Sustainable Logistics Capturing Dynamic Input Factors

Nachhaltige Logistik durch Bestimmung dynamischer Einflussfaktoren

Paul Ryan, Paul Liston, Cathal Heavey,
Enterprise Research Centre, University of Limerick, Limerick (Ireland)
PJ Byrne, Dublin City University Business School, Dublin City University (Ireland)

Abstract: Across the European Economic Area more goods are being transported over longer distances more frequently than ever before. As a result, Greenhouse Gas (GHG) emissions from transport increased overall by 24% between 1990 and 2003 for the 32 countries in the EEA, with emissions from the transport sector in Ireland growing by 130% in the same period. With incoming Kyoto regulations, and opinion resistant to heavy freight traffic, efficient freight transport has become growing concern. This paper will document the tools already used in environmental Supply Chain (SC) analysis and propose the use of Discrete Event Simulation (DES) as a Decision Support System (DSS) to aid decision makers choose the most environmentally friendly SC design.

1 Introduction

As of 2006, only eight of the EU-15 Member states are predicted to reach their GHG Emission reduction Kyoto targets. In the transport sector GHG emissions are the result of burning petrol, diesel and kerosene in internal combustion engines. Transport is the fastest growing consumer of energy in the EEA and energy demand particularly in road freight is predicted to grow (EEA 2006a). Figure 1 shows the trends in GHG Emissions from Transport from selected countries in the EEA, from 1990–2003. For the EEA-32 countries, freight transport volumes have grown by 34% from 1993 to 2003, with the economy only growing 26% in the same period. 21% of the EU-15 total GHG emissions now are attributed to transport. Freight transport by road now holds a 77% market share over rail and water freight with road transport contributing 93% of the total of all transport emissions (EEA 2007; EEA 2006b).

Over recent years, the increase in popularity of Supply Chain Management (SCM) techniques such as lean manufacturing, outsourcing and in particular, postponement and Continuous Replenishment (CR) policies for materials and stock levels has
meant a redesign of traditional supply chains. Transport has become a major factor in these supply chains. The ability to get the right materials, to the right place, at the right time, is central to modern day manufacturing. The practice of CR has increased the frequency of material delivery, using transportation with high GHG emissions (i.e. smaller trucks, partially filled), (Archibald et al. 1999). Globalisation and the outsourcing of products and services has de-centralised production facilities creating large distances between interacting companies that now contribute to the production of a finished consumer product, (Edgington 1993). This makes efficient transportation economically vital to all in the supply chain, while also causing enormous CO2 emissions in the transportation stage of the supply chain.

Van Hoek (2001) plainly describes postponement as delaying activities in a supply chain until a demand is realised. This is the basis of the SCM model used in this paper. As stated by McKinnon (2003) most of the research on postponement has focused its effects on inventory levels, with little work appearing to have been done to assess its effects on transport efficiency. Adding to this, Yang et al. (2005), discusses the impact of postponement on transport; expressing the need to further understand the trade-offs between optimal supply chain efficiency and its environmental impact. This paper highlights the negative environmental impacts of goods movement by road, and proposes methods for environmental analysis in industrial road transport. Section 3 discusses the need for DES in supply chain analysis, with section 4 describing a DSS tool to aid more environmentally conscious supply chain decisions. The concluding section discusses preliminary results and findings from the model.

2 Review of Carbon Accounting Tools

Backstrom (2008) highlights the care that must be taken when developing a tool for use in Carbon Accounting/Footprinting/Monitoring. Using multiple methods of Ecological Footprinting (EF), Backstrom measured the movement of a standard pallet weighing 500kg on a train travelling 1500 Km’s. The highest Kg CO2 value
was .761Kg CO\textsubscript{2} with the lowest .222Kg CO\textsubscript{2}. This uncertainty in EF analysis led Backstrom to suggest selection methods of analysis in transportation should be allocated to the mode and method by its “limiting physical dimension”.

- In Distribution - Floor Space
- In Bulk Transport - Weight /Volume
- In Air Freight - Weight
- In Container Transport - TEU (Twenty foot Equivalent Unit) Position
- In RoRo Ship - Lane meter

For environmental calculations in the simulation model, conversion factors from “Guidelines for Company reporting on Greenhouse Gas Emissions” released by the Department for Environment Food and Rural Affairs (DEFRA 2005) were used. The NAEI (National Atmospheric Emission Inventory) has developed this information for the UK. The factors are given in the form of “per Kg unit of CO\textsubscript{2}”, released (see fig. 4).

When looking at the carbon footprint of a specific product it is important to consider the total carbon output from the product. This includes raw material extraction, manufacturing, distribution, retailing, consumption, disposal and recycling (Carbon Trust 2006). In many instances emissions from logistics make up a large part of total product emissions therefore this paper is focusing on reducing emissions in the logistics stage of the supply chain.

A company’s full carbon footprint covers 3 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, and 3) indirect emissions from products or services, (i.e. the sourcing of products and their eventual disposal or reuse). The Carbon Trust (2006) identifies two main reasons why a company would calculate its carbon footprint 1) To manage the footprint and reduce emissions over time; 2) To report the footprint accurately to a third party. A recent report on Carbon Footprinting (Carbon Trust 2007) highlights the following five steps for accurate calculation of a carbon footprint;

- Define the methodology – use consistent conversion factors, and a reliable method of calculation
- Specify the boundary and scope of the coverage – which and what emissions are included, how far up and down the supply chain to calculate
- Collect emissions data and calculate the footprint – accuracy relies on calculating the correct data
- Verify the results – verification from a third party to add credibility
- Disclose the footprint – make all the above information available for review.

Recent studies focusing on elimination of air emissions have shown that some lean techniques (i.e. CR, JIT) may not be the most environmentally conscious methods of manufacturing. By using CO\textsubscript{2} emissions as a Key Performance Indicator, Venkat and Wakeland (2006) analyse supply chains by emissions and categorises them as
being highly sensitive to the frequency and mode of delivery of goods. The type and amount of inventory stored at each company is also a factor though the main impediment to CO₂ minimisation is distance.

Static simulation studies carried out by Venkat have shown that by varying the order size at each point of the supply chain, the optimal order size at each stage (that minimises emissions), can be calculated. In short, Venkat claims that lean supply chains do not necessarily reduce CO₂ emissions, particularly when distances along the supply chain are significant, adding that larger deliveries at less frequent intervals all along the supply chain generally lead to the lowest emissions.

Measurements like the ones discussed help to identify areas of increased emissions in the supply chain. However the measurements are based on excel spreadsheet data and do not reflect the true dynamic nature of modern SC design. The tools discussed apply the basic methods needed to understand carbon management; however it is felt that they have limited applications in the type of study required.

3 Discrete Event Simulation in Supply Chain Analysis

The work in this paper is part of an on-going research project to evaluate the use of simulation as a decision support for designing environmentally sustainable supply chains. Globalisation has now made supply chains more complex, with material moving in smaller quantities more often over longer distances than ever before. This paper proposes DES to help decision makers evaluate and design supply chains in a more environmentally friendly fashion. DES permits 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 (Chang 2001).

The use of simulation tools can aid a human planner to make a right decision by providing quantifiable information. However, in order for the correct use of the tool, the human planner should be able to interpret and modify the plan in order to achieve better supply chain performances (Chang 2001). When studying a supply chain model and analysing the data requirements Chang highlights some of the questions the users might have:

- Which supplier policy is achieving best delivery performance under given demand pattern?
- Which supplier policy is most robust under demand fluctuation?
- Which is the most cost saving inventory policy under given demand pattern?
- How would profit be impacted by adding X% more capacity?
- What is the trade-off between delivery performance and inventory cost when building more inventory?

All of the above questions have the capacity to be addressed by an supply chain simulation model; however it is the addition of another four questions that forms the
basis of the environmental supply chain simulation model undertaken for this project. The questions are;

- What are the environmental and economic trade-offs in altering supply chain design?
- How is the carbon footprint of a supply chain altered by increasing or decreasing suppliers, and or focusing on supplier locations and delivery modes?
- How is the carbon output of a supply chain affected if there is a spike in demand, and how to find the best resultant action, environmentally?
- What is the optimum environmental supply chain design of interacting companies using different inventory policies economic order quantities and production systems etc?

4 Simulation Tool to Aid Environmental Decision Making

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 simulation model used in this research (see fig. 2) was developed around an existing model that was built to analyse the supply chains associated with outsourced electronics manufacturing (Liston et al. 2007). The advantage of using this model as a basis was that many of the operational details of a supply chain were already captured. The original model was primarily interested in the cost implications of real life supply chain constraints, some of which are explicitly specified in contractual agreements (e.g. minimum order quantities) between supply chain partners while others are inherent to manufacturing processes (e.g. production bottlenecks). Although logistical activities were included in this model, much greater detail was required to generate the necessary metrics for determining the environmental impact of the supply chain configuration. The new model has greater granularity in the logistical elements, with more refined cost structures and the ability to select alternative transport modes. By recording the distances and modes of simulated transport tasks and applying fuel conversion factors a carbon metric is established for the supply chain thus allowing for financial/environmental trade-offs to be analysed for various supply chain scenarios. The following points give an overview of the series of simulated activities.

1. Initial product demand 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 (see fig. 3).

2. The CM references this demand information against the bill of materials (BOM) data, corresponding raw material inventory levels, and open purchase orders. Where necessary, components are ordered from suppliers in order 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.

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 are used to calculate the carbon output for this shipping activity.

The mock SC used in this simulation experiment is an example of an assembled component used in a medical device. The component has seven independent parts supplied by the four suppliers mentioned below in figure 3. Once the parts arrive at the Manufacturer they are fabricated and shipped to the OEM. Also shown in figure 3, are the OEM, Manufacturer and Supplier variables used in the model. The interaction of overview points 1, 2 and 3 are also illustrated.

Figure 4 shows the Carbon Conversion factors mentioned in Section 2. The table for transport cost calculation is also shown. The transports costs were founded on a base call out price for a Van, Rigid Truck or Articulated Lorry, with an additional price
for each pallet used. The authors understand this may not reflect actual transport cost pricing, due to contract agreements held between companies however for purposes of the model it gives a standard for which to measure results. The outputs of the model are also shown of which the six metrics mentioned can be seen in figure 5.

![Figure 3: Supply Chain Node Variables](image)

![Figure 4: Logistical Variables and Model Output Metrics](image)

### 5 Simulation Model Results

Six Different experiments were used in the simulation model to get an understanding of the different logistical options a specific SC may have. The six different supply chain (SC) experiments breakdown as follows;

**Exp. 1** - SC uses postponed, JIT batch sizes, only transported by Van

**Exp. 2** - SC uses postponed, JIT batch sizes, only transported by Rigid Truck

**Exp. 3** - SC uses postponed, JIT batch sizes, only transported by Articulated Lorry

**Exp. 4** - SC uses batch sizes customised to max fill and only uses Van
Exp. 5 - SC uses batch sizes customised to max fill and only uses Rigid Truck
Exp. 6 - SC uses batch sizes customised to max fill and only uses Articulated Lorry

The six model outputs are presented in figure 5. In each model output the six experiments are presented along side one another in Box-Plot format. The Box-Plots are the results of 30 replications carried out in the simulation sequence. The Total Cost (TC) is of the manufacturers finished assembly sold to the OEM. The Logistics Costs (LC), Storage Costs (SC) and Carbon Output (Kg CO₂) are based on one individual assembly. The On-time delivery (OTD) and Vehicle Utilisation (VU) are a figure for the entire SC.

![Experiment Boxplots - COST](image)

![Experiment Boxplots - Logistics Cost](image)

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

![Experiment Boxplots - Storage Cost](image)

![Experiment Boxplots - Carbon](image)

![Experiment Boxplots - Vehicle Utilisation](image)

Figure 5: Simulation Model Results

### 5.1 Results Analysis

The results can be broken into 3 sections, (1) analysis of experiments 1, 2 and 3; (2) analysis of experiments 4, 5, and 6; (3) overall analysis. What becomes evident from the results of the first 3 experiments with JIT batch is that the OTD and SC are the same. The difference is in the LC (which correlates with the TC) and the Kg CO₂ per product outputted. In the first three experiments using an Articulated Lorry to transport the goods showed a lower cost and Kg CO₂ output per product closely followed by the Rigid Truck. Experiments 4, 5 and 6 followed much the same pattern with the Articulated Lorry again showing the best Kg CO₂ output and lowest cost. However the OTD of the goods for the articulated lorry showed an increase,
coupled with an obvious increase of storage costs due to using the larger vehicles. An interesting observation is the dramatic increase in VU when using the batch sizes which in the case of the Articulated Lorry, jumped from a mean of 58% to 89%.

6 Discussion and Conclusion

McKinnon used computer simulation in 1998 to look at the relationship between inventory centralisation and the scheduling of freight flows. His objective was to ascertain the transport cost levels at which firms would have an economic incentive to restructure their logistical systems or move to a more consolidated pattern of delivery. Conclusions from the simulation model at the time was that even in the case of products with a relatively low value density, transport costs would have to rise by over 100% to make it economically beneficial to move to a more decentralised structure (McKinnon 1998). McKinnon looked at the issue of globalisation and patterns of sourcing in companies again in 2003 where he states For most product groups, only a very steep increase in transport costs and/or transit times would be likely to offset these production cost differentials and promote a return to more localised sourcing, (McKinnon 2003). The authors suggest in the recent light of ever rising transport costs and environmental concerns, that DES may be a useful tool in adding to research in this area.

The simulation model described in this paper shows the ability of DES to capture the results of differing SCs while also highlighting areas for definite environmental improvement. The simulation model shows the ability of DES to easily correlate these reductions in CO2 emissions to possible economic savings making it an excellent tool for testing in the decision making SC planning process. The spreadsheet data used for the model variables (i.e. fig. 3) can give approximate values and even before using simulation, possible areas for environmental improvement may be visible. However, the use of DES captures the added dynamic supply chain effects and interactions, which help to display any potential trade offs Environmental verses Economic Costs. The future work in this project relates to further development of the model to account for backhauling, Kg CO2 of extra inventory in storage also additional transport options such as air and sea shipping.

References


