Tracking and Tracing (RFID)</td>
</tr>
<tr>
<td></td>
<td>• Bin Management</td>
<td>• Guided Put-Away</td>
</tr>
<tr>
<td></td>
<td>• Order picking</td>
<td>• Task Scheduling</td>
</tr>
<tr>
<td></td>
<td>• Tracking and Tracing (RFID)</td>
<td>• Cycle Counting</td>
</tr>
<tr>
<td></td>
<td>• Generation of Labels and Barcodes</td>
<td>• Generation of Labels and Barcodes</td>
</tr>
<tr>
<td></td>
<td>• Charging and re-charging for storage,</td>
<td>• Charging and re-charging for storage, handling and warehouse</td>
</tr>
<tr>
<td></td>
<td>handling and warehouse operations</td>
<td>operations</td>
</tr>
<tr>
<td><strong>Supplier Relationship Management (SRM)</strong></td>
<td>• Strategic Purchasing and Sourcing</td>
<td>• Procurement/Sourcing (RFx tools)</td>
</tr>
<tr>
<td></td>
<td>• Supplier Collaboration</td>
<td>• Contract Management tools</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Catalogue Management tools</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Spend Analysis tools</td>
</tr>
</tbody>
</table>

Table 3-2; Identified categories of software in the logistics management sector

Table 3-2 shows an overview of the identified categories of software in the Logistics Management Sector. Also in Table 3-2 are the functions and telematic (mobile / handheld devices to gather and transmitting real-time data) features that enable the software to function. These tools have the
potential be disruptive technologies in their area. Little is known about the adoption of these tools useful for the advancement of logistics management among companies in the Mid-West Region of Ireland. The survey presented in Section 3.5 will address the uptake of the ICT based tools shown in Table 3-2.

3.3 Previous Logistics Surveys

This section presents the results from a study of logistical based survey analysis. The section has three subdivisions; (i) a review of logistics survey analysis carried out internationally, (ii) a narrower focus on recent logistics studies from Ireland and (iii) an overview of current environmentally based logistical analysis emerging from Europe and America.

3.3.1 International Logistics Survey Analysis

Previous international studies on logistics have assessed the views of buyers and sellers of logistics services. Leahy et al. (1995) surveyed asset and non asset based logistics firms by mail, yielding 37 responses, with a 72.5% response rate. This U.S. based survey was implemented in 1995 targeting Logistic Service Providers (LSPs) when at the time, most previous survey analysis just analysed transport service users. The survey documented the increased development of integrated relationships between transport users and providers, the growth in the outsourcing of logistics services, and was correct in its predictions of continued growth in the years to come.

*Disruptive technology is term for an Innovation that improves a product or service in a way that the market does not expect. Examples include the telephone, personal computers and plastics, Evans (2003).
Larson and Gammelgaard (2001) issued a survey to a specific audience, LSPs in Denmark. The survey yielded 78 responses with 11.5% response rate, giving a snapshot of the industry at the time of the study.

Lieb and Miller (2002) surveyed 78 large US manufacturing companies on LSP usage with a 17% response rate. The survey also documents the continued growth of LSPs; LSP usage in large companies, and the steady growth in the percentage of logistics operating budgets which LSP receive. Lieb and Miller also noted how “information applications” were generally outsourced by the surveyed companies. These applications include freight payment/accounting, transportation planning/optimisation, shipment tracking, international documentation and warehouse management systems.

### 3.3.2 Logistics Survey Analysis in Ireland

**InterTradeIreland Logistics Study**

InterTradeIreland (2008) carried out a cross sectional survey for the island of Ireland. The survey was administered using an online questionnaire with 130 responses, holding interviews with 47 transport providers and users, and chairing 2 focus groups. The survey was undertaken to gain insights on various aspects of current logistical issues in Ireland. The study highlights how:

- Transport users see reverse logistics / environmental issues becoming more important over the next 10 years, and cite Irish infrastructure as being “very poor relative to other key EU countries” (resulting congestion makes time planning difficult).
- 73 per cent of logistics companies predict an increase in load factors through more efficient use of lorry space over the next 10 years.
- All transport providers foresee a slight decline in the use of rail for freight coupled with an increase in road transport costs.
Inadequate infrastructure, fuel prices, peripherally and traffic congestion are ranked as the most serious issues faced by the transport providers on the island of Ireland, (InterTradeIreland 2008).

**Teagasc Survey on Irish Food Processing Industry**

A 1999 report carried out by Henchion et al. (1999) for the institution Teagasc (the Irish agriculture and food development authority) studied the impact on the competitiveness of the Irish food processing industry and of the logistics process in the food chain including transport, storage and distribution. The study collected data for 78 product chains, undertaking 45 personal interviews with food exporters and 46 with transport providers. This was supplemented by in-depth interviews with a small panel of haulage industry and shipping experts.

The research found that the Irish food sector in general has to date shown a strong capacity to accommodate the increasingly demanding requirements of its export markets. Transport and logistics costs vary widely depending on the nature of the goods (particularly the weight to value ratio) and destination.

The survey of food exporters revealed a wide range of sophistication in logistical practice, depending on the exposure of individual firms to sophisticated market demands. Considerable scope exists for information transfer, benchmarking and best practice in the industry. A survey of British retailers indicated that Irish food suppliers were perceived to be less flexible in accommodating changes in demand, reduced order lead times and last minute changes in orders than their best non-Irish suppliers. The study recommends:

- Increased supply chain integration between food producers and other supply chain members.
- Accelerated and broader range of usage of information communication technologies (ICT).
• Increased information transfer and benchmarking of logistics practices in the food industry.
• The inclusion of flexibility in logistics solutions developed by food producers and logistics service providers.
• Increased application of food engineering, packaging innovations and other technologies in the development of logistics solutions.
• Greater co-operation between food producers in logistics activities.
• Increased focus on logistics customer service criteria and strategies to improve customer service performance.
• A focus on improvement programmes and on-going monitoring of key trends and performance indicators. (Henchion et al. 1999)

Adoption of Supply Chain Management in Ireland

Huber and Sweeney (2007) assessed the level of supply chain management adoption in Ireland by surveying a broad range of industrial sectors. A total of 776 companies responded with a response rate of 47%. Of these responses 85% were small and medium-sized enterprises, and 70% were indigenous. Huber and Sweeney’s analysis includes that:

• 45% of companies identified “transport infrastructure” as an overriding constraint of the continuing development of business in Ireland. The problems reported mainly relate to costs and ensuring deliveries on time.
• 59% of companies do not know their total supply chain costs;
• 41% of firms do not know their transport costs; and
• 82% of companies do not formally measure warehousing in terms of key performance indicators.

In terms of ICT, one in five companies accepts their ICT systems are not well integrated across the company or the supply chain. Twenty-seven per cent of companies would not use the latest systems technology. Although Huber and Sweeney do not compare their results to other international
surveys, the author notes that this lack of understanding of supply chain metrics may not be limited to Ireland and may in fact be representative of an international statistic. Huber and Sweeney claim that overall, there is some improvement potential in particular for warehousing, production planning and transportation. The study recommends:

- Making these companies aware of SCM and developing the necessary internal capability is essential for Ireland’s industrial base in order to:
  - Minimise the impact of peripherally;
  - Enable small firms to take advantage of global supply chains; and
  - Exploit opportunities to manage virtual supply chains from Ireland.

Huber and Sweeney conclude with affirming how the pressures imposed and opportunities afforded by globalisation, the open nature of the Irish economy and recent developments in ICT mean that SCM has a critical role to play in both the medium term and the long term.

3.3.3 Environmentally Based Logistics Surveys

This section reviews the most recent data available on environmentally based logistics surveys, both domestically and internationally. The previous studies also provide benchmarks required for comparison with the current study in order to obtain a useful survey.

Environmentally based surveys have recently become popular among research institutes and companies; with most previous literature focusing on operational rather than environmental aspects of manufacturing and logistics. Two such survey analyses have been carried out by Bearing Point and the Transport Institute in 2008. The design and results of these two surveys are of significant importance to the current survey presented in this thesis and have been previously discussed in the introduction Section 1.5.
The results of these two environmentally based surveys will be further analysed and correlated in line with the results of the current survey results presented in Section 3.5. The following section defines the methodology to the design and implementation of the questionnaire.

### 3.4 Questionnaire Design Methodology

The previous two sections (3.2 and 3.3) have provided the background information to the development of the survey analysis undertaken in this thesis. This section outlines the design methodology of how questionnaire style survey analysis was selected, designed and implemented. According to Burgess (1982), field research is a learning situation in which researchers have to understand their own action and activities as well as those of the people they are studying. Forza (2002) identifies that field research data can be collected in a variety of ways, in different settings, and from different sources, however for survey research, the main methods used to collect data are interviews and questionnaires. The field research carried out in this project comprised of a questionnaire administered both in-person at the respondent company site. The following section will discuss questionnaires, their design, and the best type for their purpose and highlight the best means of administration for gaining effective results. Each relevant section is concluded by the “action” taken in the survey analysis presented in Section 3.5.

#### 3.4.1 Questionnaires

According to the EconomicsNetwork (2007) questionnaires are effective mechanisms for efficient collection of certain kinds of information. They are not, however, a comprehensive means of evaluation and should be used to support and supplement other information gathering procedures.
Questionnaires can be used as a mechanism for obtaining information and opinion; questionnaires have a number of advantages and disadvantages when compared with methods of data collection such as interviewing. Shown below are the advantages and disadvantages of questionnaires:

**Advantages of questionnaires**

- **Cost** - it is possible to provide questionnaires to large numbers of people simultaneously.
- **Uniformity** - each respondent receives the identical set of questions. With closed-form questions, responses are standardised, which can assist in interpreting from large numbers of respondents.
- Often, questionnaires are designed so that answers to questions are scored and scores summed to obtain an **overall measure** of the attitudes and opinions of the respondent.
- They permit anonymity. It is usually argued that anonymity increases the **rate of response** and may increase the likelihood that responses reflect genuinely held opinions.

**Disadvantages of questionnaires**

- **Quality** of data is probably not as high as with alternative methods of data collection, such as personal interviewing.
- They can be **misinterpreted**
- They are **complex** instruments and, if badly designed, can be misleading.
- It may be **difficult to obtain a good response** rate. Often there is no strong motivation for respondents to respond.

### 3.4.2 Design of Questionnaires

While outlining the initial considerations when designing a questionnaire Hair et al. (2007) highlights that before developing a questionnaire the researcher must be clear as to exactly what is being studied and what is
being expected from the study. This means the research problem must be clearly defined, project objectives must be clarified and research questions agreed upon. In addition Hair et al. claims that if these tasks are completed properly it is much more likely that the research questions will be answered with a greater degree of accurately. Hair et al. defines the initial consideration in the design of a questionnaire as:

**Initial Considerations**

- Clarify the nature of the research problem and objectives
- Develop research questions to meet research objectives
- Define target population and sampling frame (identify potential respondents)
- Determine sampling approach, sample size and expectant response rate
- Make a preliminary decision about the method of data collection.

**Action** – The lack in information on the readiness of companies to adopt more sustainable logistics practices has been identified as a research problem in the Introduction. Therefore the purpose of the survey presented in Section 3.5 is to (i) ascertain the level of awareness of sustainable logistics in companies and (ii) to evaluate the preparedness of companies in adopting sustainable logistics operations strategies.

### 3.4.3 Question Types: Using Open and Closed Questions

Oppenhiem (2001) explains that, most questions are either “open” or, “closed”. A closed question is one in which the respondents are offered a choice of alternative replies. They may be asked to underline their chosen answer(s) in a written questionnaire. Open or free-response questions are not followed by any kind of choice and the answers have to be recorded in full. Oppenhiem also highlights that in the case of a written questionnaire, the amount of space of the number of lines provided for the answer will
partly determine the length and fullness of the responses obtained. Shown in tables 3-3 and 3-4 are the advantages and disadvantages of using open and closed questions.

<table>
<thead>
<tr>
<th>Open Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Freedom and spontaneity of the answers</td>
</tr>
<tr>
<td>Opportunity to probe respondent</td>
</tr>
<tr>
<td>Useful for testing hypothesis about ideas or awareness</td>
</tr>
</tbody>
</table>

Table 3-3; Advantages and disadvantages of open questions (Oppenheim 2001)

<table>
<thead>
<tr>
<th>Closed Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>Require Little time</td>
</tr>
<tr>
<td>No extended writing</td>
</tr>
<tr>
<td>Make group comparisons easy</td>
</tr>
<tr>
<td>Useful for testing specific hypothesis</td>
</tr>
</tbody>
</table>

Table 3-4; Advantages and disadvantages of closed questions (Oppenheim 2001)

3.4.3.1 Question Wording

Oppenheim (2001) explains that question wording cannot be carried out in accordance with a “simple set of rules”, and many authors have only succeeded in stating the obvious or listing the pitfalls of incorrect wording. With this in mind, Oppenheim describes some basic rules of question wording. Oppenheim carefully states that questionnaires are not created by rules, such as the ones below, but each questionnaire is unique and presents its own special problems:

- **Length**: questions should not be too long, and should not contain sentences of more than twenty words.
- **Avoid proverbs**: and other popular sayings especially when measuring attitudes, for such sayings tend to provoke “unthinking agreement”.

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• Avoid double negatives.
• “Don’t know” and “Not Applicable” categories are often left out, allow for the possibility that the respondent does not know, or that other complication in which an answer may not be allowed to be given.
• Use simple words, avoid acronyms, abbreviations, jargon and technical terms; or else explain them.
• Some words are notorious for their ambiguity; and are best avoided or else defined.
• All closed questions should start their lines as open ones; so that the answer categories will be based as much as possible on pilot work. Always consider the inclusion of an ‘other (please specify)’ category.
• Beware of “leading” questions; i.e. ‘When did you last borrow a videotape?’ It assumes that all respondents have access to a videotape player that they generally borrow tapes, and it is not done by someone else on their behalf.
• Don’t over-tax the respondent’s memories.
• Pay due attention to detail; such as layout, show cards and prompts.

Action – After reviewing the literature and studying other previous surveys available on the subject an eight page survey was drafted in consultation with industrial and academic personnel. The survey consists of both open and closed question types and is available in Appendix 7.1.

3.4.3.2 Sampling

According to Moser (1972) two major principles underline all sample design. The first is the desire to avoid bias in the selection procedure; the second is to achieve the maximum precision for a given outlay of resources. In order for the researcher to evaluate questions from the respondents
perspective, Hair et al. (2007) explains that the target population (i.e. the population for which the information is required) for the study must be specified. Hair et al. adds that if the target population is not precisely defined the researcher cannot evaluate the questions. It is at the point in the study that they must consider to what extent respondents can be contacted and convinced to respond.

**Action** - The sample population for this survey is quite broad. In order to gain an insight into all facets of logistical operations for companies in the Mid-West Region of Ireland, a wide variety of companies need to be surveyed. Companies were selected from the Company Directory of the Shannon Development Region.

### 3.4.4 Piloting the Questionnaire

Hair et al. (2007) recommends that no questionnaire should be administered before the researcher has evaluated the likely accuracy and consistency of the responses. This is achieved by pre-testing the questionnaire using a small sample of respondents with characteristics similar to the target population. Hair adds respondents should complete the questionnaire in a setting similar to the actual research project. Moreover they should be asked probing questions about each part of the questionnaire, from instructions to scaling to format to wording, to ensure each question is relevant, clearly worded and unambiguous.

**Action** - An initial survey was piloted online and tested by academic and industrial personnel. Feedback from piloting the questionnaire with industrial and academic personnel brought it through four subsequent revisions. The modifications included:

1) Descriptions of terms used  
2) Removal of “unnecessary” questions  
3) Shortening of Introductory letter
4) Adding more closed questions

5) Introducing Likert 1-5 Scales on opinion questions.

Resulting from this pilot implementation questions were added and reworded and a decision was made to administer the survey on a face to face interview basis. With this in mind the following section documents interviewing techniques.

3.4.5 Interviewing Techniques

Moser (1972) advocates interviewing as the most appropriate procedure for data collection as compared to observation and mail surveys. However interviewing also introduces various sources of error and bias. In a standard interview the interviewer is neither trying to help the informant nor to educate him/her, neither to gauge his/her suitability for a job nor trying to get his/her expert opinion. Costs are also a concern with interviewing. Oppenhiem (2001) adds, the larger and more dispersed the sample, the greater the total cost of the interviewing operation.

Frey (1995) identifies interviewing is a key data-collection tool for conducting surveys, and describes a data collection tool as a structured method of obtaining information about selected characteristics, or variables in a target population. Depending on the topic of the questionnaire, the variables may include specific knowledge, attitudes and behaviours prevalent among the members of the population. The ultimate goal of the survey is to produce quantifiable measures. Shown below are the two different interviewing measures used in this methodology.

**In-Person Interviewing** - One on one, in person interviews have advantages over telephone interviews in terms of fewer limitations on the types and length of questioning and in the ability to use visual aids. Even thought his type of interviewing is hampered by higher field costs, increased difficulty obtaining permission from management to conduct interviews in
the workplace, it is regarded by researchers as one of the best ways to obtain detailed data.

**Telephone Interviewing** - Cost efficiency, speed of data collection and the prevalence of telephones in the market place as reasons to the popularity of administering questionnaires by telephone. Listening devices and recording equipment can also be useful for the accuracy of data generated, (Frey 1995).

### 3.4.6 Improving Questionnaire Response Rates

Systematic research on response rates leads Oppenhiem (2001) to discuss the following factors on increasing response rates to either mail surveys or to personal interviews. These measures include:

- **Advance warning**: A letter informing the respondent of the study in advance and inviting participation
- **Sponsorship**: This may take the form of an interviewer identification card plus a pamphlet describing the research organisation or a covering letter.
- **Confidentiality**: all survey data must be treated as confidential, in the sense that only the researcher will have access to them, and steps must be taken to ensure that no information will be published about identifiable persons or organisations without their permission
- **Incentive**: small incentives have generally proves helpful however larger ones often are not
- **Length**: try to keep short however if the topic is of a certain degree of interest to the respondent, length usually isn’t an issue.
- **Rapport**: it is the part of the interviewer to establish and sustain rapport, so that the respondent remains motivated and will complete the interview.
Action - Between the months of November 2007 and April 2008, the respondents were contacted by telephone and asked to participate in the questionnaire on location at the participating company.

3.4.7 Summary

This section has documented the design and implementation of the survey to (i) ascertain the level of awareness of sustainable logistics in companies and (ii) to evaluate the preparedness of companies in adopting sustainable logistics operations strategies. To review, the main points of the survey administration are:

- Potential respondent companies were selected from the Company Directory of the Shannon Development Region.
- 58 potential respondent companies were contacted, with 28 respondents (22 companies; 6 Logistic Service Providers (LSPs)) agreeing to participate in the survey.
- Response rate of 48%.
- The survey was administered by in person interviewing at the respondent company sites between the months of November 2007 and April 2008.
- The survey contains four categories of questions, they include:

1) **Company information:** To generate a profile of respondent companies in relation to size, sector and, for LSPs, the sector(s) serviced. The demographic of the respondent’s supplier/customer base is also tested.

2) **Environmental Awareness:** To gather information on the awareness of companies of sustainability in general and specifically in relation to logistics.

3) **Logistics Business Practices:** To gather information on logistic services purchased and provided, and to understand the business
practices used in this sector. This is seen as important in developing approaches for implementation of sustainability programs in the logistics sector.

4) Efficiency in logistics operations: Here the readiness of companies to adopt more sustainable logistic operational practices is tested. Methods of increasing logistical efficiency as outlined by Potter and Lalwani (2005) are assessed. Questions relating to monitoring of logistic costs, the use of ICT in logistical and supply chain operations and the willingness to participate in shared transportation networks are used to provide indicators for company readiness.

3.5 Questionnaire Results

Figure 3-1 gives the range of economic sectors that companies represented. The breakdown of employee numbers at the respondent company site as well as annual turnover in also shown in Figure 3-1. The majority of respondents (93%) were SMEs (according to the definition of an SME by the European Commission (2008)) with two large enterprises (LEs) making up the respondents.
This reflects the demographic of SMEs in Ireland with SMEs representing 90% of registered companies (BITC 2009). To gain an understanding of logistic operations in the companies surveyed, the geographic locations of the respondents’ customers and suppliers are shown in Table 3.5 The results are split between the companies and the LSPs (for LSPs, only customer locations were asked).

Companies source half their supplies within the island of Ireland with the majority of supplies imported into Ireland sourced from other European countries. Companies supply customers globally with a more balanced spread among regions, than that for company suppliers. The majority of the LSPs surveyed served a domestic market (71.4%).
### 3.5.1 Environmental Awareness of Companies

Questions on environmental awareness showed that:

- 36.4% of companies had an environmental officer, of which 14.3% had a remit that extended to the supply chain.
- 22.7% of companies have implemented ISO 14001.
- 9% of companies state they have measured their carbon footprint.
- No LSPs surveyed have implemented ISO14001 or ever measured their full carbon footprint. However 33% of respondents say it is in their future plans.

Comparing the results above with those obtained by Kewill (2008) where 450 respondents from around the world were surveyed, 34.4% of those companies had measured their carbon footprint compared to 9% of companies and none of the LSPs in this survey. This indicates that environmental impact measurement by companies is low in Ireland when compared internationally. However, of the 91% of companies who have never measured their carbon footprint, 55% of these stated it was in their company’s future plans to do so.

The Kewill (2008) survey highlights that 73% of companies now make environmental compliance part of their tender documents. In an effort to
assess Irish companies’ attitudes towards using more environmentally friendly LSPs, respondents were asked the following two questions;

1) Would your company consider using a LSP that proved to be more environmentally sustainable over its competitors, and provided equal price?

2) Would your company consider using a LSP that proved to be more environmentally sustainable over its competitors, but cost 5% more to use?

The results in Figure 3-2 show that a majority (23% ‘Consider’ and 31% ‘Maybe Use’) of companies would be willing to use LSPs that prove to be more environmentally sustainable over their competitors. However this is not the case if the LSP charges more for their business.

Interestingly, respondents who answered “never use in decision making” (which relates to question 1 above) all cited cost as the overriding factor, which indicates that companies perceive that there is a cost associated with environmental sustainability (i.e., a supplier must be less competitive in
terms of cost if they provide a greener service). Chapter 4 explores this issue quantitatively, the trade-off between cost and environmental impact.

### 3.5.2 Logistic Business Practice

To introduce sustainability approaches into the logistics sector in Ireland, it is important to gain an understanding of business practices in this sector. Table 3.6 gives the logistics services that companies outsource to LSPs and the services that the LSPs provide to their customers.

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>% of Companies that use</th>
<th>% offered by LSPs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warehousing</td>
<td>33.3</td>
<td>83.3</td>
</tr>
<tr>
<td>Cross-Docking</td>
<td>38.1</td>
<td>50</td>
</tr>
<tr>
<td>Air Freight Forwarding</td>
<td>81</td>
<td>16.7</td>
</tr>
<tr>
<td>Ocean Freight Forwarding - Full Container Loads</td>
<td>52.4</td>
<td>0</td>
</tr>
<tr>
<td>Ocean Freight Forwarding - Consolidation Services</td>
<td>52.4</td>
<td>0</td>
</tr>
<tr>
<td>Returns Management</td>
<td>33.3</td>
<td>50</td>
</tr>
<tr>
<td>Temperature Controlled Transport</td>
<td>38.1</td>
<td>83.3</td>
</tr>
<tr>
<td>Transport of Hazardous Goods</td>
<td>42.9</td>
<td>66.7</td>
</tr>
<tr>
<td>Documentation and Invoicing</td>
<td>52.4</td>
<td>66.7</td>
</tr>
<tr>
<td>Purchasing / Procurement</td>
<td>23.8</td>
<td>16.7</td>
</tr>
<tr>
<td>Product or Component Assembly</td>
<td>14.3</td>
<td>16.7</td>
</tr>
<tr>
<td>Pick Pack Kitting</td>
<td>9.5</td>
<td>50</td>
</tr>
<tr>
<td>Labelling</td>
<td>33.3</td>
<td>33.3</td>
</tr>
<tr>
<td>Testing / Quality Control</td>
<td>9.5</td>
<td>16.7</td>
</tr>
</tbody>
</table>

Table 3.6: Logistics services outsourced by companies / offered by LSPs

Companies were also asked how many LSPs their companies worked with. The results were that:

- 23.8% worked with between 1-3 LSPs,
- 38.1% worked with between 4-8 LSPs,
- 33.3% worked with between 9-13 LSPs, and
- 4.8% worked with between 14-18 LSPs.
Combining these results gives a picture of a sector that is highly fragmented. This is an important factor to take into account in developing strategy in promoting sustainability in this sector.

3.5.3 Efficiency in Logistics Operations

Results given here report on the preparedness of both the purchaser of logistic services and the provider of these services in adopting strategies for more sustainable operations. Measurement is a key cornerstone in implementing sustainable approaches. Therefore, questions were asked about measurement of logistic costs, which would provide a strong indication of the preparedness of companies to measure the environmental impact of their logistic operations. Another cornerstone in implementing sustainability in logistics operations is ICT, to support, for example, collaborative relationships, consolidated shipments, measurement and monitoring of environmental impact, etc. Therefore questions relating to ICT usage are reported here.

3.5.3.1 Logistic Costs

![Figure 3-3; Calculation of logistics costs](image)

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Companies were asked how often their logistics costs were calculated and by what method they do so (see Figure 3-3). Approximately half the companies review their logistics costs on an ongoing basis with all but one of the LSPs surveyed stating that they do. Most companies say their logistics costs are calculated by weight. All respondents who used the “other” category state the costs are negotiated as per the specific contract set out by the company and the LSP.

### 3.5.3.2 Exploitation of ICT

ICT in logistics operations is vital to efficiently manage supply chain operations, and in this survey 86.4% of companies have implemented some form of ICT in their logistics operations, the breakdown of which is in Table 3.7. Also highlighted in Table 3.7 are the results from LSPs in the survey and LSPs in the Larson and Gammelgaard (2001) survey. When referenced against their Danish counterparts, there is a low level of adoption in ICT services among LSPs in the Mid-West Region of Ireland. Also of note is that the Larson and Gammelgaard survey took place in the summer of 1999, almost nine years prior to the survey analysis carried out here, thus compounding the level of advancement of the Danish logistics sector.

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Response (%) Companies</th>
<th>Response (%) LSPs</th>
<th>L&amp;G survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Web Track and Trace of Consignments</td>
<td>89.5</td>
<td>33.3</td>
<td>44.3</td>
</tr>
<tr>
<td>Electronic Proof of Delivery Systems (e-Pod)</td>
<td>73.7</td>
<td>33.3</td>
<td></td>
</tr>
<tr>
<td>SMS Alerts</td>
<td>15.8</td>
<td>33.3</td>
<td></td>
</tr>
<tr>
<td>Transport Planning Tools</td>
<td>5.3</td>
<td>16.6</td>
<td></td>
</tr>
<tr>
<td>Fleet Monitoring / Tracking Systems</td>
<td>5.3</td>
<td>16.6</td>
<td></td>
</tr>
<tr>
<td>In-Cab Communication systems</td>
<td>0</td>
<td>16.6</td>
<td></td>
</tr>
<tr>
<td>GPS / Satellite Navigation Systems</td>
<td>0</td>
<td>16.6</td>
<td></td>
</tr>
<tr>
<td>Distribution Network Optimisation</td>
<td>0</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>Vehicle Routing Systems</td>
<td>0</td>
<td>33.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.7; Use of ICT in logistical operations

Choy (2004) argues supplier relationship management (SRM) tools can create competitive advantage through substantial reductions in the true cost
of parts and materials, increased flexibility to respond to changes in customer demand, and faster cycle times. Companies were asked about their use of SRM tools, with 45.5% of them using a SRM tool at the time of the survey. To gather further insight into the level of use of SRM tools, companies were asked what methods they use when placing orders with their suppliers, see Table 3.8.

<table>
<thead>
<tr>
<th>By what method are your company’s orders usually placed?</th>
<th>Response Count</th>
<th>&lt;20%</th>
<th>21-40%</th>
<th>41-60%</th>
<th>61-80%</th>
<th>81-100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-mail</td>
<td>19</td>
<td>47.4</td>
<td>15.8</td>
<td>5.3</td>
<td>0.0</td>
<td>31.6</td>
</tr>
<tr>
<td>Fax</td>
<td>17</td>
<td>76.5</td>
<td>5.9</td>
<td>11.8</td>
<td>5.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Phone</td>
<td>15</td>
<td>46.7</td>
<td>20.0</td>
<td>13.3</td>
<td>13.3</td>
<td>6.7</td>
</tr>
<tr>
<td>EDI</td>
<td>8</td>
<td>62.5</td>
<td>12.5</td>
<td>12.5</td>
<td>12.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Internet</td>
<td>7</td>
<td>85.7</td>
<td>14.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Mail</td>
<td>2</td>
<td>100.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
<td>0</td>
<td>0.0</td>
<td>0.0</td>
<td>100.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Table 3.8; Breakdown of companies ordering methods (suppliers)

In the survey seven options for answering the question were given as indicated in the table. The response count for each option and the percentage breakdown of the resulting percentiles are then given (i.e. 15 companies use phone when ordering supplies with 46.7% of the 15 using it <20% of the time). E-mail is the most popular method of ordering with 31.6% of companies who use e-mail, ordering 81-100% of their orders in that way. 36.4% of companies use some form of electronic data interchange (EDI) for ordering products. Note that LSPs were not asked this question. The results given for ‘Phone’ and ‘Fax’ show that there is a still a high level of non state-of-the art ICT tools use by companies in the operation of their supply chains.

3.5.3.3 Utilising Collaborative Relationships

Sweeney et al. (2008) state that the development of collaborative and partnership relationships throughout the supply chain is a fundamental
principle of effective SCM. From the results given in Section 3.5.2 it is clear that due to the level of outsourcing of logistical activities, increased collaboration among enterprises will be an important factor in implementing more sustainable practices. In a report into the establishment of an Eco-Industrial network in the Mid-West Region, O’Regan and Moles (2009) makes a similar point when stating that small-to-medium-sized enterprises could influence transport practices through collaborative procurement.

As identified earlier in Table 3.5 companies are sourcing a high proportion of their goods locally. However, of the surveyed companies 77.3% are not involved in any collaborative/shared transportation relationships with their customers / suppliers / other companies. On answering this question, respondents who answered “No” were then asked if they would ever consider getting involved in a shared transportation network under differing circumstances, see Figure 3-4.

If No, would your Company ever consider using shared transportation networks, even if it meant....

![Figure 3-4; Company opinions on adopting shared transportation networks in the Mid West Region of Ireland](image)

What becomes evident from the results is that there is interest in setting up shared transportation networks among companies where possible. 50% of companies reported that they would be interested in setting up a transport network. However, these same companies would not be interested
if it impacted on the responsiveness of the transport network, i.e. having to
wait for shipment of their goods less than 1 day, as indicated by the dark
blue columns in Figure 3.4. It must be noted that a high proportion of
freight forwarders (who constitute 29% of total surveyed respondents), said
they would not like to get involved in a shared transport relationships as
company policy. Surprisingly, as it is a very competitive sector, 83% of the
LSPs surveyed were involved in collaborative or shared transport
relationships with other LSPs at the time of the survey.

3.5.3.4 Transport Practices

As outlined in the literature review, transport practices such as shipment
consolidation and the backloading of goods play an important role in
reducing the environmental impact of a transport network and therefore
companies were questioned on such practices. The survey results are:

1) 77.3% of companies consolidate their inbound or outbound
shipments;
2) 50% of LSPs currently have a system for acquiring backloads on
shipments and journeys;
3) 50% of LSPs match vehicles to transport assignments;
4) No LSPs implemented bonus schemes for drivers for fuel efficiency.

The results show that a high number of companies (77% for
consolidation of orders) do implement strategies that improve logistic
efficiency resulting in lower environment impact. It is interesting to compare
this level of internal company activity against collaborative activities where
the results show the exact opposite (77% do not participate in collaborative
transport sharing). LSPs implement a lower level of practices that address
environmental impact.

According to Huber and Sweeney (2007) transport infrastructure has
been identified by 45% of companies as an overriding constraint of the
continuing development of business in Ireland. The problems reported by companies in the Huber and Sweeney survey mainly relate to costs and ensuring on time deliveries. Transport efficiency is tightly coupled to environmental impact, therefore questions were framed to test the companies’ perceived understanding of the trend in transport efficiency over time. Specifically, companies were asked if they felt their transport efficiency had improved over the last 6 months, 1 year, 5 years and 10 years, see Figure 3-5. Results are presented separately for companies and LSPs (see Figure 3-6), as differences in perception would be important to understand when engaging the sector in sustainability initiatives.

In the current survey most companies believe their transport efficiency has increased over recent years, citing the proliferation of ICT in logistical operations as a reason why. This statistic correlates to use of ICT in companies as highlighted in Table 3.7 where for instance 89.5% of the companies surveyed use web track and trace for their shipments. However, the majority of companies believe there has been a decrease in efficiency over the last 6 months. This possibly relates to the time when the survey took place, which was before the current economic downturn, when there was still growth in road traffic.
In direct contrast to the companies, LSPs believed that over the last 10 and 5 years there was no increase in the transport efficiency of their company, citing traffic congestion as the main impediment. However, LSPs believe their recent adoption of ICT has helped increase overall efficiency over the last year / six months, see Figure 3-6. With no correlation between the views of companies and LSPs on recent transport efficiency, the statistics suggest that different approaches for engagement on the topic of sustainable logistics of both buyer and seller may be needed.

![Figure 3-6; LSPs opinions on transport efficiency](image)

### 3.6 Summary

A summary of the main points from this survey are:

- Results from supplier and customer demographics (Table 3.5) show that companies operate in a global market.
- Companies employ fewer strategies to lower environmental impact compared to companies internationally. This is shown most clearly by the fact that 34.4% of the companies in the survey by Kewill (2008) had measured their carbon footprint compared to 9% in the present survey.
• Measures to address the impact of logistics in companies and LSPs are currently nonexistent. For example, no LSPs surveyed have implemented ISO14001 or ever measured their full carbon footprint. However, with all LSPs, except one, measuring their costs on an ongoing basis, the results show that LSPs have the capability to implement logistic environmental impact measurement systems.

• There is a willingness among companies to implement practices to address the environmental impact of their activities. This is seen from the result where 33% of LSPs say it is in their future plans to measure their carbon footprint and where, of the 91% of companies who have never measured their carbon footprint, 55% of these stated it was in their company’s future plans to do so.

• The results seem to highlight that there is a lack of understanding of the relationship between efficiency and the environmental impact of logistic activities by purchasers of logistic services. This is highlighted by the result that 32% of companies surveyed stated that they would never use in their decision making the criteria of environmental sustainability when comparing competing logistic service providers, due to the perceived increase in cost.

• Results from Logistic Business Practices show clearly that the logistics sector is a very fragmented sector, due to the high level of outsourcing. This is an important factor to take into consideration when implementing policy to address sustainability in this sector. This view is backed up by Comhar (2008) which notes that there are many small freight transport operators in Ireland with little coordination or external leadership.

• There is a low penetration of ICT in companies in support of logistic operations. This is shown in the results on company ordering methods where there is still a high level of reliance on dated ICT tools in supply chain practices (Table 3.8).

• This is also borne out by the results shown in Table 3.7, where LSPs are shown to have a lower level of usage of ICT tools against Danish
companies surveyed in 1999. This indicates that there is scope in improving the efficiency and hence sustainability of logistics via the wider adoption of ICT.

- Increased collaboration is often cited as a means to reduce the environmental impact of logistic networks, (Barrat 2004); (Mason and Lalwani 2005). The results show that among companies there is a level of collaboration on transportation, albeit low (23%). In the case of LPSs the level of collaboration (83%) is high. However, the survey does not reveal the benefits to the environment of this collaboration. It would be useful for future analysis, to carry out a study that would give an understanding of these benefits and improve collaboration strategy in this sector.

- Mason and Lalwani (2006) identify low fill rates and bad vehicle utilisation as factors that adversely affect the efficiency (and sustainability) of a freight transport system. According to the Department of Transport Ireland (2008) “typically around a third of vehicle-kilometres are sub-optimal depending on length of haul, type of vehicle, industrial sector and the nature of the delivery operation”. The results from the survey on Transport Practice (only 50% of LSPs implement backordering) show that this is an area with scope for improvement. Also, empty haulage in Ireland is not monitored as in other countries and no definitive statistic currently exits. The author believes this is an area for future research and monitoring

3.7 Conclusion

The low penetration of ICT in companies and indecisiveness in the collaboration of transport services is evident throughout the survey results. In addition, the results depict how there is no company currently measuring the environmental impact of their logistical operations. Irrespective of this,
the results do show how there is some awareness of environmental issues as indicated by a number of the companies’ future plans to measure their carbon footprint.

Furthermore, the link between environmental and monetary savings appears skewed by companies, who tend to assume environmental savings only come with an increased cost to their operations. As the majority of businesses are designed around the concept of profit making, it is important that the relationship between economic cost and environmental solutions is not ignored. With companies reluctant to implement more environmentally friendly options under the fear of additional costs, the following section will document the design and results of a simulation study to greater quantify the potential cost/service verses environmental savings that may not be instantly obvious to supply chain designer/operators.
4 Quantitative Analysis of Environmental and Economic Trade-Offs

4.1 Introduction

This chapter presents the development and results of a quantitative analysis study carried out to provide insight into the potential trade-offs between environmental impact and cost/service levels in a supply chain when operating using different transport strategies. This analysis was motivated by (1) results from the survey reported in Chapter 3 which showed that companies are reluctant to implement more environmentally friendly options if additional costs might be incurred; and (2) to provide insight to practitioners into how advanced analysis methods can complement more standard analysis methods (i.e. LCA) in developing more sustainable operating strategies in the operation of a supply chain. With regard to (1) there are no results reported in the literature that quantify the tradeoffs between the three measures of environmental impact, cost and service level in a realistic supply chain setting.

From the desk-based review reported in the Chapter 2, it can be seen that tools have recently appeared on the market with advanced analysis capabilities, for example, SEAT – Supply Chain Environmental Analysis/Optimisation Tool and Supply Chain Network Optimisation Workbench (SNOW) by IBM. However, being commercial tools there is little transparency on the inner workings of these tools. This lack of transparency leaves opportunities for open source software* development, where the low.

* Open Source Software is software that must be downloaded with source code included or easily available, such as free download from the internet. Industrial examples include he internet browser Mozilla firefox and the GNU/Linux operating system Kavanagh (2004)
cost and flexibility associated with open source software can drive future growth in the area. A popular method for programming, Open source software has the ability to model complex supply chain interactions and perform supply chain analysis and is freely available on the internet. It is in this free and wide availability that open source software can be a useful method for both raising the public awareness and building an understanding of sustainability in the supply chain sector.

The following section introduces simulation, and the simulation modelling techniques that are used in the quantitative analysis study. The simulation model development, operation and subsequent results are then presented, with conclusion drawn on the capabilities of simulation as a useful method for advanced analysis in reducing the environmental impact of supply chains.

4.2 Simulation Modelling for the Environmental Analysis of Supply Chains

Chapter 2 presented the static modelling tools for the environmental analysis of supply chains (e.g carbon footprinters, life cycle analysers and supply chain mapping tools). Many of these tools and techniques simply attempt to measure/model the environmental impact of a particular supply chain as it is presently constructed. Little or no attempt has been made in many of these tools to introduce the trade-off concept of economic cost versus service levels versus the environmental cost of supply chain design. As previously mentioned, there are commercial tools emerging which attempt to provide these trade-offs, but show minimal results applicable in an academic supply chain study. Nonetheless, the tools discussed in Chapter 2 do apply the fundamental methodologies needed to understand the environmental analysis of supply chains, and provide a framework for future studies in the area. However a shortcoming in these tools is that they
typically use static spreadsheet analysis which can only deal with
deterministic inputs. It is only in using simulation that the stochastic nature
of supply chain operation can be modelled over a real time setting.

Using simulation in environmental and supply chain analysis is not a new
concept, (McDonald et al. 2002) uses simulation to expand static value
stream mapping analysis of a manufacturing system. McDonald used
simulation to “answer questions that could not be addressed by the static
view provided by VSM”. Adding to this, Semini et al. (2006) argues 4 main
reasons why a simulation study can support manufacturing logistics
decision-making:

• A simulation model facilitates understanding of the real system and its
behaviour.
• The actual exercise of building a simulation model reveals previously
hidden relationships and provides a systematic way to analyze the
situation.
• A simulation model can facilitate communication and provide a basis
for discussions.
• “What-if” analyses can be carried out, allowing the decision-maker to
test the affects of different alternative scenarios without having to
make changes in the real system.

Most simulation modelling of supply chains has to date focused on
providing economic and performance related metrics. Examples of these
metrics include

• The expected lead time on products,
• The expected percentage of sales orders that will be delivered on time
and in full to the customer,
• The amount of sales demand the system can cope with, and
• The cost of providing products to customers.

In this study environmental impact is added as a metric to a simulation
based supply chain analysis. This will allow for the trade-off between cost,
performance and environmental impact to be quantified when assessing operational issues in supply chain design. The following section will identify the main simulation modelling techniques for supply chains analysis.

4.2.1 Simulation Modelling Techniques for Supply Chain Analysis

There is a wide range of modelling techniques that can be used to address supply chain design and operational analysis. From the user's point of view it is important to differentiate between generative models and evaluative models, see Figure 4-1.

Generative models provide the user with an ‘optimal solution’ that satisfies the user's objective function. Evaluative models, unlike generative models, do not provide the user with an 'optimal solution'. Instead, these models evaluate a given set of decisions by providing the user with performance measures. Although generative models have the advantage of providing the user with an 'optimal solution', they are, in general, restrictive in terms of their structural assumptions, which are usually only transparent to the model developer. Although evaluative models do not guarantee the user an `optimal solution`, they usually provide the user with valuable insights into the problem being addressed.
Figure 4-1; Models for systems design

An evaluative model is the appropriate model for the purposes of the study here. There are two main classes of evaluative models that can be used in supply chain analysis, queuing network models and simulation. Huang et al. (2003), as an example, used queuing models to study dyadic supply chain structures (i.e. structures consisting of two echelons; a buyer and a vendor for example) but states that discrete-event simulation (DES) is required to analyse more complex supply chain structures. DES is used in this supply chain study and is described in the following section.

4.2.2 Using Discrete Event Simulation (DES)

Law and Kelton (2000) describe DES as the “modelling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time. These points in time are the ones at which an event occurs, where an event is defined as an instantaneous occurrence that may change the state of the system”. Chang (2001) remarks DES as being able to permit the evaluation of operating performance prior to the implementation of a system. It also enables companies to perform powerful what-if analyses leading them to better planning decisions. DES also allows the comparison of various operational alternatives without interrupting the real system; it permits time compression so that timely policy decisions can be made (Chang 2001). There are many DES software packages available for supply chain analysis Section 4.2.3 outlines the selection process applicable to this study.

4.2.3 Selecting a Discrete Event Simulation Package - eM-Plant

The simulation software package used for building the model is eM-Plant. eM-Plant is an object-oriented discrete event simulation package developed
by Tecnomatix (www.tecnomatix.com). The eM-Plant package was chosen to develop this model due to existing licensing availability and existing expertise in the University of Limerick. Development methods available in eM-Plant such as polymorphism and the inheritance of component structures coupled with eM-Plant’s internal programming language called SimTalk lead Su and Shih (2002) to highlight 5 advantages of using eM-plant:

- It can build hierarchical models either bottom up or top down.
- It can reuse sub models or parts of models stored in the engineering database.
- It can use several modelling techniques for different levels to verify the results of each level and dramatically increase productivity.
- It can centralise and define changes of all relevant system parameters in one table, and
- It can integrate in real time with other software.

4.2.3.1 Modelling using eM-Plant

The following paragraphs describe the fundamental objects used in eM-Plant for building simulation models. They are a summary of selected objects from eM-Plant software “help files”, available in the eM-plant package. These are the building blocks which have been used to develop the models presented in this document and are referred to in the model descriptions throughout the remainder of the chapter.

The **Frame** is a window into which other objects are placed to develop a model. By placing other frames inside a frame a hierarchical model structure can be achieved.

The **Entity** is a moving object without a propulsion system of its own. It symbolises goods being produced or transported.

The **Single Processing Unit** receives and processes a single moving
The Method is a window into which the SimTalk code is written to control the behaviour of each of the aforementioned objects during a simulation run.

The Tablefile is a spreadsheet-like object with columns and rows for holding data which is used during, and generated by, a simulation run.

The EventController coordinates and synchronizes the different events taking place during a simulation run. When an Entity enters a processing station, for example a Single Processing Unit, eM-Plant computes the time it takes to process it and enters that event and that time into the list of scheduled events of the EventController.

4.3 The Discrete Event Simulation Model

The DES model reported on in this section, which is based on a real case study focuses on the freight transportation activities between three tiers of a supply chain; a product manufacturer together with its preceding and succeeding supply chain nodes (as illustrated in Figure 4-2). Typically the different partners in the supply chain outsource the supply of components/products. For example, the Customer (typically an OEM) will outsource the manufacture of a product to a Contract Manufacturer (CM), who in turn purchase or outsource the manufacture of components.
This outsourcing practice can recur along the supply chain resulting in complex multi-echelon supply chain networks with numerous transportation activities between the various nodes (Byrne et al. 2008). While the demand along any supply chain is ultimately driven by the end customers, operational constraints at each node such as batch sizes, processing times and safety stock levels cause additional fluctuations which make supply chain management difficult and ultimately affect the transportation operations between the different nodes (Liston et al. 2007). Lean manufacturing strategies such as Just-In-Time place the emphasis on reducing the stock held by each node, resulting in an increase in transport frequency.

The supply chain model is based on a real case study where a CM produces a subassembly for an electronic medical device under contract with an OEM. The CM employs lean manufacturing principles and has a Material Requirements Planning (MRP) system to control the ordering of material from suppliers, while deliveries to the OEM are subject to Quantity Flexibility terms which the OEM has stipulated in the outsourcing contract (as discussed in Section 4.3.1.1) In these contracts the buyer, at the beginning of the horizon, commits to purchase a certain quantity in each period of the contract. This above scenario reflects the circumstances of many companies
operating in Ireland who can be involved in a number of these supply chains at any given time.

### 4.3.1.1 Quantity Flexibility Constraints

Quantity flexibility constraints in supply chain modelling, as studied by Lian and Deshmukh (2009) and Walsh et al. (2007) are typical of the order flexibility determined and contracted in the quotation process between two acting supply chain members. These commitment revision constraints allow the companies to revise previously agreed order quantities by restricted amounts depending on the immediacy of the respective due-date, (i.e. the OEM would confirm these constraints with the CM before the contract is signed). However, the true implications of these constraints are not immediately obvious. This is because such constraints are zone-based, i.e. the percentage increases stipulated in the contract are based on the magnitude of the order upon entering the respective zones. Taking for example the constraints illustrated in Table 4-1, for any orders with between 4 and 8 weeks left to the due-date, the OEM is entitled to change the order amount (either up or down) by up to 15% of whatever the order was when entering that zone (i.e. the size of the order exactly 8 weeks before the due-date.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Time to Due Date</th>
<th>Upside Flexibility</th>
<th>Downside Flexibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 - 4 weeks</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4 – 8 weeks</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>3</td>
<td>8 – 15 weeks</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>4</td>
<td>15+ weeks</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Table 4-1: Typical period commitment revision constraints*
4.3.2 Developing the Model

Figure 4-3; Simulation model overview

Figure 4-3 gives an overview of the scope of the developed DES model. As can be deduced from the inputs and outputs listed here, this model does not attempt to capture the entire environmental impact of operating a supply chain and many drivers of GHG emissions (such as the lighting and heating of buildings for example) are not considered. The objective here is not to conduct extensive life cycle analyses but study the effect of transport operational decisions on the environment, customer service levels, as well as costs. The following gives an overview of the supply chain actions as simulated in the DES model;

1) Initial product demand (see Figure 4-4) is based on an inputted annual demand forecast. As the simulation runs, the OEM passes sales orders to the contract manufacturer (CM) and revises previously placed orders according to contractually agreed commitment revision terms (these allow the OEM to change
previous order quantities by amounts dependent on the immediacy of the delivery date).

2) The CM references this demand information against their existing bill of materials (BOM) data, corresponding raw material inventory levels, and open purchase orders. Where necessary, components are ordered from suppliers to maintain levels of stock adequate to satisfy forthcoming product demand. Purchasing constraints (i.e. minimum order quantities and batch sizes) for products on the supplier side will have influence on the size of these orders.

3) The suppliers then ship the requested amount of their respective components to the CM, if they are unable to ship the entire requested amount then the remainder is placed on “backorder” and shipped when available. The number of units per pallet is cross-referenced with the transport mode used to determine vehicle utilisation rates. These utilisation rates and the distance from supplier to manufacturer are used to calculate carbon emissions. (see section 4.3.2.1 for calculation of carbon emissions)

4) The CM determines its maximum production capacity (based on physical capacity and material constraints) and produces the outsourced product accordingly. Any available or required buffers of finished goods are also considered at this point.

5) Once manufactured, the products are tested and then shipped to the OEM where they are recorded into stock. Again, the product dimensions, transport mode and distance travelled are used to calculate the carbon output for this shipping activity.

These activities are repeated over a simulated one year period. Each time an activity is triggered the model accumulates the cost associated with conducting the activity and, in the case of transportation activities, the carbon emitted. Customer service levels are also recorded. The frequency and nature of the activities are dependent on the interaction of the different
operations and model variables. Due to variable demand the simulation model is replicated 30 times.

Figure 4-4 shows the demand profile inputted to the model. This profile is based on real product demand experienced by an electronics manufacturer and typifies the demand volatility which exists in the sector.

4.3.2.1 Calculation of Carbon Emissions

To account for the amount CO$_2$ released when transporting goods in a supply chain, a “carbon conversion factor” for transport activities is required. A carbon conversion factor converts the weight of goods moved over a specified distance, by a specific vehicle into an equivalent CO$_2$ emission, given in the form of “per Kg unit of CO$_2$”, released.

The carbon conversion factors used in the model are derived from a report released by the UK Department for Environment Food and Rural Affairs called “Guidelines for company reporting on greenhouse gas emissions”, (DEFRA 2005). As noted in the literature review the absence of a global standard, environmental standards means standards like this are numerous and continually evolving. The DEFRA factors were selected for this
analysis due to the geographical proximity of the UK to Ireland. Within the DES model, each time a transportation activity is simulated, the distance travelled is multiplied by the appropriate fuel conversion factor to calculate the amount of carbon emitted. As can be seen in Table 4.2, the choice of appropriate conversion factor is dependent on the vehicle type and the percentage of load capacity (number of pallets carried) that is utilised.

<table>
<thead>
<tr>
<th>Transport Mode</th>
<th>Fuel Conversion Factor (Kg CO₂/Km)</th>
<th>Number of Pallets Carried</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van</td>
<td>0.19</td>
<td>2</td>
</tr>
<tr>
<td>Rigid Truck_25%</td>
<td>0.26</td>
<td>2</td>
</tr>
<tr>
<td>Rigid Truck_50%</td>
<td>0.29</td>
<td>4</td>
</tr>
<tr>
<td>Rigid Truck_75%</td>
<td>0.31</td>
<td>6</td>
</tr>
<tr>
<td>Rigid Truck_100%</td>
<td>0.34</td>
<td>8</td>
</tr>
<tr>
<td>Articulated Truck_25%</td>
<td>0.36</td>
<td>6</td>
</tr>
<tr>
<td>Articulated Truck_50%</td>
<td>0.38</td>
<td>12</td>
</tr>
<tr>
<td>Articulated Truck_75%</td>
<td>0.41</td>
<td>16</td>
</tr>
<tr>
<td>Articulated Truck_100%</td>
<td>0.45</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 4.2: Carbon conversion factors

4.3.2.2 Generation of Results

Hunt (2008) recognises boxplots as providing a simple graphical summary of a set of data. It shows a measure of a central location (the median), two measures of dispersion (the range and inter-quartile range), the skewness (from the orientation of the median relative to the quartiles) and potential outliers (marked individually). An example of a typical Boxplot is identified in Figure 4-5. In this model, a number of application macros were build up in VBA (Visual Basic for Applications) to eliminate the need to manually carry out the tedious steps in creating each Boxplot. These macros automatically execute the copying, sorting, plotting and editing tasks to create the results.
4.3.3 Model Interface

The model development was carried out using the eM-Plant package of which a screenshot can be seen in Figure 4-6. The eM-Plant modelling frames and objects that contain the specific and characteristic information for the main functions and elements of the model, and are described below:

- **Demand** - this frame is used to hold the original demand data. This data comprises of a single value which states the total forecasted demand for the length of the contract (i.e. annual demand) and a list of forecasted demand values for each period (i.e. a demand pattern or profile as in Figure 4-4).

- **OEM** - this object processes the demand data over the simulation run. It passes product demand back to the manufacturer and then alters this demand during the simulation run according to the flexibility constraints of the contract. To record service levels, this frame also

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Figure 4-5; Example of a Boxplot taken from (Montgomery and Runger 1999)
compares the quantities of product received from the manufacturer with the purchase orders placed.

- **Manufacturer** - this object holds a record of the bill of materials for the product, production costs, and capacity constraints. The Manufacturer frame records stock levels for each component and reorders from the corresponding supplier according to a specified reorder policy.

![Simulation Model](image)

**Figure 4-6; The simulation model**

- **Supplier(s)** - here data is recorded for the components provided by that particular supplier. This information includes component part numbers, unit prices, lead times, batch sizes, minimum order quantities and finished stock levels.

- **Results** - holds the model outputs from each of the supply chain nodes.
• **Costs** - holds input costs such as administrative costs and storage costs.

• **Replicate** - controls the replications (in this model - 30), which occur during the simulation analysis and sets the different random number seeds for each.

• **Experiment** - This object was developed to allow for different experimental settings to be specified and then executed sequentially from a single command. This avoids the need for the user to manually reconfigure the model after each individual experiment.

• **Carbon Meter** – this frame contains the majority of the SimTalk code developed for this simulation model and is discussed in detail in the next section.

### 4.3.3.1 The Carbon Meter

The Carbon Meter frame contains six tables and two methods for calculating the carbon output from the transportation stage of the supply chain. The eight objects include:

• **Route Details Table** – As an input this table contains the distances between the supply chain echelons. The vehicle used during the current transport stage is also updated here during the simulation run.

• **Capacity Details Table** – this table contains information on the units per pallet which each product can carry also the specific pallet carrying capacity of the vehicles used.

• **Transport Mode Details Table** – this table contains the specific fuel conversion factors (Table 4.2). The number of pallets used during the current transport stage is also recorded here.

• **Transport Cost Table** – this table contains the transport and pallet transport costs are further discussed in the next section.

• **Carbon per Trip Table** – this table records the start point in the supply chain, the article transported the quantity transported the
vehicle used, the emissions generated and the transport cost for each supply chain movement.

- **Carbon per Article Table** – this table records the CO$_2$ emissions per the product from the transportation stage during the current supply chain movement.

- **Calc Carbon Method** – this Method uses SimTalk to orchestrate the movement and record the output to the results tables. The SimTalk code is given in full in Appendix 7.2

- **Init Method** – this method initiates the demand pattern to be sent from the OEM.

![Figure 4-7; Screenshot of Carbon Meter](image)

### 4.3.4 Model Outputs

The six output metrics are measured in Box Plot Format and the results are presented in section 4.4.1. The six model outputs are as follows:
• **Unit Cost (€)** - this involves a total cost of materials, processing and administration to the manufacturer. For the purposes of comparing the results costs are itemised per product of a finished good.

• **Storage Costs (€)** - this is the total costs of storage to the manufacturer per product finished goods and raw materials.

• **Logistics Costs (€)** - this is the total logistics cost of inbound and outbound transportation and is itemised per product. Per product itemisation allows the ability to establish a % cost of the total costs of the product.

• **% On Time Delivery (%)** – this is the % of on time delivery of finished goods which reaches the OEM as per the specific commitment revision constraints.

• **Carbon Output (Kg CO₂ p/Km)** - this is the carbon output from the product. This figure is a per product measure of the CO₂ output from transport of the goods from the supplier to the manufacturer and the manufacturer to the OEM.

• **Vehicle Utilisation (%)** – this is the total utilisation of the goods vehicles from transport of the goods from the supplier to the manufacturer and the manufacturer to the OEM. Backhauling levels and empty running on return trips are not accounted for in this model.

This section has defined case scenario, development and the input and output variables for the DES model. The next section will report on the different experiments and subsequent results from the simulation runs.
4.4 Experimentation & Results

As has been documented in the previous section, the supply chain design used in the simulation experiments represent an assembled component that is used in an OEM produced medical device. The model inputs for the Manufacturer, OEM and the four Suppliers nodes are provided in Figure 4-8.

![Figure 4-8: DES model inputs](image)

The following six experiments are based on two factors; purchase order batch size and transport vehicle type. Two levels are used for batch size, the first is based on MRP driven purchase orders which follow JIT principles, and the second is based on ordering material to fully utilise the transport vehicle. For the transport vehicle factor there are three levels; Van, Rigid Truck, and Articulate Lorry (each sized according to Table 4.2). Specifically, the experiments are:

1) JIT based batch sizes are used and goods are only transported by Van;

2) JIT based batch sizes are used and goods are only transported by Rigid Truck;
3) JIT based batch sizes are used and goods are only transported by Articulated Lorry;
4) Batch sizes are customised for maximum vehicle utilisation and goods are only transported by Van;
5) Batch sizes are customised for maximum vehicle utilisation and goods are only transported by Rigid Truck;
6) Batch sizes are customised for maximum vehicle utilisation and goods are only transported by Articulated Lorry.

The six model outputs (as noted in Figure 4-3) are presented in the following figures (Figure 4-9 - Figure 4-14). For each model output, the six experiments are presented beside each other in boxplot format. The boxplots show the location and spread of results for 30 replications of the simulation sequence and allow the experimental results to be quickly compared.

4.4.1 Results - Total Cost

Figure 4-9 shows the total cost (p/product) to the manufacturer when producing the finished component. Experiments 1 and 4 (using Vans for transport only) show the highest cost. Experiment 3, using a lorry to transport goods on a JIT basis shows the lowest cost.
4.4.2 Results - Logistics Costs

Figure 4-10 shows the logistics costs p/product. Again experiments 1 and 4 show the highest cost, with experiment 6, always using a full articulated lorry showing the lowest cost.

![Experiment Boxplots - Logistics Cost](image)

Figure 4-10; Results for logistics cost metric

4.4.3 Results – On Time Delivery

Figure 4-11 shows the on time delivery at the OEM. The Manufacturer must pay penalties for late deliveries; therefore this is of high importance. Experiment 6 shows the best on time delivery, but as the next set of results shows, this has an effect on the costs of storage.

![Experiment Boxplots - On Time Delivery](image)

Figure 4-11; Results for on time delivery metric
4.4.4 Results – Storage Costs

Figure 4-12 confirms experiment 6 as creating greater costs for the storage of goods. This is as a result of experiment 6 creating large quantities of finished goods / raw material in storage while waiting for a full articulated lorry load to accumulate before shipping.

4.4.5 Results – Carbon Output

Figure 4-13 shows the carbon output p/product confirming that smaller vehicles moving at greater frequencies create a greater carbon output p/product.
4.4.6 Results – Vehicle Utilisation

Figure 4-14 confirms articulated lorries which transport JIT batch sizes have the lowest utilisation of the fleet. Experiments 1 and 4 show the highest utilisation with experiment 6 showing an 88% utilisation figure for the Lorry.

4.5 Discussion

For the most part the results are as one would intuitively expect. For instance in Figure 4-10, Experiments 1 and 4 (using only Vans for transport) showed the highest logistics costs per item while Experiment 6 (using fully loaded Lorries to transport goods) showed the lowest. Similarly in Figure 4-12, Experiment 6 yielded the highest storage costs by far; while this is a logical consequence of purchasing larger quantities of components that have to be held in storage until consumed by the production process, the financial impact would be difficult to quantify without this type of dynamic analysis.

Figure 4-11 shows the results for the percentage of goods delivered on time at the OEM. Not only does this metric give an indication of customer satisfaction but many supply chain contracts specify that the manufacturer
must pay penalties for late deliveries; therefore it is important to include this performance metric in the analysis.

The carbon output results in Figure 4-13 confirm that smaller vehicles moving at greater frequencies create a greater carbon output per product. The adverse effects of JIT production may not appear as pronounced as one would initially expect but as the values shown are per item produced the cumulative effect over time would be substantial.

Interestingly, the trade-off between on-time delivery, cost and carbon output for Experiments 3 and 6 showed that, for similar cost, significantly lower carbon output and slightly higher service level could be achieved with Experiment 6. This is an example of how the trade-off between financial and environmental metrics is not always initially clear. In this case, the similarity in total cost results for Experiments 3 and 6 owes to the higher logistics cost for Experiment 3 being offset by lower storage costs; showing that the balance could easily shift if transportation costs were to rise. In light of recent fluctuations in fuel costs, it is clear that optimal supply chain design can be quickly distorted by changes in road haulage activity and this should be considered in supply chain management analyses.

### 4.6 Conclusions

The above study presented a methodology for the analysis of supply chains that allows for the environmental impact, service level and cost trade-off of different operational strategies to be ascertained. However, it is worth noting that the model inputs and supply chain design used are of a specific supply chain structure and as such, the results are case specific. With this in mind, the model results should not be taken as a holistic solution to environmental supply chain design, but it does show how monetary and environmental cost savings are possible under certain operating conditions. Additionally, the ability to modify and control any
subsequent changes to the model inputs and supply chain structure portray how the DES modelling methodology and practice is a useful tool in capturing the dynamic elements in supply chain analysis.

As previously stated, the experiments presented are case specific and as such, limited conclusions can be made. Notwithstanding this, two definitive results can be drawn from the study. First they show that there is a high correlation between total cost per product and carbon output per product, which (as the results from the survey in Chapter 3 show) seems to be misunderstood by some practitioners. Chapter 3 documented how companies tend to assume environmental savings only come at a cost to their operations, and as this model shows, this may not always be the case. Secondly the results show that even if not fully utilised, larger freight vehicles give lower carbon output and lower cost than smaller freight vehicles.

Using the analysis framework presented, quantitatively backed guidelines for practitioners in operating supply chains in a more sustainable manner can be provided. Finally, the framework has a role when combined with more standard LCA methods in providing decision support in designing and operating more sustainable supply chains.
5 Discussion and Conclusions

Developments in supply chain and its interactions with the environment are continuing to grow at an exceptional rate. Organisations, researchers and practitioners are investing large sums of time, money and effort towards environmentally friendly deliverance of products and services. The deliverance of these products and services is encapsulated in ever evolving supply chains, which continue to grow in complexity. This change provides both opportunities and threats.

For Ireland as a country to remain competitive in an international market it needs to embrace this change, particularly with respect to environmental supply chain management. This thesis has focused particularly on the operational elements of the transport sector in Irish based supply chains. From this study it is clear that Ireland’s policy makers need to address a number of key areas that will have a significant bearing on the competitiveness of Irish supply chains in the future. The following three sections are of direst importance to the creation of sustainable logistics in Ireland

5.1 Environmental Supply Chain Monitoring and Analysis

Environmental supply chain monitoring and analysis is continuing to grow at an extra ordinary pace. This can be seen from the number of large scale research works that are being carried out in this area, at an EU level and the number and scale of large organisations, which are carrying out related initiatives. It is clear from the analysis of the standards, methodologies and tools that this is an area that has grown considerably in the last number of years. As a consequence of this rapid growth, a number of parallel streams of work have taken place in the development of standards and
methodologies to determine the environmental impact of business activity. Two dominant standards have emerged for EMSs, the ISO 14000/4 and the PAS 2050. In relation to carbon conversion factors and carbon accounting tools less consensus has been reached. At present many carbon accounting mechanisms are used, and in some cases the results from these different mechanisms are in contradiction of each other. Within the last 1-2 years several new tool sets have been brought to the market to address environmental management of supply chains. The efficacy of these tool sets is difficult to assess, without detailed access to the tools. Being commercial products and with these tools being very recently introduced into the market this was not possible in this study.

5.1.1 Conclusion

This thesis deals with only one distinct theme in this topic area, but there are many more which are of relevance to Ireland as a trading nation. For supply chain management there are many companies offering software solutions and services. These companies are well placed to develop environmental management additions to their current offerings. However, notwithstanding this, it is felt that there are opportunities for companies in Ireland to develop new innovative software and service offerings in this sector.

5.2 Awareness and Attitudes towards Sustainable Logistics

It is clear from this survey that many organisations, have little or no awareness of environmental issues with respect to the operations of the logistical elements of their supply chains and beyond. Additionally, their appears to be a lack of motivation for such organisations (particularly SMEs) to embrace environmental issues in the supply chain domain. Ultimately,
organisations that don’t embrace such business evolution will find it difficult to remain competitive in the longer term.

5.2.1 Conclusions

The survey presented in this thesis shows that no LSP is currently measuring the environmental impact of their logistic operations. However, it does show that there is some awareness of environmental issues as indicated by a number of the companies’ future plans to measure their carbon footprint. This it is felt indicates that the sector would be responsive to engagement in a program for the development of sustainable practices. However, the fragmentation evident in the sector, as a result of the high level of outsourcing practices is seen as a major barrier that would need to be overcome.

More initiative and guidelines from government is needed for logistics sector in Ireland. McKinnon (2003) a leading researcher into logistical activities advises that governments can directly influence logistics management decisions through the use of:

- Fiscal measures: mainly fuel duty, vehicle taxes and road user charges.
- Financial incentives: these have been used more encourage a transfer of freight traffic between modes than to influence the rate of freight traffic growth.
- Regulations: on freight capacity and tariff levels.
- Changes in Construction and Use Regulations, such as raising maximum lorry weight.
- Infrastructure and land use planning: the provision of network and terminal capacity and land use planning policies clearly affects both the total volume and geographical distribution of freight traffic.
- Advice and exhortation: identifying and promoting best practice in vehicle loading and fuel efficiency.
These measures could be quite beneficial in Ireland as the survey particularly identified the lack of co-ordination with respect to logistical practices in Irish supply chains. These findings relate to both logistical service providers and their customers. This is an area which is further developed in both the UK and mainland Europe, particularly with respect to issues surrounding empty hauling. Other strategies that could be leveraged to increase environmental sustainability of the sector are wider adoption of ICT and increased collaborations either among common parties in the sector (i.e., LSPs) and/or across different parties that exist along the supply chain.

5.3 Environmental versus Economic trade-offs in Supply Chain Design and Operation.

As the majority of businesses are designed around the concept of profit making, it is important that the economic cost of environmental solutions is not ignored. Organisations must remain competitive in the marketplace and environmental aspects is only one variable in the larger profit making equation. There is still an uncertainty as to the cost of operating in an environmental friendly fashion and the economic benefit of doing so. The instances where this issue has been addressed are limited and in many cases are based on underlying assumptions, such as static supply chains. This work is not unique to Ireland, but a better understanding of the economic versus environmental trade-offs must be undertaken.

5.3.1 Conclusions

The quantitative analysis study undertaken, while being case specific, did provide insight into the trade-off between environmental impacts, cost and service level in a realistic supply chain setting. As cost reduction will be a prime motivator for companies in implementing more sustainable
approaches, increased understanding of their effect in lowering costs in supply chain management needs further research. This research will increase the possibilities of industry implementing more sustainable supply chain management practices thus promoting a green and efficient Irish economy.
6 References


%20SOFTWARE%20SECTOR%20AS%20AN%20AID%20TO%20IDENTIFYING%20USER%20REQUIREMENTS%20FOR%20A%20SIMULATION-BASED%20CONTRACT%20COSTING%20TOOL.pdf


Tenekcioglu, G. (2004) Increasing Intermodal Transportation in Europe through Realising the Value of Short Sea Shipping. Ocean Engineering, Massachusetts Institute of Technology, Master of Science in Ocean Systems Management, 89,
7 Appendices

7.1 Sustainable Logistics Questionnaire
<table>
<thead>
<tr>
<th></th>
<th>Company Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Company Name</td>
</tr>
<tr>
<td>1.2</td>
<td><strong>Annual Turnover</strong></td>
</tr>
<tr>
<td></td>
<td>&lt;$250K</td>
</tr>
<tr>
<td></td>
<td>€250K - €300K</td>
</tr>
<tr>
<td></td>
<td>€301K - €1M</td>
</tr>
<tr>
<td></td>
<td>€1M - €5M</td>
</tr>
<tr>
<td></td>
<td>€5M - €20M</td>
</tr>
<tr>
<td></td>
<td>€20M - €50M</td>
</tr>
<tr>
<td></td>
<td>€50M - €100M</td>
</tr>
<tr>
<td></td>
<td>€100M+</td>
</tr>
<tr>
<td>1.3</td>
<td><strong>No. of Employees</strong></td>
</tr>
<tr>
<td></td>
<td>&lt;10</td>
</tr>
<tr>
<td></td>
<td>10 – 25</td>
</tr>
<tr>
<td></td>
<td>26 – 50</td>
</tr>
<tr>
<td></td>
<td>51 – 100</td>
</tr>
<tr>
<td></td>
<td>101 – 250</td>
</tr>
<tr>
<td></td>
<td>250+</td>
</tr>
<tr>
<td>1.4</td>
<td><strong>Year Established</strong></td>
</tr>
<tr>
<td></td>
<td>Pre 1950</td>
</tr>
<tr>
<td></td>
<td>1950 – 1970</td>
</tr>
<tr>
<td></td>
<td>1971 – 1985</td>
</tr>
<tr>
<td></td>
<td>1986 – 1995</td>
</tr>
<tr>
<td></td>
<td>1996 – 2005</td>
</tr>
<tr>
<td></td>
<td>Post 2005</td>
</tr>
<tr>
<td>1.5</td>
<td><strong>Contact Name</strong></td>
</tr>
<tr>
<td>1.6</td>
<td><strong>Contact Email</strong></td>
</tr>
<tr>
<td>1.7</td>
<td><strong>Contact Job Title</strong></td>
</tr>
<tr>
<td>1.8</td>
<td><strong>Contact Phone No.</strong></td>
</tr>
<tr>
<td>1.9</td>
<td><strong>Remain Anonymous</strong></td>
</tr>
<tr>
<td>1.10</td>
<td><strong>Request results of Questionnaire</strong></td>
</tr>
<tr>
<td>1.11</td>
<td><strong>As a company, are you making an effort to carbon reduction</strong></td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>No</td>
</tr>
</tbody>
</table>
### General Logistics Information

2.2 Does your company currently work with a Logistic Service Provider (LSP), and/or Outsource any of your logistic services?  
*(If No go to question 2.6)*  
Yes  
No

2.3 If Yes, how many LSPs does your company currently work with?

2.4 Please rate your satisfaction with your company’s current outsourced Logistics Service Provider(s)

<table>
<thead>
<tr>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Un-Satisfied</td>
<td>Un-satisfied</td>
<td>No Opinion</td>
<td>Satisfied</td>
<td>Very Satisfied</td>
</tr>
</tbody>
</table>

2.5 Which (if any) of the following activities does your company outsource to a LSP?

- Transportation of Full Loads
- Transportation of Partial Loads
- Warehousing
- Cross-Docking
- Air freight Forwarding
- Ocean Freight Forwarding – Full Container Loads
- Ocean Freight Forwarding – Consolidation Services
- Returns Management
- Hazardous transport
- Temperature Controlled Transport
- Documentation / Invoicing
- Purchasing / Procurement
<table>
<thead>
<tr>
<th>Product or Component Assembly</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pick Pack Knitting</td>
<td></td>
</tr>
<tr>
<td>Labeling</td>
<td></td>
</tr>
<tr>
<td>Testing / Quality Control</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
</tr>
</tbody>
</table>

**2.6 When did your company last review its logistic costs / operations?**

- Up to 1 Month ago
- Between 1 and up to 3 Months ago
- Between 3 and up to 6 Months ago
- Between 6 Months and up to 1 Year ago
- Between 1 and up to 3 Years ago
- 3 and more Years ago
- Never,  

**2.7 How often does your company review its logistic costs / operations?**

- On going
- Every 3 Months
- Every 6 Months
- Every Year
- Every 3 Years
- Every 5 Years
- Never,  

**2.8 How are your company’s logistics costs rates calculated?**

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per case/km</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per Journey</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of Sales</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other please specify</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**2.9 Does your company use any form of Information Communication Technology (ICT) in its logistics operations?**

<table>
<thead>
<tr>
<th></th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Routing Systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport Planning Tools</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GPS/ Satellite Navigation Systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-Cab Communication systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMS Alerts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fleet Monitoring/ Tracking systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Web Track and Trace of Consignments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronic Proof of Delivery Systems (e-PoD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distribution Network Optimisation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Supplier information

<table>
<thead>
<tr>
<th>3.1 By what method are your company’s orders usually placed? (and please estimate, in percentage, the distribution of orders placed)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phone</td>
<td></td>
</tr>
<tr>
<td>Fax</td>
<td></td>
</tr>
<tr>
<td>E-Mail</td>
<td></td>
</tr>
<tr>
<td>Mail</td>
<td></td>
</tr>
<tr>
<td>Internet</td>
<td></td>
</tr>
<tr>
<td>EDI (Electronic Data Interchange)</td>
<td></td>
</tr>
<tr>
<td>Other, Please specify?</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3.2 Does your company use any form of Supplier</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

Question 3.4 is looking for information from the vehicles carrying supplies from your suppliers to your company, where they are generally coming from and their typical fill rate on entering the company. Question 3.5 concerns the same vehicles fill rate on leaving the company.

### 3.3 Of your suppliers, please state how many are located in each region; and please estimate the average the fill percentage (relative to max weight or dimension of vehicle used) of the delivery vehicles on entry?

<table>
<thead>
<tr>
<th>No. in Location</th>
<th>% fill rate of vehicle used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local &lt; 100km</td>
<td>20-40 41-60 61-80 81-100</td>
</tr>
<tr>
<td>National (within the Island of Ireland)</td>
<td></td>
</tr>
<tr>
<td>Western Europe</td>
<td></td>
</tr>
<tr>
<td>Eastern Europe</td>
<td></td>
</tr>
<tr>
<td>Americas (North and South)</td>
<td></td>
</tr>
<tr>
<td>Western Asia</td>
<td></td>
</tr>
<tr>
<td>Eastern Asia</td>
<td></td>
</tr>
<tr>
<td>Other;</td>
<td></td>
</tr>
</tbody>
</table>

### 3.4 Please estimate the average level of fill (relative to max weight or dimension of vehicle used) of the same supply vehicles on leaving your company?

- 0-20%
- 21-40%
- 41-60%
- 61-80%
- 81-100%
<table>
<thead>
<tr>
<th></th>
<th>Warehousing Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Has company warehousing space decreased in recent years (5 – 10) due to utilisation of Lean manufacturing techniques?</td>
</tr>
<tr>
<td>4.2</td>
<td>Does your company utilise RFID (Radio Frequency Identification) for product management</td>
</tr>
</tbody>
</table>
## Customer Ordering Information

### 5.1 By what method are your company’s orders usually received? (and please estimate, in percentage, the distribution of orders received)

<table>
<thead>
<tr>
<th>Method</th>
<th>20</th>
<th>41-60</th>
<th>61-80</th>
<th>81-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fax</td>
<td></td>
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<tr>
<td>E-mail</td>
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<td>Mail</td>
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<td>Internet</td>
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</tr>
<tr>
<td>EDI (Electronic Data Interchange)</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 5.2 Does your company use any form of Customer Relationship Management (CRM) Tool

<table>
<thead>
<tr>
<th>CRM Tool</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
</table>

Question 5.3 is looking for information from the vehicles carrying products from your company to your customers, where your customers are generally located, and their typical fill rate on leaving your company. Question 5.4 concerns the same vehicles fill rates as they enter your company.

### 5.3 Of your customers, please state how many are located in each region and estimate the average the fill percentage *(relative to max weight or dimension of vehicle used)* of the delivery vehicles on leaving your company?

<table>
<thead>
<tr>
<th>Region</th>
<th>No. in Location</th>
<th>20</th>
<th>41-60</th>
<th>61-80</th>
<th>81-100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local &lt; 100km</td>
<td></td>
<td>20</td>
<td>41-60</td>
<td>61-80</td>
<td>81-100</td>
</tr>
<tr>
<td>National (within the Island of Ireland)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western Europe</td>
<td></td>
<td>20</td>
<td>41-60</td>
<td>61-80</td>
<td>81-100</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td></td>
<td>20</td>
<td>41-60</td>
<td>61-80</td>
<td>81-100</td>
</tr>
<tr>
<td>Americas (North and South)</td>
<td></td>
<td>20</td>
<td>41-60</td>
<td>61-80</td>
<td>81-100</td>
</tr>
<tr>
<td>Western Asia</td>
<td></td>
<td>20</td>
<td>41-60</td>
<td>61-80</td>
<td>81-100</td>
</tr>
<tr>
<td>Eastern Asia</td>
<td></td>
<td>20</td>
<td>41-60</td>
<td>61-80</td>
<td>81-100</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>20</td>
<td>41-60</td>
<td>61-80</td>
<td>81-100</td>
</tr>
</tbody>
</table>

Please estimate the average level of fill *(relative to max weight or dimension of vehicle used)* of the same vehicles on entering your company:

<table>
<thead>
<tr>
<th>Fill Rate</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20%</td>
<td></td>
</tr>
<tr>
<td>21-40%</td>
<td></td>
</tr>
<tr>
<td>41-60%</td>
<td></td>
</tr>
<tr>
<td>61-80%</td>
<td></td>
</tr>
<tr>
<td>81-100%</td>
<td></td>
</tr>
</tbody>
</table>
## Environmental Awareness

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Does your company’s have a system for acquiring Backloads on shipments?</td>
</tr>
<tr>
<td></td>
<td><em>(Comments)</em></td>
</tr>
<tr>
<td>6.2</td>
<td>Is your company involved in any collaborative / shared transport relationships with other suppliers / customers / companies?</td>
</tr>
<tr>
<td>6.3</td>
<td>If no, would your company ever consider using shared transportation networks, even if it meant,</td>
</tr>
<tr>
<td></td>
<td>Other companies have knowledge of your level of goods transportation</td>
</tr>
<tr>
<td></td>
<td>Some orders inbound from suppliers may be slightly delayed (&lt; 1 day)</td>
</tr>
<tr>
<td></td>
<td>Some orders outbound to customers may be slightly delayed (&lt; 1 day)</td>
</tr>
<tr>
<td>6.4</td>
<td>Are any of your company’s inbound or outbound shipments ever consolidated? <em>(i.e. mixing products to create fuller vehicle loads)</em></td>
</tr>
<tr>
<td>6.5</td>
<td>Are Reverse Logistics networks utilised in your company’s supply chain decisions? <em>(e.g. return of used/defective products or goods)</em></td>
</tr>
<tr>
<td>6.6</td>
<td>In your opinion has your company’s transport efficiency improved in the last...</td>
</tr>
<tr>
<td></td>
<td>6 months</td>
</tr>
<tr>
<td></td>
<td>1 year</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
</tr>
<tr>
<td></td>
<td>10 years</td>
</tr>
<tr>
<td>6.7</td>
<td>Does your company have the facility to assign different vehicles to different operations to carry out specific functions? <em>(i.e. using a small van for a small load rather than a large van for a small load)</em></td>
</tr>
<tr>
<td>6.8</td>
<td>Are your company’s vehicles specially designed to accommodate for the maximum utilisation of space for the products to be transported?</td>
</tr>
<tr>
<td>6.9</td>
<td>Does your company have bonus schemes for drivers who use the least amount of fuel over specified journeys?</td>
</tr>
<tr>
<td>7.1</td>
<td>Does your company have an environmental officer</td>
</tr>
<tr>
<td>7.2</td>
<td>If Yes, are they involved in any supply chain decisions</td>
</tr>
<tr>
<td>7.3</td>
<td>Has your Company ever measured its Carbon Footprint</td>
</tr>
<tr>
<td>7.4</td>
<td>Has your company implemented ISO14001?</td>
</tr>
<tr>
<td>7.5</td>
<td>If No, Does your company have any future plans to measure its Carbon Footprint, in the next….</td>
</tr>
<tr>
<td></td>
<td>6 months</td>
</tr>
<tr>
<td></td>
<td>1 year</td>
</tr>
<tr>
<td></td>
<td>3 years</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
</tr>
<tr>
<td></td>
<td>Not in Future Plans</td>
</tr>
<tr>
<td>7.6</td>
<td>Does your company have a means of calculating its Carbon Footprint?</td>
</tr>
<tr>
<td>7.7</td>
<td>Does your company have a means of examining its Carbon Footprint?</td>
</tr>
<tr>
<td>7.8</td>
<td>Does your company ever employ methods to minimise its carbon Footprint?</td>
</tr>
<tr>
<td>7.9</td>
<td>Would your company consider using a Logistics Service Provider that proved to be more environmentally sustainable over its competitors, and provided equal price?</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>No Opinion</td>
</tr>
<tr>
<td>7.10</td>
<td>Would your company consider using a Logistics service provider that proved to be more environmentally sustainable over its competitors, but cost 5% more to use?</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Never use if more expensive</td>
</tr>
</tbody>
</table>
7.2 SimTalk code for Calculating Carbon

```plaintext
/* Carbon Calculations Based on Transport */

-- Called By: Supplier Move A Manufacturer Shipping

| startDistancet string, Article string, Qty Integer |

| numPallets, numVehicles, numFullVehicles, partialFill, routeDistance, KF, Carbon, tranCost, vehicleUtilization, numFane, numTrucks, numartic, requaVans, requaTrucks, requaartic, 

| VenPallets, TruckPallets, articPallets, 

| totalsVehicleStill, totalsVehicleReal, 

| tranCost string |

do numPallets = ceil(Qty/ Capacity_Details["Units Per Pallet", Article]);

| routeDistance = Route_Details["Distance", startPoint];

| CurrentNode = Route_Details["Transport Mode", startDistancet]; -- Set Global Variable

| tranCost = 0;

| if CurrentNode = "Optimal MultiMode" then

| while numPallets > 0 loop

| requaVans = numPallets/Capacity_Details["Pallets Per Van", Article];

| requaTrucks = numPallets/Capacity_Details["Pallets Per Rigid Truck", Article];

| requaartic = numPallets/Capacity_Details["Pallets Per Artic", Article];

| if requaVans <= 1 then

| numVans = requaVans;

| numPallets = numPallets - numPallets;

| numartic = numartic - numartic;

| elseif requaTrucks <= 1 then

| numTrucks = requaTrucks;

| TruckPallets = TruckPallets + numTrucks;

| numartic = numartic - numartic;

| elseif requaartic <= 1 then

| numartic = requaartic;

| articPallets = articPallets + (floor(requaartic) • Capacity_Details["Pallets Per Artic", Article]);

| numartic = numartic - (floor(requaartic) • Capacity_Details["Pallets Per Artic", Article]);

| -- if there is more than a full artic but not less than full van or truck then remaining pallets are taken by artic

| else

| numartic = requaartic + floor(requaartic); articPallets = articPallets + (floor(requaartic) • Capacity_Details["Pallets Per Artic", Article]);

| numartic = numartic - (floor(requaartic) • Capacity_Details["Pallets Per Artic", Article]);

| -- if there is more than full artic then loop to see if remaining pallets can be taken by van or truck

| end;
```

- 116 -
if numVans > 0 then
  --numVehicles = numPallets/Capacity_Details["Pallets Per Van", article];
  numFullVehicles = floor(numVans);

  PUF = Transport_Mode_Details["Fuel Conversion Factor", "Van"].(Carbon = Carbon + (PUF * routeDistance * cm(\text{numVans})) -- Round Up (because only one category for Vans)

  transCost = transCost + (Transport_Cost("Van Base Cost", startPoint) * numFullVehicles) /* number of vehicles */ + (Transport_Cost("Van Pallet Cost", startPoint) * numPallets) /* number of pallets */

  totalVehicleUtil = totalVehicleUtil + numVans;
  totalVehicle := totalVehicle + cm(\text{numVans});
end;

if numTrucks > 0 then
  --numVehicles = numPallets/Capacity_Details["Pallets Per Rigid Truck", article];
  numFullVehicles = floor(numTrucks); -- Round Down
  partialFill := numTrucks - numFullVehicles.

  PUF = Transport_Mode_Details["Fuel Conversion Factor", "Rigid Truck_100"];
  Carbon = Carbon + PUF * routeDistance * numFullVehicles;

  if 1 < partialFill and partialFill <= 0.25 then
    PUF = Transport_Mode_Details["Fuel Conversion Factor", "Rigid Truck_25"];
    Carbon = Carbon + PUF * routeDistance * partialFill;
  end;

  if partialFill > 0 then
    Carbon = Carbon + (PUF * routeDistance); -- add CO2 for partially filled vehicle to that for full vehicles
  end;

  transCost = transCost + (Transport_Cost("Rigid Truck Base Cost", startPoint) * cm(numTrucks)) /* number of vehicles */ + (Transport_Cost("Rigid Truck Pallet Cost", startPoint) * TruckPallets) /* number of pallets */

  totalPalletUtil = totalPalletUtil + numTrucks;
  totalVehicles := totalVehicles + cm(numTrucks);
end;
if numArticles > 0 then
  --numVehicles = numPallets/Capacity_Details("Pallets Per Article", Article);
  numFullVehicles = floor(numArticles); -- Round Down
  partial Fill = numArticles - numFullVehicles;

  PCF = Transport_Mode_Details("Fuel Conversion Factor", "Articulated Truck_100");
  Carbon = Carbon + PCF * routeDistance * numFullVehicles;

  if partial Fill <= 0.25 then
    PCF = Transport_Mode_Details("Fuel Conversion Factor", "Articulated Truck_75");
  elseif 0.25 < partial Fill <= 0.5 then
    PCF = Transport_Mode_Details("Fuel Conversion Factor", "Articulated Truck_50");
  elseif 0.5 < partial Fill <= 0.75 then
    PCF = Transport_Mode_Details("Fuel Conversion Factor", "Articulated Truck_25");
  elseif 0.75 < partial Fill <= 1 then
    PCF = Transport_Mode_Details("Fuel Conversion Factor", "Articulated Truck_0");
  end

  if partial Fill > 0 then
    Carbon = Carbon + (PCF * routeDistance); -- add CO2 for partially filled vehicle to that for full vehicles
  end


  totalVehicleUtil = totalVehicleUtil + numArticles;
  totalVehicle = totalVehicle + ceil(numArticles);
end

vehicleUtilisation = (totalVehicleUtil / totalVehicle) * 100;

else
  numPallets = ceil([Qty/Capacity_Details("Units Per Pallet", Article]));

  if Current Mode = "Optimal_SingleMode" then
    --Choose Mode according to order size
    numVans = numPallets/Capacity_Details("Pallets Per Van", Article);
    numTrucks = numPallets/Capacity_Details("Pallets Per Rigid Truck", Article);
    numArtic = numPallets/Capacity_Details("Pallets Per Artic", Article);

    -- According to the carbon factors and vehicle capacities it is always most efficient
    -- to use least number of vehicles

    if numVans < 1 then
      Current Mode = "Van";
      numVans = numTrucks;
    elseif numTrucks < 1 then
      Current Mode = "Rigid Truck";
      numTrucks = numArtic;
    else
      Current Mode = "Artic";
    end

    numArticles = numArtic;
  end
```plaintext
inspect CurrentNode
when 'Van' then
  numVehicles = numPallets/Capacity_Details['Pallets Per Van', Article];
  numFullVehicles = floor(numVehicles);

  PCF = Transport_Node_Details['Fuel Conversion Factor', 'Van'];
  Carbon = PCF * routeDistance * ceil(numVehicles); — Round Up (because only one category for Vans)

  taskCost = [Transport_Cost['Van Base Cost', startPoint] * numFullVehicles] / number of vehicles */
            + [Transport_Cost['Van Pallet Cost', startPoint] * numPallets] / number of pallets */

when 'Rigid Truck' then
  numVehicles = numPallets/Capacity_Details['Pallets Per Rigid Truck', Article];
  numFullVehicles = floor(numVehicles); — Round Down
  partialFill = numVehicles - numFullVehicles.

  PCF = Transport_Node_Details['Fuel Conversion Factor', 'Rigid Truck_100%'];
  Carbon = PCF * routeDistance * numFullVehicles;

  if partialFill < 0.25 then
    PCF = Transport_Node_Details['Fuel Conversion Factor', 'Rigid Truck_50%'];
    elsenfi 0.5 < partialFill and partialFill < 0.75 then
      PCF = Transport_Node_Details['Fuel Conversion Factor', 'Rigid Truck_50%'];
    elsenfi 0.75 < partialFill and partialFill < 1 then
      PCF = Transport_Node_Details['Fuel Conversion Factor', 'Rigid Truck_100%'];
  end;

  if partialFill > 0 then
    Carbon = Carbon + (PCF * routeDistance); — add CO2 for partially filled vehicle to that for full vehicles
  end;

  taskCost = [Transport_Cost['Rigid Truck Base Cost', startPoint] * ceil(numVehicles)] / * number of vehicles */
            + [Transport_Cost['Rigid Truck Pallet Cost', startPoint] * numPallets] / * number of pallets */

when 'Artic' then
  numVehicles = numPallets/Capacity_Details['Pallets Per Artic', Article];
  numFullVehicles = floor(numVehicles); — Round Down
  partialFill = numVehicles - numFullVehicles.

  PCF = Transport_Node_Details['Fuel Conversion Factor', 'Articulated Truck_100%'];
  Carbon = PCF * routeDistance * numFullVehicles;

  if partialFill < 0.25 then
    PCF = Transport_Node_Details['Fuel Conversion Factor', 'Articulated Truck_25%'];
    elsenfi 0.5 < partialFill and partialFill < 1 then
      PCF = Transport_Node_Details['Fuel Conversion Factor', 'Articulated Truck_50%'];
    elsenfi 0.75 < partialFill and partialFill < 1 then
      PCF = Transport_Node_Details['Fuel Conversion Factor', 'Articulated Truck_100%'];
  end;

  if partialFill > 0 then
    Carbon = Carbon + (PCF * routeDistance); — add CO2 for partially filled vehicle to that for full vehicles
  end;

  taskCost = [Transport_Cost['Artic Base Cost', startPoint] * ceil(numVehicles)] / * number of vehicles */
            + [Transport_Cost['Artic Pallet Cost', startPoint] * numPallets] / * number of pallets */

end;

vehicleUtilisation = (numVehicles / ceil(numVehicles)) * 100;
```

endi: —else multiproduct

Carbon_Per_Trip["Start Point", Carbon_Per_Trip yDias] +1] : startPoint;
Carbon_Per_Trip["Article", Carbon_Per_Trip yDias] : Article;
Carbon_Per_Trip["Qty", Carbon_Per_Trip yDias] : Qty;
Carbon_Per_Trip["Costs", Carbon_Per_Trip yDias] : Costs;
Carbon_Per_Trip["No. Vehicles", Carbon_Per_Trip yDias] : numVehicles;
Carbon_Per_Trip["No. Vans", Carbon_Per_Trip yDias] : numVans;
Carbon_Per_Trip["No. Rigid Trucks", Carbon_Per_Trip yDias] : numTrucks;
Carbon_Per_Trip["No. Artic", Carbon_Per_Trip yDias] : numArtic;
Carbon_Per_Trip["Vehicle Utilisation", Carbon_Per_Trip yDias] : vehicleUtilisation;
Carbon_Per_Trip["CO2", Carbon_Per_Trip yDias] : Carbon;
Carbon_Per_Trip["Transport Cost", Carbon_Per_Trip yDias] : transCost;

Carbon_Per_Article["CO2", Article] + Carbon_Per_Article["CO2", Article] + Carbon;

Root: Carbon + Root: Carbon;

---------

if startPoint = "Manufacturer" then
else
---------

endi