UNIVERSITY OF VAASA

FACULTY OF TECHNOLOGY

DEPARTMENT OF PRODUCTION

Yang Chen

A SIMULATION MODEL FOR MAPPING CARBON DIOXIDE EMISSIONS TO DEVELOP A GREEN LOGISTICS SYSTEM

Master's Thesis in

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I would like to thank Prof. Petri Helo and Mr. Harri Jaskari heartily for your priceless encouragement and mentorship for my study and career improvement.

And this thesis is also dedicated to my mother, Liping Ying, for her unconditional and ceaseless love.

Vaasa, March 2014

Yang Chen

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ABBREVIATIONS

CO2	Carbon Dioxide Emissions
CP	Payload Capacity
CU	Capacity Utilization
DE	Discrete Event
EC1	Environment Class 1
ECF	Final Energy Consumption Per Net Tonne Km For Each Energy Carrier
ECOTRANSIT	Ecological Transport Information Tool
ECT	Total Energy Consumption Of Transport
ECU	Upstream Energy Consumption For Each Energy Carrier
EMT	Total Emissions Of Transport
EMU	Upstream Emissions For Each Energy Carrier
EMV	Vehicle Emissions Consumption Per Net Tonne Km For Each Energy Carrier
ET	Empty Trip Factor
HGV	Heavy Goods Vehicle
LCV	Light Commercial Vehicle
LF	Load Factor
NOx	Nitrogen Oxides
OTD	On Time Delivery
PEC	Primary Energy Consumption
PM	Particulate Matter
SKU	Stock Keeping Unit
SOx	Sulfur Oxide
TEU	Twenty-Foot Equivalent Unit
WSC	Winter Simulation Conference
EPA	Environmental Protection Agency
MJ	Mega-joule
3PL	Third Part Logistics

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UNIVERSITY OF VAASA
Faculty of Technology

Author:	Yang Chen
Topic of the Thesis:	A Simulation Model for Mapping Carbon Dioxide Emissions to Develop a Green Logistics System
Supervisor:	Prof. Petri Halo
Department:	Department of Technology
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ABSTRACT:

The aim of this thesis is to develop a simulation tool that helps companies to track and re-evaluate the environmental impacts on their logistics systems. A discrete event based simulation model is used and developed in this thesis and it provides a simple and visible solution to map the carbon emission footprints and calculate carbon emission values throughout an outbound logistics distribution network. The total carbon emission level in a simplified logistics distribution system is primarily determined by the total transport distance and different emission factors which categorized by many other important parameters such as load factor, empty trip rate, batch size, vehicle type and fuel consumption rate and so on. By visualizing carbon emission footprints and understanding how the carbon emission values in different transport paths are accumulated in the whole distribution system, the developed simulation model helps supply chain and logistics planners to investigate their current logistics systems and identify improvement areas in their systems to lead a better and greener logistics design. Website-based simulation software is also purposed as future research recommendation for realistic industry use.

KEYWORDS: Carbon Emission, Simulation, Logistics Network Design, Distribution System, ExtendSim.

1. INTRODUCTION

This chapter provides background information why the research topic is increasingly important and how to build up a simulation model to solve these research problems and questions.

1.1. Background and Problem Discussion

Global warming, energy crises, soar of global population and environment deterioration gives significant warnings to every individual and industry. It is a chain reaction phenomenon that, in order to solve environmental issues and improve sustainability, these inevitable environment and sustainability issues have to be put on our agenda and to be solved urgently. The increased carbon dioxide (CO2) emission level in the atmosphere unsustainably released by burning of fossil fuels for energy extraction is primary cause for many environmental issues.

EU research indicates that passage and freight transportation takes for 20% of all European Greenhouse Gas Emissions. The proportion of transport emissions is constantly increasing and it would be more than 30% of total European emissions by 2020. Emissions from freight transport stands for nearly one third of total greenhouse emissions. 93-95% of Greenhouse emissions from transportation are accounted for by CO2 emissions. (Verkinden 2011: 2-3)

Although some efforts and actions were made by companies to improve the energy efficiency of freight transportation, these improvements are not sufficient to outweigh the soaring increase in emissions caused by enlarged transportation freight volumes due to the reason of the sturdy increase in global trade and the further enlarged EU.

To meet the targets of EU transport emission reduction for 2020 and beyond, the actions to reduce CO2 emissions from transport are received a lot of attention and it is expected to receive even more force in the future years. As a result, in order to reach these urgent and ambitious reduction targets of greenhouse emissions, most industries will have to design decarburization strategies of their logistics operations in the futruce. The chemical industry, accounting less than 10% of total transport emissions, has to utilize new approaches to reduce the environmental impact of its logistics operations as well, in close collaboration with its logistics service partners.

1.2. The Need for the Greener Logistics

Globalization is enlarging supply chain networks, thereby enlarging the transport world economy intensity. The total carbon emission emitted by each ton/km of freight transport also appears to be increasing in emission-intensive transport modes, especially in trucking and airfreight transport modes, which account a large percentage of the freight market. Redesigning and implementing feasible and low cost carbon mitigation strategies for the transportation and logistics sectors will therefore present most important challenges. (Mckinnon, 2010)

A traditional logistics system based on cost optimum does not necessarily equal an optimum solution for a "Green and sustainable logistics system", with huge fluctuation of oil prices and increasing pressures coming from environmental, energy crisis and new regulations, more and more companies start to research on "environmental costs" of their logistics systems to design a greener solution. The industry needs of minimal transport emission, more efficient distribution planning and environment-friendly supply chain system are becoming vital topics to all of supply chain designers and logistics planners.

The key research initiative in this thesis is to build up a simple and understandable simulation model to reveal visualize and map total CO2 emission footprints and calculates the emission values in an outbound logistics network. The simulation model primarily aims to help companies to access and evaluate the environmental impacts of their logistics systems to identify improvement areas which lead to a greener logistics network design.

2. THEORETICAL FRAMEWORK

This chapter aims to expose current challenges and environmental issues on the design of supply chain and logistics system. Why it is increasingly important to design and develop a “Green Logistics System” for enterprises and public sectors.

2.1. Finnish and Swedish Companies are Facing Challenges in Global Supply Chain and Logistics Network

It becomes obvious that the center of globe trade is shifting from Europe and North America to Asian countries, especially in manufacturing sector, many of European enterprises experience the same dilemma that when they tend to optimize their logistics networks by utilizing “sourcing locally” to achieve control, responsiveness and simplicity in their supply chain systems but it became unbearable to use very expensive raw materials and semi-finished items, how to balance cost efficiency and lead time generates significant pressure on supply chain and logistics planners. The critical factors in most of supply chain designs are related to transportation, warehousing costs and cost of the wasted time as a result of delays. The optimal solution has to be found by the choices between centralized and decentralized warehouse policies together with the right organization of transportation modes.

Although the global trade between Nordic countries and their Asian souring partners China, South Korea and India has been increased significantly, there are huge imbalances in the traffic flows between these countries as well as their transportation infrastructures. In order to bridge the gap and diminish the traffic flow imbalance, it is crucial to realize the characteristics of logistics system in Nordic countries such as Finland and Sweden and their supply chain partners and make the optimal resource allocation strategies. (Hilmola and Szekely, 2006)

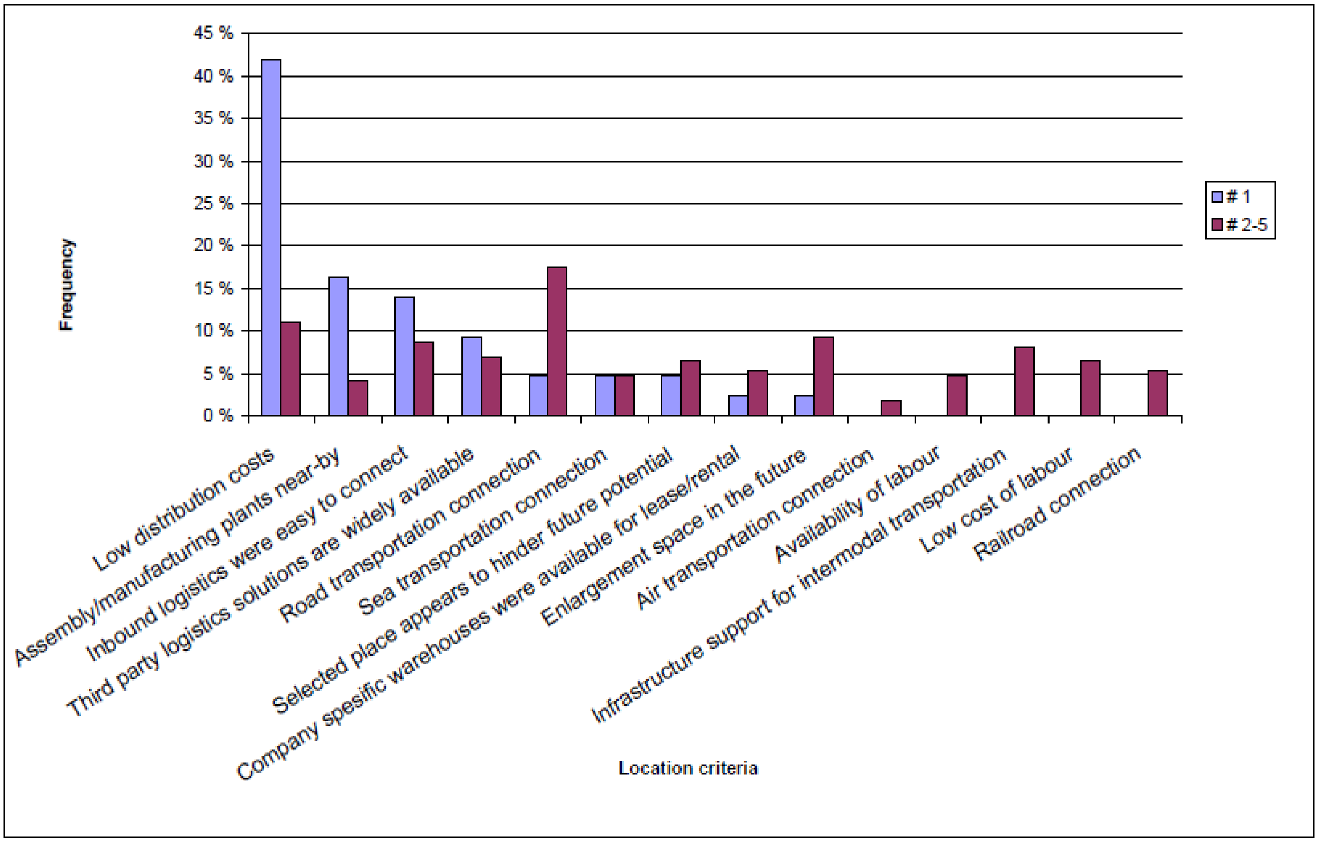


Figure 1. How Finnish and Swedish companies design their logistics networks in terms of determining location of distribution center, warehousing and transportation model in 2006 (n=43)

In the figure above, the blue column represents each individual factor as first priority factor in the decision making process of these selected enterprises and the red column represents the aggregated importance from 2 to 5 of a criteria in selecting location of the targeted enterprises. The figure indicates that that there are four most important decision making factors, they are low distribution costs, manufacturing and assembly plants should be nearby warehouse, inbound logistics is better to be connected and 3PL logistics solutions availability. In order to lower distribution cost, it is clear that the most important factor in enterprises' decision making process is how to locate their warehouses. The figure also indicates that road connection is far less important comparing to be the number one factor, buy when considering the aggregated indicator (red columns), it becomes most voted one. This indicates that enterprises do not only regard each individual transport as an independent entity but they want to optimize their whole distribution system to transportation costs. 3PL service providers become more and more popular currently to facilitate enterprises to achieve this goal.

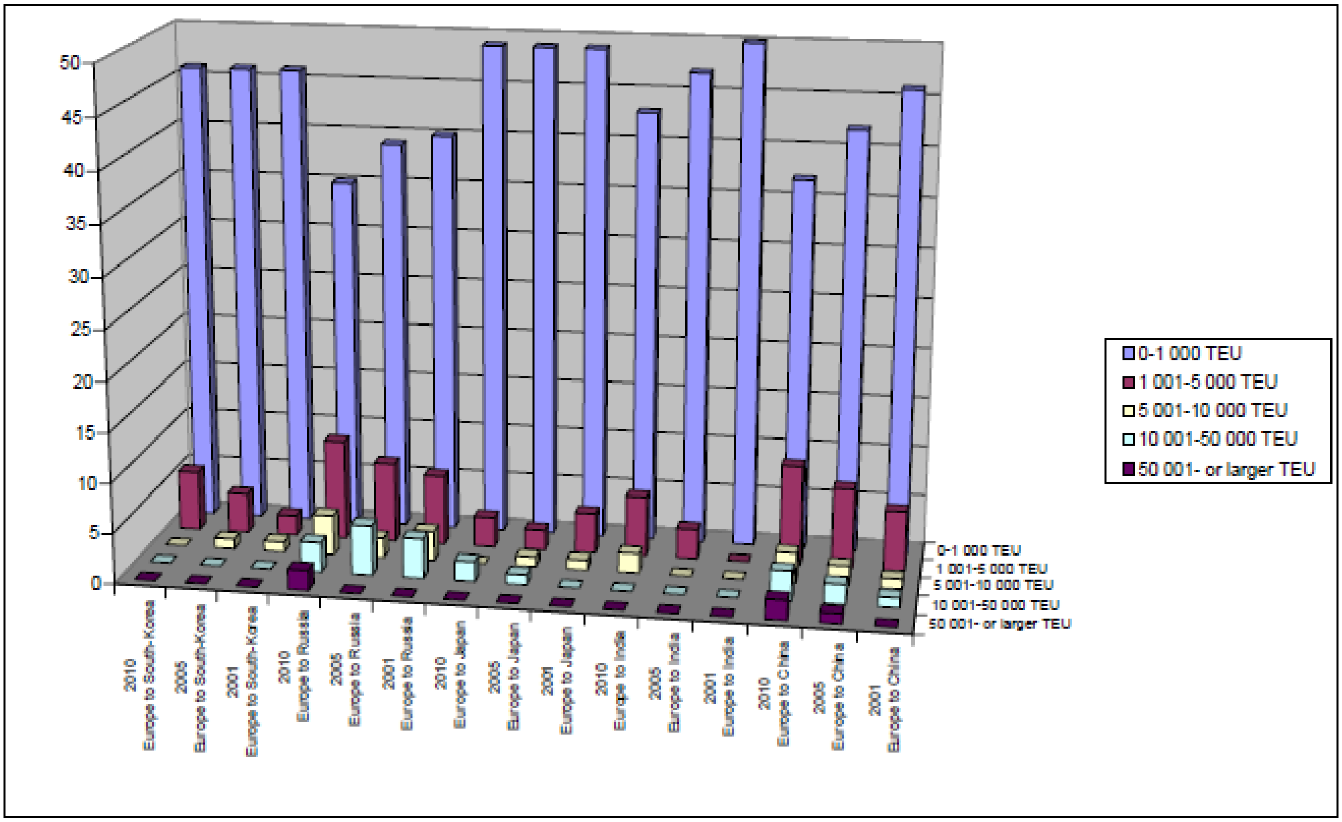


Figure 2. The traffic flows between five selected countries (South Korea, Russia, Japan, India and China) between Europe.

The figure above illustrates how traffic flows within the enterprises in selected five different countries and Europe as a whole. It appears that traffic flows between Europe and other five countries South Korea, Russia, Japan, India and China are going to be increasing significantly in following years. It is arguable that larger enterprises will increase their transportation volumes quite significantly, shifting to more than 50,000 containers annually in a five year period. It is showed exactly in cases of both Russia and China. However, in second traffic growth route, India and Europe, transportation volumes are increasing rapidly, but it is within a smaller scale. (Hilmola and Szekely, 2006)

2.2. How to Design a Logistics Network

Supply establishment, warehousing and distribution infrastructure are main elements to design a logistics network. It also includes procurement, inventory control policies, value-add and postponement activities. A well-designed logistics network aims to minimize logistics cost as well as to offer the great level of flexibility to secure service level requirements.

More and more legislation and consumers urged enterprises to re-design their logistic system in order to minimize negative impacts on environment. The goal in the logistic network design has changed from minimizing cost only, to minimizing cost and environmental impact both. (Peng, 2007)

2.2.1. Selecting a Suitable Distribution Network

Supply chain and logistics network designers need to evaluate product characters as well as network requirements when they design appropriate transportation system. Most enterprises are intended to have a combination of delivery networks. The different distribution modes have different strengths and weaknesses. From supply chain perspective, the suitability of different delivery networks in different distributing situations is shown in below table.

Table 1. The suitability of different delivery designs. (Chopra, 2003: 123-140)

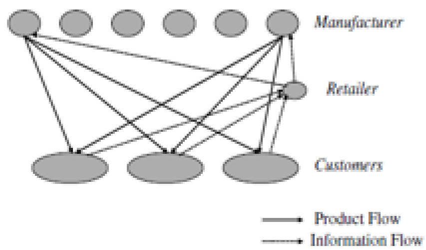
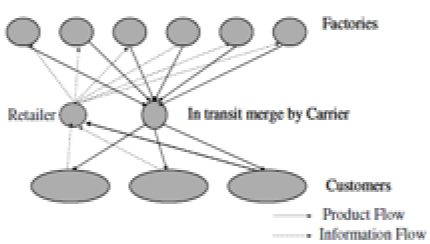
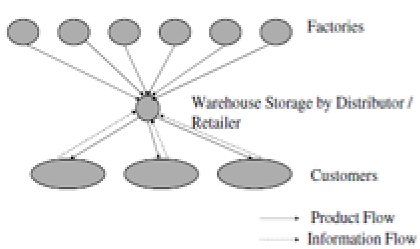
Performance of delivery networks for different product/customer characteristics

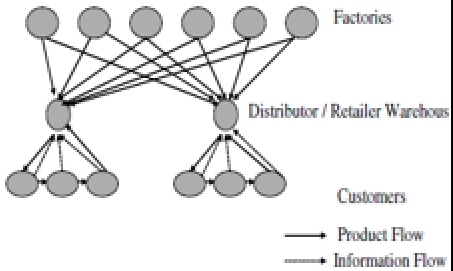
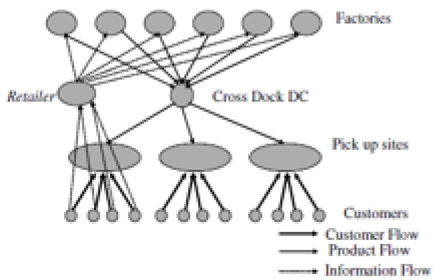
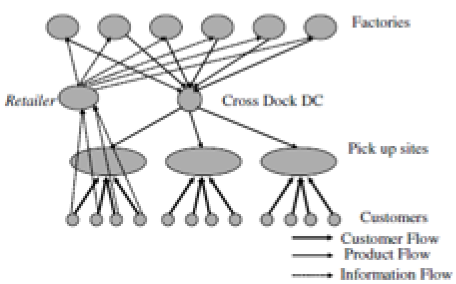
	Retail storage with customer pickup	Manufacturer storage with direct shipping	Manufacturer storage with in-transit merge	Distributor storage with package carrier delivery	Distributor storage with last mile delivery	Manufacturer storage with pickup
High demand product	++	−−	−	+−	+	−
Medium demand product	+	−	+−	+	+−	+−
Low demand product	−	+	+−	+	−	+
Very low demand product	−−	++	+	+−	−−	+
Many product sources	+	−	−	++	+	+−
High product value	−	++	+	+	+−	++
Quick desired response	++	−−	−−	−	+	−−
High product variety	−	++	+−	+	+−	++
Low customer effort	−−	+	++	++	++	−

++: Very suitable; +: somewhat suitable; +−: neutral; −: somewhat unsuitable; −−: very unsuitable.

For instance, emergency and fast-moving items are stocked in local inventory and the customers can either request the products shipped depending upon the urgency or pick them up directly. Slow-moving items can be storaged at a center distribution center from where they are able to be transported to the customers within two days. Very slow moving units are usually produced and shipped from the manufacturer and a longer lead-time is involved.

Table 2. The classification and comparison of six distinct distribution network designs.

	Distribution Network	Characteristics
1.	Manufacturer storage with direct shipping.  	• Product is shipped directly from the manufacturer to the end customer, by passing the retailer (who takes the order and initiates the delivery request). This option is also referred to as drop shipping. • All inventories are stored at the manufacturer. Information flows from the customer, via the retailer, to the manufacturer, while product is shipped directly from the manufacturer to customers
2.	Manufacturer storage with direct shipping and in-transit merge.  	• Unlike pure drop shipping where each product in the order is sent directly from each manufacturer to the end customer, in-transit merge combines pieces of the order coming from different locations so that the customer gets a single delivery. Information and product flows for the in-transit merge.
3.	Distributor storage with package carrier delivery  	• Under this option, inventory is not held by manufacturers at the factories but is held by distributors/retailers in intermediate warehouses and package carriers are used to transport products from the intermediate location to the final customer. Information and product flows when using distributor storage with delivery by a package carrier

4.	Distributor storage with last mile delivery  	• Last mile delivery refers to the distributor/retailer delivering the product to the customers' home instead of using a package carrier. Unlike package carrier delivery, last mile delivery requires the distributor warehouse to be much closer to the customer, increasing the number of warehouses required.
5.	Manufacturer/distributor storage with costumer pickup.  	• In this approach, inventory is stored at the manufacturer or distributor warehouse but customers place their orders online or on the phone and then come to designate pickup points to collect their orders. Orders are shipped from the storage site to the pickup points as needed. Distributor storage with delivery by a package carrier
6	Retail storage with customer pickup.  	• In this option, inventory is stored locally at retail stores. Customers either walk into the retail store or place an order online or on the phone, and pick it up at the retail store.

2.2.2. Cost Relations of a Distribution System

When planning and running a distribution operation it is important to be aware of key costs that are involved in the total distribution system, many enterprises utilize conventional accounting systems to track their cost information, but most of these cost information cannot be broke down to indicate any detailed segments into integrated parts which reflects their distribution structure.

A distribution network is operated in a fast-changing and unstable environment by its very nature. This makes a very difficult and complex process to plan of a distribution system. Due to cost interaction, any modifications to one of the critical cost elements in a distribution structure will affect the whole system. In order to overcome the problem, it is important to have a “global” vision to understand and measure the system as a whole. The figure below illustrates how total distribution cost is composed by the individual distribution cost elements.

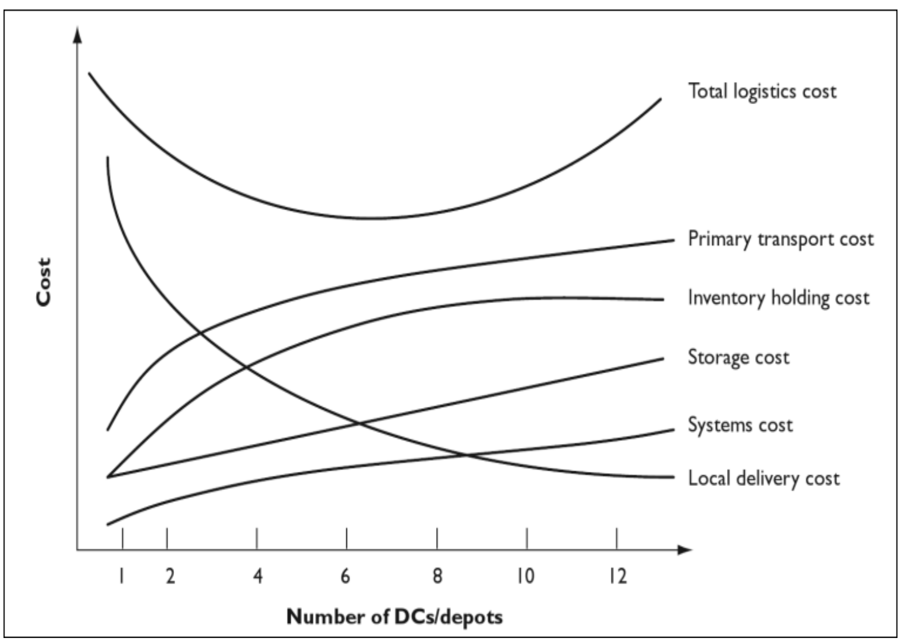


Figure 3. The relationship between total cost and number of distribution centers.

The figure above illustrates the impact of a number of different deports and the corresponded costs on the total distribution costs. The constituent cost elements that comprise the total, in this case, the lowest solution is at the minimum point on the total cost curve, somewhere between six and eight deposit. (Rushton and Croucher et al., 2010).

2.2.3. Oil Price Volatility Impacts on Logistics Network

Since the 1990s, many enterprises intended to minimize operational costs and develop a lean supply chain by the off-shoring, outsourcing manufacturing, rationing plants, and consolidating facilities. (David Simchi-Levi, 2010). The reason behind this tendency was cheap oil price. In some industries, transportation costs do not account for large percentage of total operational costs. Hence, the focuses were giving to reducing manufacturing costs through outsourcing, off-shoring, and rationalizing plants to take advantage of economies of scale in production expense and reduce capital investment, as well as consolidating warehouses and distribution centres to reduce fixed facility costs and inventory levels.

The increasing oil price has fundamentally reversed this tendency, when the crude oil prices increases, distribution cost becomes more important relative to inventory, production, and facility fixed costs. Three are four main trade-offs emerged. (David Simchi-Levi, 2010)

1) Regional distribution centres are more utilized

As oil price increases, the outbound distribution cost becomes more expensive, it is critical to minimize the distance of the final transport – from distribution centres to retail outlets. This can be accomplished by adopting more warehouses with the each in charge of a specific region. However more warehouses generates more safety stocks, higher inventory level regarding more costs. Higher transportation costs will force companies to ship larger quantities of cargos to take advantage of economies of scale, however it means bigger warehouses will be needed.

2) Production and sourcing are moving closer to demand

As off-shoring (cheaper manufacturing costs) are offset by increased transportation costs, more and more manufacturing and souring activities has trend to move to near-shoring. The total landed cost concludes production costs, inventory and handing costs, transportation costs, duty and taxation costs, as well as finance costs. Landed cost indicates the effective cost of manufacturing or sourcing in one location and serving customers in different locations and it is used when making manufacturing and sourcing decisions. Consequently, as total transportation cost increases, the role of production and sourcing costs in total landed cost diminishes.

3) Organizations will focus more on supply chain flexibility.

In volatility of oil price, it becomes crucial to satisfy demand from the closest manufacturing site. However, it is not feasible if each production site specializes in manufacturing just a few products, dedicated manufacturing is a known production strategy (a design of no flexible logistics network). The dedicated manufacturing environment decreases producing costs because economies of scale come and very fewer set-ups are needed to switch producing different products. Tactlessly, dedicated manufacturing strategy gives result in long delivery cycle to market demand and hence increases transportation costs. By contrast, a fill flexibility manufacturing strategy, where each production site is able to manufacture all products, although production costs increased (due to frequent set-ups and smaller lot-sizes), it reduces transportation costs. This is a clear implication that the higher oil price, the more important it is to utilize flexible manufacturing strategy because it decreases transportation costs.

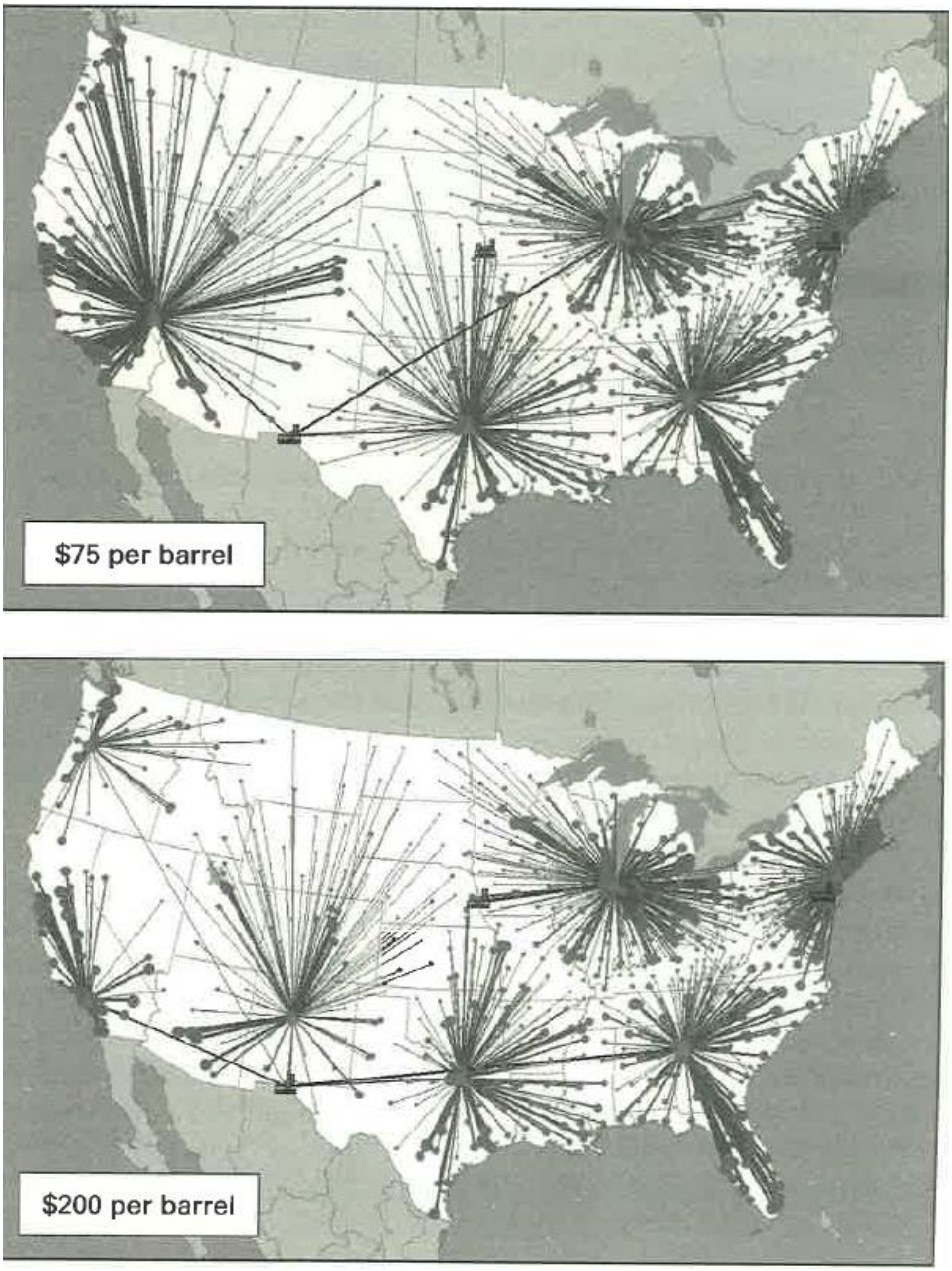


Figure 4. Reducing transportation costs by increasing the number of regional distribution centers. (David Simchi-Levi, 2010)

The figure above demonstrates how increasing the number of regional distribution centers has reduced transportation costs. As cost per barrel rise from $75 to $200, the optimal number of DCs increases from five to seven.

4) Oil price volatility impacts on transportation strategies

Cheap oil price is foundation of many current transportation strategies, such as quick and frequent shipments, just-in-time delivery, and using mixed fleet types. For instance, the transportation strategy of frequent deliveries was aimed to reduce inventory levels by increasing the frequency of deliveries in order to reduce lead-time and increase service level. However, since 2008, oil price was largely increased, distribution becomes far more expensive than inventory. As a result, three important trends are emerged:

Efficient packaging is used to improve truckload utilization and larger lot sizes are shipped with less frequency. Just-in-time strategy has been switched to better utilization of transportation capacity.

Switching trucking to rail to cut fuel consumption ad moving shipment from air to ground fleet to reduce cost. Fast delivery strategy has been changed to cheaper and sometimes slower transportation modes.

Adopting more third party logistics carriers and increasing quantities of consolidated warehouses. Third party logistics can batch shipments from many vendors and fulfil full truckload shipments rather than less than full truckloads to decrease transportation costs. Correspondently, more consolidated warehouses enlarge order quantities into full truckload transportation to decrease total transportation costs.

2.3. The Need of Greener Logistics

In addition to oil price volatility and global warming, the recent global economy crisis has accelerated the needs to grow a sustainable economy where better usage of natural resources becomes critical. Societies and governments become more aware of business operations impacting on natural environment and resources. It urges all industries and companies to take responsibilities to react to challenges of green issues by developing more sustainable (or green) logistics and supply chain management solutions.

Due to large percentage of greenhouse emissions are generated by transport and logistics related activities. At a macro level, transport and distribution companies (3PLs) takes more important roles in responding the challenges of developing more environmentally sustainable strategies in their logistics systems.

2.3.1. Environment Impacts by Transportation

Transportation accounts for the highest cost element among all logistics activities. It consists almost 65% of the total operation costs (Stock et al., 2006). The main reason behind is that globalized economy has increased the distances between the resources and the consumptions time by time. It is also impacted by the increased product demands, as well as sourcing from low-cost manufacturing countries in far-East.

Transportation has serious impacts on the environment. Life Cycle Analysis (LCA) has primarily analyzed these impacts. All possible environmental impacts has been outlined in extensive investigation. (Borken and Patyk et al., 1999). The environmental impacts have been categorized below:

1. Resource consumption
2. Land use
3. Greenhouse effect
4. Depletion of the ozone layer
5. Acidification
6. Eutrophication
7. Eco-toxicity (toxic effects on ecosystems)
8. Human toxicity (toxic effects on humans)
9. Summer smog
10. Noise

According to "Eurostat 2003", transportation operations has consumed approximately 33% of total energy consumption in the Europe in 2001, this rate is equal to 910 million tons of CO2. Comparing these numbers with those from 1991, it indicates that carbon emission has been increased by 22% whilst almost half of energy consumption generated by fossil fuels in Europe in 2001. (Eurostat Yearly Energy Statistics, 2003)

Transportation has been increasingly generating substantial amounts of contaminants. These contaminants are CO2 gases, HC, NOX, and additionally CO and SO2 gases, which are generated by various sources. All these emissions have huge detrimental impacts on the environment.

Table 3. Environmental and human health impacts by toxic emissions

Abbr.	Description	Reasons for inclusion
PEC	Primary energy consumption	Main indicator for resource consumption
CO_2	Carbon dioxide emissions	Main indicator for greenhouse effect
CO_2e	Greenhouse gas emissions as CO_2-equivalent. CO_2e is calculated as follows (mass weighted): $CO_2e = CO_2 + 25 * CH_4 + 298 * N_2O$ CH_4: Methane N_2O: Nitrous Oxide For aircraft transport the additional impact of flights in high distances can optionally be included (based on RFI factor)	Greenhouse effect
NOx	Nitrogen oxide emissions	Acidification, eutrophication, eco-toxicity, human toxicity, summer smog
SO_2	Sulphur dioxide emissions	Acidification, eco-toxicity, human toxicity
NMHC	Non-methane hydro carbons	Human toxicity, summer smog
Particles	Exhaust particulate matter from vehicles and from energy production and provision (power plants, refineries, sea transport of primary energy carriers), in EcoTransIT World particles are quantified as PM 10	Human toxicity, summer smog

In most cases, fuel consumption are related to direct proportion of carbon emissions but it is additionally impacted by outside environments (wind, temperature etc.). Negative effects of contaminants generated by transportation can be reflected into costs. However only very few countries have applied environmental costs to their regulations and policies. (Eriksen, 2000: 9-25).

2.4. Mapping the Carbon Footprint

Assumptions, basic definitions, and calculation rules of freight transport are given in this sub-chapter. What are common rules in all transport modes and what are the basic differences between these transport modes will be focused. The equations and special rules for each transport mode are defined and explained in details.

2.4.1. Emission Calculation Methodology

The Ecological Transport Information Tool (EcoTransIT) is an internet-based programming tool to compare the environmental impacts generated by different transport modes. The methodology was developed by IFEU (Institut für Energie- und Umweltforschung) with collaboration of different transportation companies. EcoTransIT tool is able to calculate the carbon emissions by defining and inputting different types of vehicles and cargos. For each transportation model, it is possible to set up the empty trip factor and load factor. Base on transportation industry data statistic. EcoTransIT tool has defined average values which are used in the calculations. The EcoTransIT tool is also integrated with a routing planner which enables inputting departure and arrival locations (EcoTransIT, 2008).

1) Main factors and impacts on energy consumption and emissions of road transport

Each transport mode has their own specific physical properties and conditions. The energy consumption and emissions of freight transport depends on various factors. The blow factors specifies the importance:

- Vehicle type, weight, transmission, pay-load capacity, motor size.
- Cargo specification: mass, volume, pallets, container.
- Capacity utilization: empty trips and load factor.
- Driving conditions: speed, air/water resistance, number of stops.
- Total transport distance and weight of vehicle.
- Traffic route: road category, rail or waterway class, curves, gradient, flight distance.

2) Parameters for the carbon emission calculation

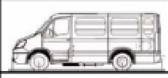
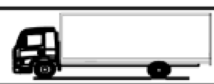
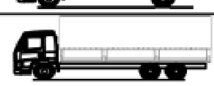
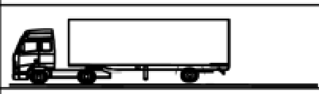
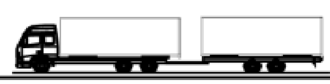
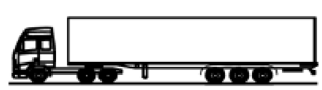
“Vehicle size, payload capacity and capacity utilization are the most important parameters for the environmental impact of freight transports, which quantify the relationship between the freight transported and the vehicles/vessels used for the transport”. (Van de Reyd and Wouters, 2005)

Vehicle size: classification of truck types

The long distance transportation is typically completed by utilizing trains and trucks. Normally, there is a limitation of the maximum gross weight of any trucks in tons, e.g., 60 tons in Sweden and Finland, 40 tons in most European countries and 80,000lbs in the USA on highways. In EcoTransIT mothodology, for cargo transport the classes of gross weight for all vehicle sizes are illustrated as follows:

Table 4. The report of truck size categories. (EcoTransIT, 2008)

EU/Japan	US EPA
Truck <=7.5t	Truck <=16,000lbs
Truck >7.5-12t	Truck >16,000-26,000lbs
Truck >12-24t	Truck >26,000-60,000lbs
Truck >24-40t	Truck >60,000-80,000lbs
Truck >40-60t	Truck >80,000lbs

No	Illustration	NTM Nomenclature	ARTEMIS Nomenclature
1	(no picture)	(LCV) Pick-up	LCV Petrol N1-II / LCV Diesel N1-II
2		(LCV) Van	LCV Petrol N1-III / LCV Diesel N1-III
3		(HGV) Small lorry/truck	RT <=7,5t
4		(HGV) Medium lorry/truck	RT >7,5-12t + >12-14t
5		(HGV) Large lorry/truck	RT >14-20t + >20-26t
6		(HGV) Tractor + 'city-trailer'	TT/AT >14-20 + >20-28
7		(HGV) Lorry/truck + trailer	TT/AT >28-34 + >34-40
8		(HGV) Tractor + semi-trailer	TT/AT >28-34 + >34-40
9		(HGV) Tractor + MEGA-trailer	TT/AT >40-50t
10		(HGV) Lorry/truck + trailer or semi-trailer on dolly	TT/AT >50-60t

Except the vehicle sizes, the vehicle emission standard is another important factor for the vehicle emissions. In EU transport, there are five different standards (EURO 1-EURO 5). The Pre-EURO 1-standard is expired for long distance transportation, hence it is not included.

The EU emission standard is also applied in many countries globally for the purpose of developing emission legislations. There are also other standards, such as US EPA (US Environmental Protection Agency) emission regulations and the Japanese emission standards. The blow tables illustrates what emission standards are utilized in EcoTransIT tool.

Table 5. Five emission standards. (EcoTransIT, 2008)

EU	EPA	Japan
Euro-I (1992)	EPA 1994	JP 1994
Euro-II (1996)	EPA 1998	JP 1997
Euro-III (2000)	EPA 2004	JP 2003
Euro-IV (2005)	EPA 2007	JP 2005
Euro-V (2008)	EPA 2010	JP 2009

In order to obtain correct carbon dioxide emission data, the information of how many grams emitted from each liter of fuel is needed. In the table below, the carbon emission for various types of fuel is stated. Note that Environment Class 1 (EC1) is considered to be domestic standard for Sweden. (Swedish Petroleum Institute, 2011)

Table 6. Emission values for most common HGV fuels57

FUEL DATA		**Diesel EC1**	**Diesel**	**Petrol EC1**	**Petrol**
		Sweden 5%Fame	Europe Low sulphur	Sweden 5% ethanol	Europe
Calorific Value	[MJ/l]	35,3	35,8	32,2	32,8
Energy content	[MJ/l]	0	0	1,1	0
Energy content	[MJ/l]	35,3	35,8	31,1	32,8
CO2 Total	[kg/l]	2,54	2,62	2,32	2,34

Payload capacity: carrying capacity of a launch vehicle, usually measured in terms of weight. The payload of a vehicle may include cargo, passenger, instrument or equipment, extra fuel, and so on.

Payload capacity is defined as mass related parameter:

$$\text{Payload Capacity [tons]} = \text{Maximum mass of freight allowed} \quad (1)$$

Capacity of marine vessels is defined as number of TEU:

$$\text{TEU capacity [TEU]} = \text{Maximum number of containers allowed in TEU} \quad (2)$$

Conditions for payload capacity determinations are different to each transport mode, as indicated in the following factors

The tuck payload capacity is determined by the maximum vehicle weight allowed. Therefore the payload capacity is the difference between empty weight of vehicle and maximum vehicle weight allowed (including driver, equipment, fuel, etc.). (Keller 2010). There are five total weight classes in truck category. The average value of each truck for payload capacity and empty weight and is showed in below table.

Table 7. Payload capacity and empty weight of selected transport vehicles.

Truck type	Unit	Full 100%	Average 50%	Empty 0%
Fuel Economy Energy Emission consumption				
Truck <= 7.5t	l /100km	14,4	13,7	13,0
Truck > 7.5-12t	l/100km	20,0	18,5	16,9
Truck > 12-24t	l/100km	23,5	21,5	19,3
Truck > 24-40t	l/100km	37,1	30,2	22,7
Truck > 40-60t	l/100km	52,3	40,4	27,1
Truck <= 7.5t	MJ/km	5,2	4,9	4,6
Truck > 7.5-12t	MJ/km	7,2	6,6	6,0
Truck > 12-24t	MJ/km	8,4	7,7	6,9
Truck > 24-40t	MJ/km	13,3	10,8	8,1
Truck > 40-60t	MJ/km	18,7	14,4	9,7
Truck <= 7.5t	g/km	120	114	108
Truck > 7.5-12t	g/km	167	154	140
Truck > 12-24t	g/km	196	179	161
Truck > 24-40t	g/km	309	251	189
Truck > 40-60t	g/km	435	336	226
CO2				
Truck <= 7.5t	g/km	381	363	344
Truck > 7.5-12t	g/km	530	490	446
Truck > 12-24t	g/km	623	569	512
Truck > 24-40t	g/km	982	799	601
Truck > 40-60t	g/km	1'384	1'068	718
NOx				
Truck <= 7.5t	g/km	0.82	0.75	0.71
Truck > 7.5-12t	g/km	1.19	1.15	1.14
Truck > 12-24t	g/km	1.49	1.61	1.61
Truck > 24-40t	g/km	2.26	1.90	2.08
Truck > 40-60t	g/km	3.08	2.44	2.30
PM				
Truck <= 7.5t	mg/km	7.31	7.25	7.04
Truck > 7.5-12t	mg/km	11.8	11.1	10.5
Truck > 12-24t	mg/km	15.1	14.8	13.6
Truck > 24-40t	mg/km	22.1	19.4	16.0
Truck > 40-60t	mg/km	30.6	25.7	19.1
Remarks: Trucks Euro V, average motorway (including gradient); technology mix: 25% EGR, 75% SCR				

Capacity utilization: this factor is defined as the ratio between payload capacity and freight mass transported (including empty trips).

The below formula illustrates the definition of capacity utilization:

$$CU_{NC} = LF_{NC} / (1+ET) \quad (3)$$

Table 8. Capacity utilization elements

Abbr.	Definition/Formula	Unit
CU_{NC}	Capacity utilization	[%]
CP	Payload capacity	[tonne]
LF_{NC}	Load Factor: mass of weight / payload capacity LF_{NC} = M / CP	[net tons/tonne capacity]; [%]
ET	Empty trip factor: Additional distance the vehicle runs empty related to loaded distance allocated to the transport. ET = Distance empty / Distance loaded	[km empty/km loaded], [%]

The table below shows load factors and default values of capacity for different truck lorry categories. (Halder and Eickmann, 2003).

Table 9. Default values of capacity and load factors for different truck lorry types.

	Lorry < 7,5 gross tons	Lorry or train 7,5 - 28 gross tons	Truck train or articulated truck 28 - 40 gross tons	Truck train 40 - 60 gross tons (Sweden and Finland)
Capacity (tons)	3.5	12	26	38
Load Factor (freight weight/capacity)	Freight weight (tons)			
10%	0.35	1.2	2.6	3.8
30% (volume freight)	1.1	3.6	7.8	11.4
50%	1.75	6.0	13	19
58% (average freight)	2.0	7.0	15	22
100% (bulk freight)	3.5	12	26	38

2.4.2. Basic Energy Consumption and Emission Calculation Rules

The emissions of each transport mode and total energy consumption are calculated for the upstream process and vehicle usage (efforts for manufacturing and transport of final energy carriers), therefore there are several important calculation steps:

- Final energy consumption.
- Combustion related vehicle emissions.
- Energy related vehicle emissions.
- Emission factors and energy consumption for upstream process per net ton-km
- Total energy consumption and total emissions per transport

The following context illustrates the basic calculation rules for each step. For each transport mode, there are slight difference in the calculation methodology. (Halder and Eickmann, 2008)

1) Final energy consumption per net ton-km

The principal calculation rule is:

$$ECF_{tkm,i} = ECF_{km,i,} / (CP * CU) \quad (4)$$

Abbr.	Definition	Unit
$ECF_{tkm,i}$	Final energy consumption per net ton km for each carrier i	[MJ/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HFO)	
$ECF_{km,i,}$	Final energy consumption of vehicle or vessel per km; normally depends on mass related capacity utilization	[MJ/km]
CP	Payload capacity	[ton]
CU	Capacity utilization	[%]

Explanations:

• Final energy consumption is the most important factor to calculate total emissions of a transportation system. Final energy consumption has to be distinguished for each energy carrier because upstream energy consumption and different inputs of emission factors are needed and utilized for each energy carrier.

• Final energy consumption is determined by different factors. Especially, it should be emphasized that final energy consumption per kilometer for vehicles also depended by capacity utilization and therefore the determiner of the formula.

• The formula signifies to a common case about truck fleets in final energy consumption per truck km. For other transport modes, the calculation methodology is different. However, all methods have the same relevant parameters, such as payload capacity, capacity utilization and final energy consumption of vessel/vehicle is needed.

2) Combustion related emissions per net ton-km

Combustion related emission calculation rule is the principal calculation rule for tracking NOx, NMHC, particles, CH_4 and N_2O emissions, it is showed in the below equation:

$$EMV_{tkm,i} = EMV_{km,i,} / (CP * CU) \quad (5)$$

Abbr.	Definition	Unit
$EMV_{tkm,i}$	Vehicle emissions consumption per net ton km for each energy carrier i	[g/tkm]
I	Index for energy carrier (e.g. diesel, electricity, HFO)	
$EMV_{km,i,}$	Combustion related vehicle emission factor of vehicle or vessel per km; normally depends on mass related capacity utilization	[g/km]
CP	Payload capacity	[ton]
CU	Capacity utilization	[%]

Explanations:

• The formula is utilized for the vessel/truck emissions of aircraft and vehicle operations.

• For factors of ship and rail combustion related emissions, they are differentiated from emissions per engine work, not per vehicle-km. Therefore they are categorized as energy related emission factors.

3) Energy related emissions per net ton-km

The principle calculation rule for the energy related vehicle emissions is:

$$EMV_{tkm,i} = ECF_{tkm,i}, * EMV_{EC,i} \quad (5)$$

Abbr.	Definition	Unit
$EMV_{tkm,i}$	Vehicle emissions per net tonne km for each energy carrier i	[g/tkm]
i	Index for energy carrier(e.g. diesel, electricity, HFO)	
$ECF_{tkm,i}$	Final energy consumption per net tonne km for each energy carrier i	[MJ/tkm]
$EMV_{EC,i}$	Energy related vehicle emission factor for each energy carrier i	[g/MJ]

Explanations:

• This formula is utilized for all emission elements which are directly related to final energy consumption (CO_2 and SO_2) and for combustion related emissions of trains and ships.

4) Upstream energy consumption and emissions per net ton-km

For the calculation of vehicle emissions, the principle rule is:

$$\mathbf{EMU}_{tkm,i} = \mathbf{ECF}_{tkm,i}, * \mathbf{EMU}_{EC,I}$$

$$\mathbf{ECU}_{tkm,i} = \mathbf{ECF}_{tkm,i}, * \mathbf{ECU}_{EC,i} \quad (6)$$

Abbr.	Definition	Unit
$EMU_{tkm,i}$	Upstream emissions for each energy carrier i	[g/tkm]
$ECU_{tkm,i}$	Upstream energy consumption for each energy carrier i	[MJ/tkm]
i	Index for energy carrier(e.g. diesel, electricity, HS)	
$ECF_{tkm,i}$	Final energy consumption per net tonne km for each energy carrier i	[MJ/tkm]
$EMU_{EC,i}$	Energy related upstream emission factor for each energy carrier i	[g/MJ]
$ECU_{EC,i}$	Energy related upstream energy consumption for each energy carrier i	[MJ/MJ]

Explanations:

• Equations for upstream energy consumption and emissions have different units.

• Equations can be applied for all transport modes.

5) Total energy consumption and emissions of transport

The principal rule for the calculation of vehicle emissions is:

$$\mathbf{EMT}_i = \mathbf{D_i} * \mathbf{M} * (\mathbf{EMV}_{tkm,i} + \mathbf{EMU}_{tkm,i})$$

$$\mathbf{ECT}_i = \mathbf{D_i} * \mathbf{M} * (\mathbf{ECF}_{tkm,i} + \mathbf{ECU}_{tkm,i}) \quad (7)$$

Abbr.	Definition	Unit
EMT_i	Total emissions of transport	[kg]
ECT_i	Total energy consumption of transport	[MJ]
D_i	Distance of transport performed for each energy carrier i	[km]
M	Mass of freight transported	[net tonne]
$EMV_{tkm,i}$	Vehicle emissions for each energy carrier i	[g/tkm]
$ECF_{tkm,i}$	Final energy consumption for each energy carrier i	[MJ/tkm]
$EMU_{tkm,i}$	Upstream emissions for each energy carrier i	[g/tkm]
$ECU_{tkm,i}$	Upstream energy consumption for each energy carrier i	[MJ/tkm]
i	Index for energy carrier (e.g. diesel, electricity, HS)	

Explanations:

• Transport distance plays crucial role in routing algorithm.

• Routing determines energy consumption and emissions (e.g. gradient, road categories and trafic, distance for airplanes).

6) Assumptions about empty run and vehicle loading factors

The values of average carbon emissions are very sensitive to vehicle empty run and loading capacity factors. The below figure indicates how the emission factors for the cargo transportation in a 44-ton truck have a negative exponential correlation with payload weight. The data are collected in the vehicle trials for the UK movement to measure the effects of payload capacity on the truck fuel efficiency by M.Coyle (2007). Over the payload weight of 1-10 tons the figure shows a significant decrease in the carbon emission factor.

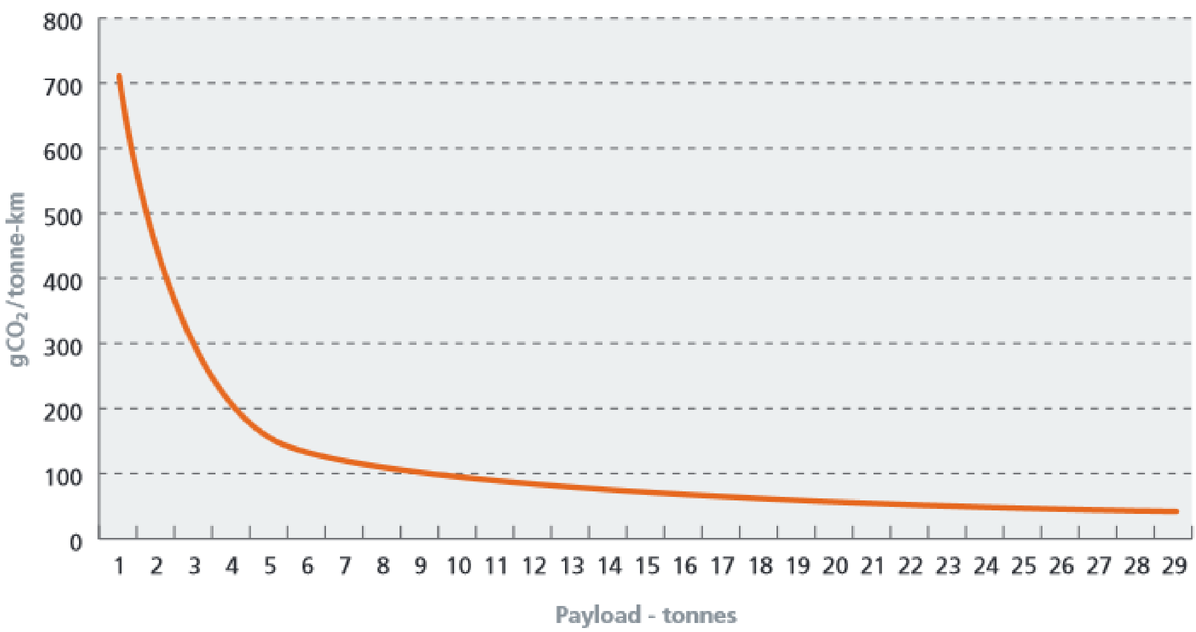


Figure 5. The correlation between truckload in tones and carbon emission factor (full range)

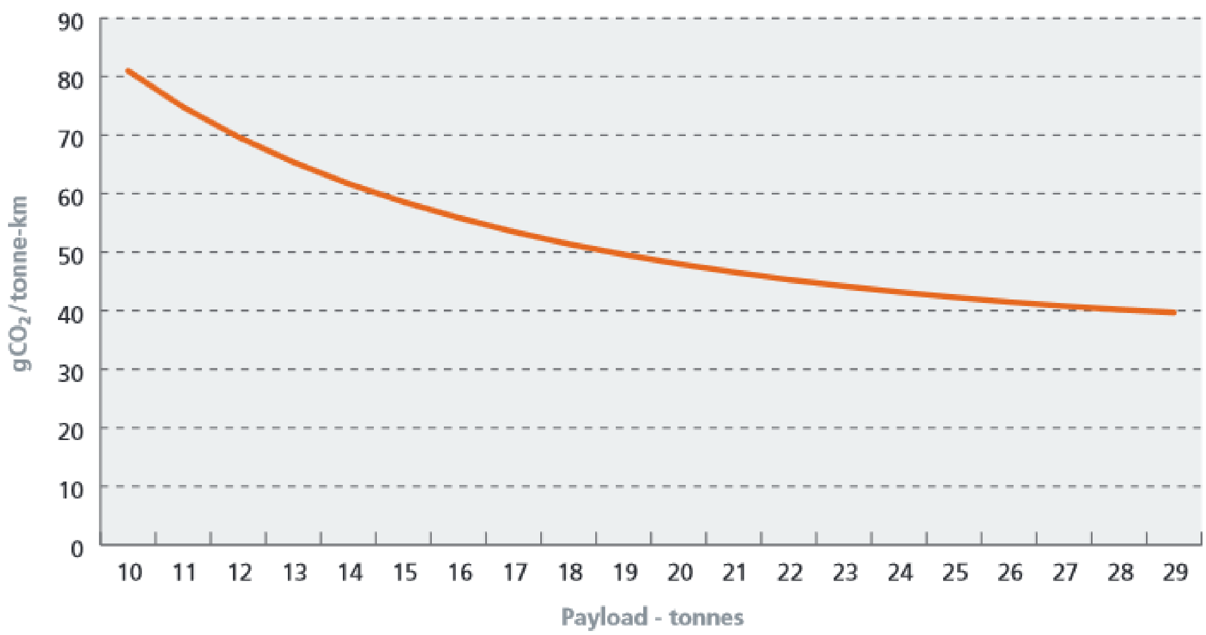


Figure 6. The correlation between truckload and carbon emission factor. (10-29 tons)

The Figure above indicates the small changes in payload will have a significant impact on the emission factor. For instance, if the payload weight is changed from 20 to 26 tons, carbon emission factor will drop from 48 to 41.5 gCO2 per ton-km. no empty running of the truck is made in this calculation.

Table 10. How levels of empty running impacts on the emission calculation factors

Payload / tons	% of truck-kms run empty										
	0 %	**5 %**	**10 %**	**15 %**	**20 %**	**25 %**	**30 %**	**35 %**	**40 %**	**45 %**	**50 %**
10	81.0	84.7	88.8	93.4	98.5	104.4	111.1	118.8	127.8	138.4	151.1
11	74.8	78.2	81.9	86.1	90.8	96.1	102.1	109.1	117.3	127.0	138.6
12	69.7	72.8	76.2	80.0	84.3	89.2	94.7	101.1	108.6	117.5	128.1
13	65.4	68.2	71.4	74.9	78.9	83.4	88.5	94.4	101.3	109.5	119.3
14	61.7	64.4	67.3	70.6	74.2	78.4	83.2	88.7	95.1	102.7	111.8
15	58.6	61.0	63.8	66.8	70.3	74.2	78.6	83.7	89.7	96.8	105.3
16	55.9	58.2	60.7	63.6	66.8	70.5	74.6	79.5	85.1	91.7	99.7
17	53.5	55.7	58.1	60.8	63.8	67.2	71.2	75.7	81.0	87.2	94.7
18	51.4	53.5	55.8	58.3	61.2	64.4	68.1	72.4	77.4	83.3	90.4
19	49.6	51.5	53.7	56.1	58.8	61.9	65.4	69.5	74.2	79.8	86.5
20	48.0	49.8	51.9	54.2	56.8	59.7	63.0	66.9	71.4	76.7	83.0
21	46.6	48.3	50.3	52.5	54.9	57.7	60.9	64.5	68.8	73.9	80.0
22	45.3	47.0	48.8	50.9	53.3	55.9	59.0	62.5	66.5	71.4	77.2
23	44.2	45.8	47.6	49.6	51.8	54.3	57.2	60.6	64.5	69.1	74.7
24	43.2	44.7	46.4	48.3	50.5	52.9	55.7	58.9	62.7	67.1	72.4
25	42.3	43.8	45.4	47.3	49.3	51.7	54.3	57.4	61.0	65.2	70.3
26	41.5	42.9	44.5	46.3	48.3	50.5	53.1	56.0	59.5	63.6	68.5
27	40.8	42.2	43.7	45.4	47.3	49.5	52.0	54.8	58.1	62.1	66.8
28	40.2	41.5	43.0	44.6	46.5	48.6	51.0	53.7	56.9	60.7	65.3
29	39.7	41.0	42.4	44.0	45.7	47.8	50.1	52.7	55.8	59.5	63.9

Furthermore, the table above provides an extra dimension to the emission calculation, which ilustratess how changing levels of empty running will affect and determine the emission factors. For a chosen payload on the transport journey, the percentage of empty running will have a significant impact on the emission factors. For instance, for an average payload tuck of 27 tons, the emission factor differs from 40.8 gCO2 per ton-km with no empty running factor to 54.8 gCO2 per ton-km while 35% of the transportation distance are run empty. (Mckinnon and Piecyk, 2011).

3. SIMULATION METHODOLOGY

One of the key initiatives to develop and utilize the simulation model is to provide simplicity for users in easily accessing and driving the transport emission calculations for their logistics systems. In order to achieve this specific goal, the thesis study is focused on developing realistic and practical simulation models to reveal and map the emission footprint of a distribution network rather than to give the impractical hypothesis of improvements to decision-makers.

In this chapter, a thorough explanation of the methodology in the study is provided. The main methodology involves simulation modeling, identifying the system requirements and the necessary steps how to adjust simulation model to reach a better emission saving result.

3.1. Simulation in General

Simulation is problem-solving method (Banks, 2000) that is very useful when the systems become so complex that common sense and simple calculations are not enough. The purpose of the simulation models is to provide the observer with enough information that the behavior of the simulated system will appear and be as similar to the real system as possible (Law and Kelton, 2000).

In modern times, the different systems of an organization can be really hard to understand and the correlation between different processes can be difficult to distinguish. The foundation of this simulation study is based on the input data from the original system that is to be simulated. The input data is used when designing the simulation model, which means that the reliability of the simulation model is based on the input data. That is why in a simulation project, the accuracy of the pre-studies becomes extremely important (Banks et al, 1996).

A simulation model in a virtual environment does not affect the real system when evaluating the different scenarios. That is why it also is effective from an economical point of view. Simulations are often used if the system has unpredictable parameters that randomly will change over time. Then a simulation model probably is the best way for creating a realistic model, or to just create an understanding for a complex system.

3.1.1. Simulation Model Types

The Models can be structured into different layers, which will indicate what type of model is the most appropriate for each simulation. The first layer is stochastic and deterministic. A deterministic model is the model that includes no randomly elements. A stochastic model is a model that is based on that random element will occur. The second layer is whether it is static or dynamic. A static model describes an average due to a specific time, while a dynamic model will observe the behavior of a system over time. The third layer is if a model is continuous or discrete. Discrete means that events can occur at a discrete point sets in time which is the opposite of the continuous system (Banks et al,1996). The events will occur at a specific time, which make the discrete-event model most feasible for tracking the carbon emissions in a distribution system. The model taxonomy can be seen in below figure. (Leemis and Park, 2006)

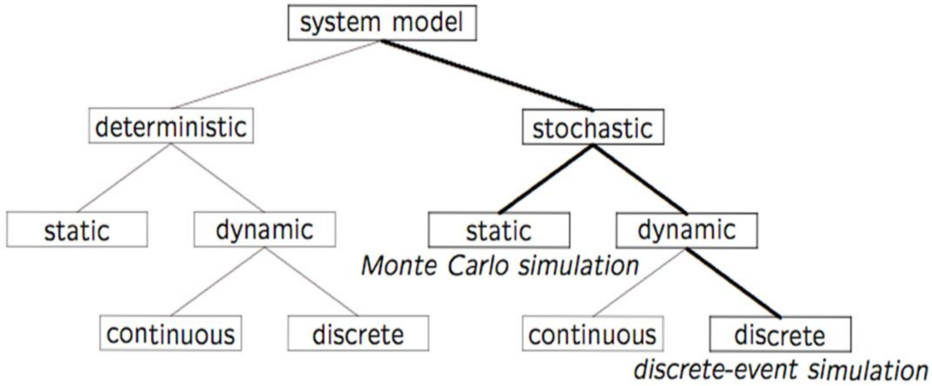


Figure 7. Model taxonomy

Explanations of stochastic models according to Richard Nance (1993) are:

Monte Carlo simulation: The name comes from its similarity to gambling strategies. It utilizes models of uncertainties where representation of time is not needed. It relies on repeated stochastic sampling to compute the results. A Monte Carlo model is most used in computer simulations of mathematical and physical systems.

Continuous simulation: Is a simulation models that are based on equations. These types of studies do not require that the explicit state and time has a certain relationship, which could lead to discontinuities in the result. Continuous simulations are often used in large-scale economic modeling. That is why the continuous simulation model not is used.

Discrete-event simulation: Simulation is a reproduction of a process or a system in the real world over time (Banks et al, 1996). The model utilizes a mathematical and logical approach. The discrete-event simulation is based on parameters that are stochastic and could change at any time and therefore affect the whole system randomly It is almost impossible to create a discrete-event simulation model that has the exact precision as the real system due to the dynamic in the real world. By using simulation it will be possible to answer different types of questions like" what if" and "is it possible" (Banks, 2000). Due to its possibility to take the dynamic in consideration, a discrete event simulation is the best alternative for the thesis. Many parameters in the FGI are stochastic and will change over time.

3.1.2. Areas of Simulation Applications in Manufacturing and Logistics

According to WSC Winter Simulation Conference (http://wintersim.org) and Banks (2001), the simulation can be used in many areas such as:

1) Applications in manufacturing

- Analysis of electronics assembly operations
- Electronics and Wafer Fabrication
- Manufacturing Controls
- Scheduling and Sequencing
- Material Handling Systems
- Optimization and Evaluation
- Quick-response replenishment
- Semiconductor manufacturing using large-facility models

2) Applications in logistics, transportation and distribution

- Evaluating strategies to improve railroad performance
- Logistics process in autonomous food production systems.
- Design of a toll plaza
- Selecting rental-car locations
- Quick-response replenishment
- Sizing rail car fleets
- Product distribution in the newspaper industry

3.1.3. Simulation Advantages and Disadvantages

If the simulation is designed and developed correctly, advantages can be obtained significantly. Simulation has advantages to simulate the given problem and avoid the disadvantages. (Banks, 2000). But users have to know the disadvantages what need to take into consideration in simulations. By basing the simulation strategy, the chances for obtain the advantages will increase.

1) Simulation advantages according to Banks et al (2001) are:

• Simulation is able to evaluate complex systems, which cannot be solved by using usual methods, or evaluating too big or too small objects, without disturbing ongoing operations of a real system.
• Simulation discovers the processes that are not efficient before that the management face them in the real world and specify the best requirements to design a system.
• Simulation can help users to identify the effects of bottlenecks in the system which can cause the delays in materials, or information between the operations, and how to minimize their negative consequences on the whole system.
• Simulation allows users to explore different scenarios, analyze and recognize the effect of all the variables in the system, which variables have the most influence and how do the variables relate to each other and diagnose any problems.
• Investigating certain phenomena which already occur in a system and find explanations, further more inspection can happened by slowing down or speeding up the phenomena in order to understand it fully.
• Using the simulation for training purposes where individuals and groups can learn by their mistakes. Graphically showing the results which is a very powerful tool to gain the validity, and that would be much better than introducing the output based on calculations only.
• As the tendency of manufacturing production to evolve a higher automation level, more attention given on logistic to reduce the overall production cost Castino and Watson (1991).

2) Simulation disadvantages according to Banks et al (2001) are:

• Building a simulation model is a time consuming process and it would not be suitable as a tool for short time decisions.

• Simulation needs a valid data to build the right model, if the data is lacking, then it's hard to perform the simulation and obtain valid results. The model can never be an exact reflex to reality and cannot solve all kind of problems; therefore the expectations that should be achieved from the simulation should be set.

• Building a simulation model needs expertise, which equipped with high theoretical and experience background.

• For the model with random generators sometimes it's not easy to figure whether the output variety comes from the randomness in the system or it's a result of manipulating a certain variable or variables in the system.

3.2. Introduction of ExtendSim and Discrete Event Modeling

ExtendSim (formerly known as Extend) is an easy-to-use simulation program for modeling processes of discrete, continuous, discrete rate and agent-based events. It is a powerful tool that facilitates users to get access and understand complex systems and produce end results better and faster. These are many applications by the utilization of ExtendSim such as:

- Optimize operations
- Visualize working processes logically in a virtual environment
- Predict end results of certain actions
- Spot problem areas before system implementation
- Adjust variables and exam effects of system modifications
- Identify inefficiencies and evaluate improvement ideas.
- Communicate the feasibility and the integrity of designed plans

In general, ExtendSim can be practically utilized in many areas such as logistics and supply chain design, defense, manufacturing process, healthcare system, communications, environment and agriculture research, energy and service industries, information systems and so on. (Strickland, 2013)

Figure 8. An example of international supply chain simulation model.

This discrete event model captures two key supply chain realities: the variances of supply chain dynamics and the non-linearity of business environments. The model uses an internal database to store the extensive amount of data, including SKUs, SKU Groups, Stock Points, and Assembly Lines.

3.2.1. Discrete Event Modeling

Discrete event, continuous, and discrete rate modeling are the most applied simulation methodologies. Continuous modeling (sometimes known as process modeling) is utilized to magnify a flow of values. Discrete event modeling tracks and records unique entities. Discrete rate modeling integrates both aspects of both continuous and discrete event modeling. (Zeigler, 1984)

In continuous models, the time is set up at the start of the simulation, time segments are in equal increments, and value changes depended straightly on the time change. In the continuous model, the value represents the status of the modeling system at any specific time point, and simulated time intervals advances equally from one time step to the next. For instance, continuous simulations can be regarded as a constant stream of fluid flowing through a pipe. The volume increases or decreases at each time interval, but the fluid flowing is continuous.

In discrete event models, the system status is changed only when “event” occurs; the passing time does not have direct effects on the system. Comparing to the continuous model, it is unlikely that the time period between events will be equal as the simulated time advances from one event to the next. For instance, assembling line is a good example of a discrete event system. The individual manufacturing parts (entities) are assembled based on receipt or anticipation of orders (events). Using the pipe analogy for discrete event simulations, rather than a continuous flow, buckets of water would run out of the pipe at random intervals.

Discrete rate simulation is a hybrid model, combining both aspects of continuous and discrete event modeling. Similar to discrete event simulation it recalculates values or rates whenever the events occur. Like continuous models it simulates the flow of goods rather than concrete items. For instance, applying the pipe analogy to a discrete rate simulation, there is a constant stream of fluid flowing through the pipe. But the routing and the rates of flow can change when an event occurs. (Zeigler, 1984).

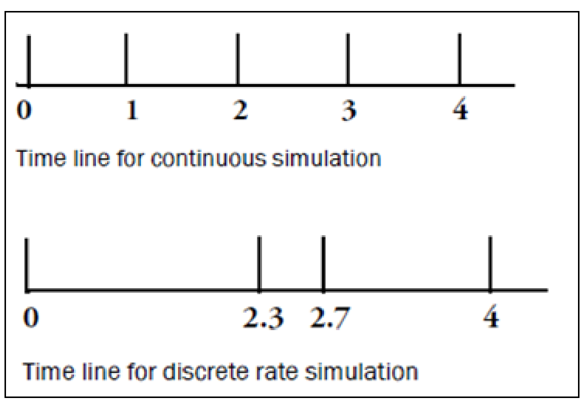


Figure 9. The time line difference between continuous and discrete rate simulation.

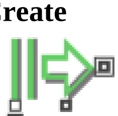
4. THE SIMULATION MODEL DEVELOPMENT

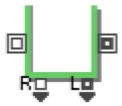
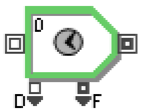
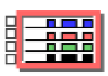
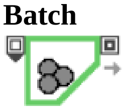
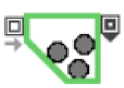
The purpose of developing a simulation model in this thesis is to identify and reveal the total CO2 emission footprints generated throughout an outbound logistics network. The developed model is used as a tool that can help companies to track and re-evaluate the environmental impacts on their logistics systems. A traditional logistics network design based on cost optimum does not necessarily equal an optimum solution for a "Green and sustainable logistics system". The keywords associated with transport emissions, distribution planning and sustainable supply chain design, are becoming vital to supply chain and logistics planners. Therefore, it is a significant need to address economic, environmental and ethical objectives explicitly as part of the whole supply chain and logistics system design.

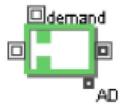
4.1. The Simulation Model Input

In discrete event modeling of ExtendSim, different blocks provide different functions or processes to compose a simulation model; for instance, a "Queue" block designed in ExtendSim can be utilized as an inventory block. A simulation model is consisted by these "blocks" which imitates real-case events of a running system from the start to the end. The different blocks and purposes of their utilizations are explained in the below table.

Table 11. The blocks and simulation modeling input

Name label	Block Function	Purpose in the simulation model
Create 	Create block generates values or items, either on schedule or randomly. If this block applied to generate items, it pushes the items into the simulation and this block has to be followed by a queue-type	This block represents production line in the factory or customer demand (Sales) in the Front Office. Production rate in terms of product quintiles in certain processing time can be decided as an input. Customer demand can be

	block.	determined by the forecast, the forecast can be calculated by previous sales history multiple seasonality.
Queue 	Queue blocks represent a resource pool queue or act as a sorted queue. If it as a sorted queue, it keeps items in a FIFO or LIFO order, or sorts items based on their priority or attribute.	"Queue block" acts as an inventory in dispatching area in the factory, The inventory here can be working as an input of factory's inventory capacity.
Activity 	Activity block produces one or more items simultaneously. Processing time either can be based on a distribution or can be constant.	"Activity block" here represents transportation process; it is the most crucial part to map carbon emission value. Vehicle speed, transport distance are main parameters as inputs.
Plotter, Discrete Event 	Plotter block provides plot tables of data that up to four value inputs in discrete rate models. Both time and value were recorded and shown in the data table for each input. In the result dialog, user is able to specify whether to plot values only to plot all values when they change.	This block gives plotter chart and template of calculation results for the demonstration that how the transport emission is escalated in different transport paths during each time unit.
Batch 	Joins multiple items into a single item for use in the model. This causes the original input items to be destroyed and replaced by one output item. A batched item may be un-batched at a later point in the model, but that is not required.	"Batch block" represents loading process; items are picked up and batched with vehicle and in this area and they becomes a single unit. As far as the vehicle loading capacity is determined, batching quantity can be adjusted for optimizing transport efficiency.
Unbatch 	Outputs multiple items for each input item. Depending on selections in the dialog, this block can separate items that were previously batched or make duplicates of items that were never batched.	"Un-batch block" represents unloading process in central warehouse, the vehicle and goods are dispatched here, the vehicles go to the warehouse dispatching gate and goods are compensated into warehouse inventory
Resource 	Stores a count of resources for the model. The resources are taken by the Queue block and released by the Resource Pool Release block at some later point in the model	The vehicle represents "resource" in simulation model; vehicle type and quantities can be determined here. The vehicle type characterizes the loading capacity, which is crucial to map carbon emission of the system.
Decision 	Can be used with Item library blocks to control the flow of items in a portion of the model.	Decision block sets up blocking mechanism to production unit that if safety stock in central warehouse is fulfilled by enough stock compensated

		by production after satisfying customer demand, the signal will be sent to production unit to stop the produce.
Gate 	Controls the flow of items in a portion of the model (area gating) or based on model conditions (Conditional gating).	The gate coordinates material flow in the simulation model. The gate is always open when there the demand comes.
Math 	Performs a mathematical operation, such as addition or subtraction, which can be used with Item library blocks to control the flow of items in a portion of the model.	How the carbon emission is calculated.
Exit 	The Exit block removes items or values from the simulation and counts them when these items leave.	This block represents the flow of material is done through the whole distribution chain and retailers are satisfied with ordered goods on their hands.

4.2. Developing a Simulation Model of "Factory–Warehouse–Retailer Stores" Distribution Network

A discrete event simulation model is built up in ExtendSim to provide a classic distribution network model of "Factory-Warehouse-Retailer Stores", the model aims to provide simplicity for all users in easily understanding, accessing and driving the transport emission calculations for designing and extending their own logistics systems.

In the simulation model, we utilize "Create" block to simulate production site. The products can be anything, but it should be accountable with its quantity, weight and size, for example, boat engines. The "Queue" bock functions as a buffer location representing a process from the products (cargo) which have been produced in production site to the products which has been batched ready to be transferred. The "Batch" block simply applies batching process, the cargo and transport vehicle are batched together here, and later the vehicle is ready to transport the cargo. The "Activity" block has many functions, such as simulating manufacturing process, car washing process and so on. In the simulation model, it represents cargo-transporting process, transferring time and distance can be determined as the model input to reflect reality. "Unbactch" block stands for the un-batching process between cargos and transport vehicles, which indicates an event that the produced cargo has been transported from production site to another location; in the simulation model it is central warehouse. Then, the vehicle goes back to beginning point, which is production site. As far as production rate is determined, the "Gate" block stands for demands or orders from customer, if customers make an order, the demand gate opens, the stored goods in central warehouse which has been produced in production can go through demand gate, they are ready to be taken care and transported to next location, customer sites. The "Resource" gate represents "transport vehicles". In simulation model, they are trucks, each vehicle has batch that signifies how much quantity of goods this vehicle can transport. Then, the "Math" block calculates emission result by utilizing emission calculation methodologies and the "Monitor" block is able to show emission numerical values right away in different transport paths. Figure 10 illustrates an overview of built-up "Factory-Central Warehouse-retailers" simulation model.

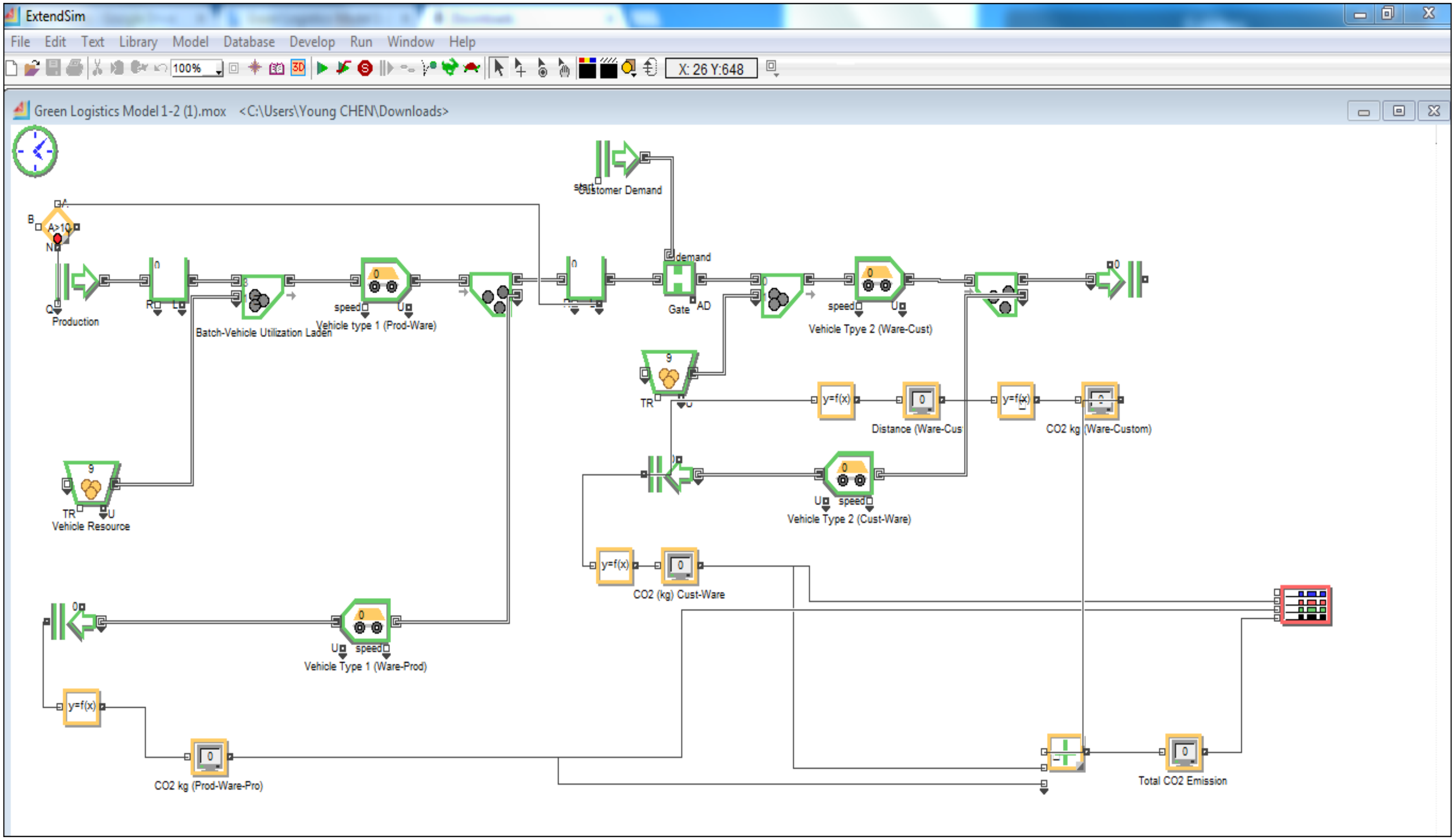


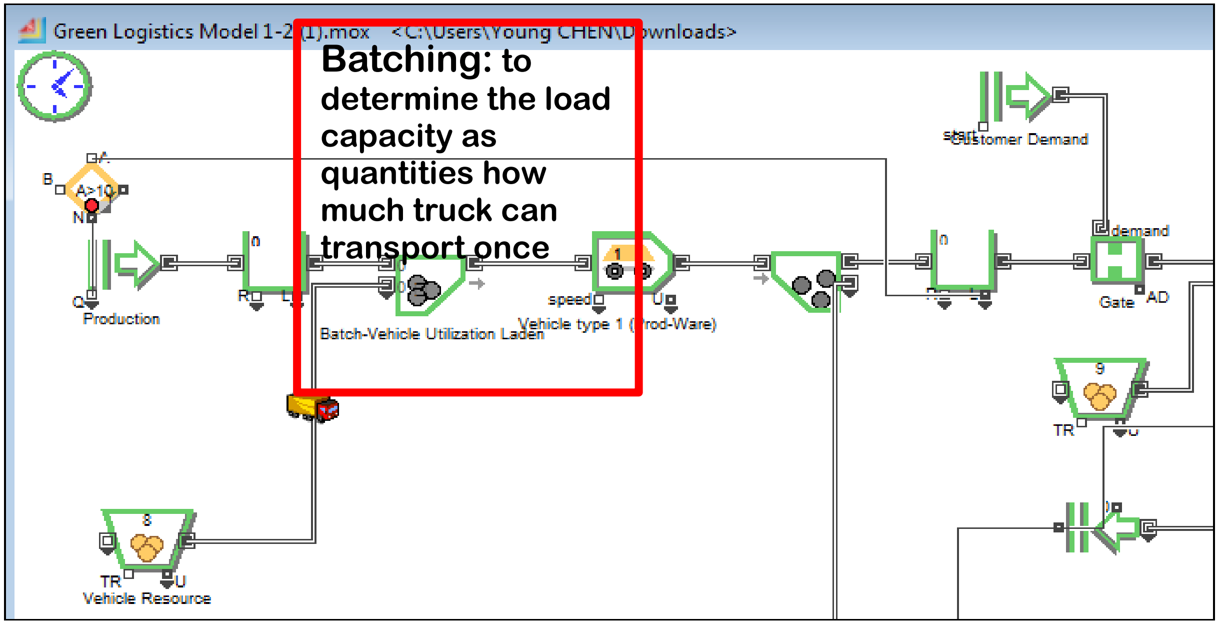
Figure 10. An overview of building up a simulation model in ExtendSim

4.2.1. Simulation Model Segments and Inputs

Production, batching, transporting, un-batching, demand gate and inventory are main segments to compose a distribution network in the simulation model. The critical processes and segments are explained as blow:

1) Batching process and input

The payload capacity is determined by the maximum vehicle weight allowed. In the simulation model, this factor is determined by the vehicle batch size, the unit of the batch size can be either quantities or weights (tons). The bigger batch size requires larger vehicle type, which is providing bigger payload capacity.



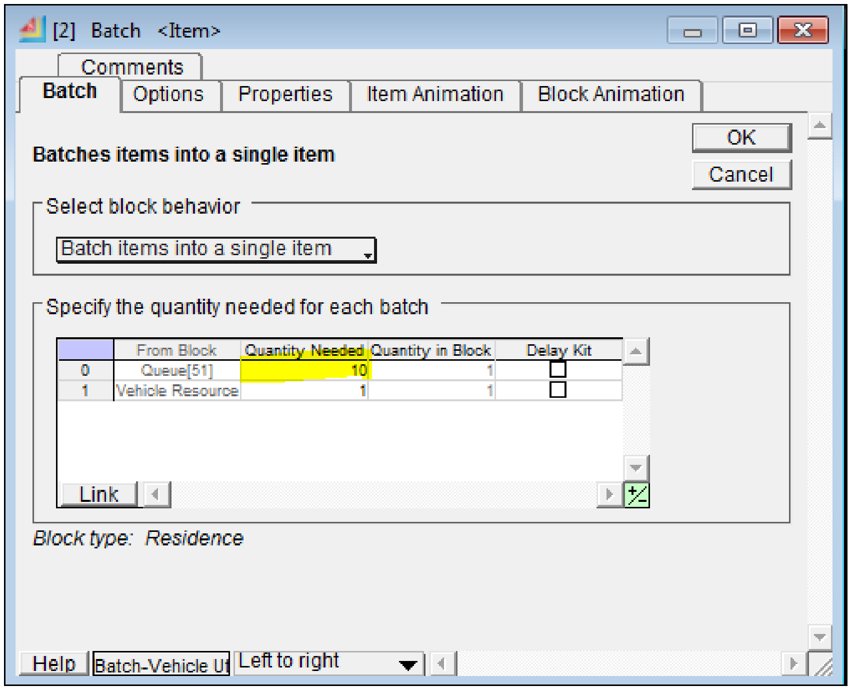


Figure 11. Batching process and input in simulation model

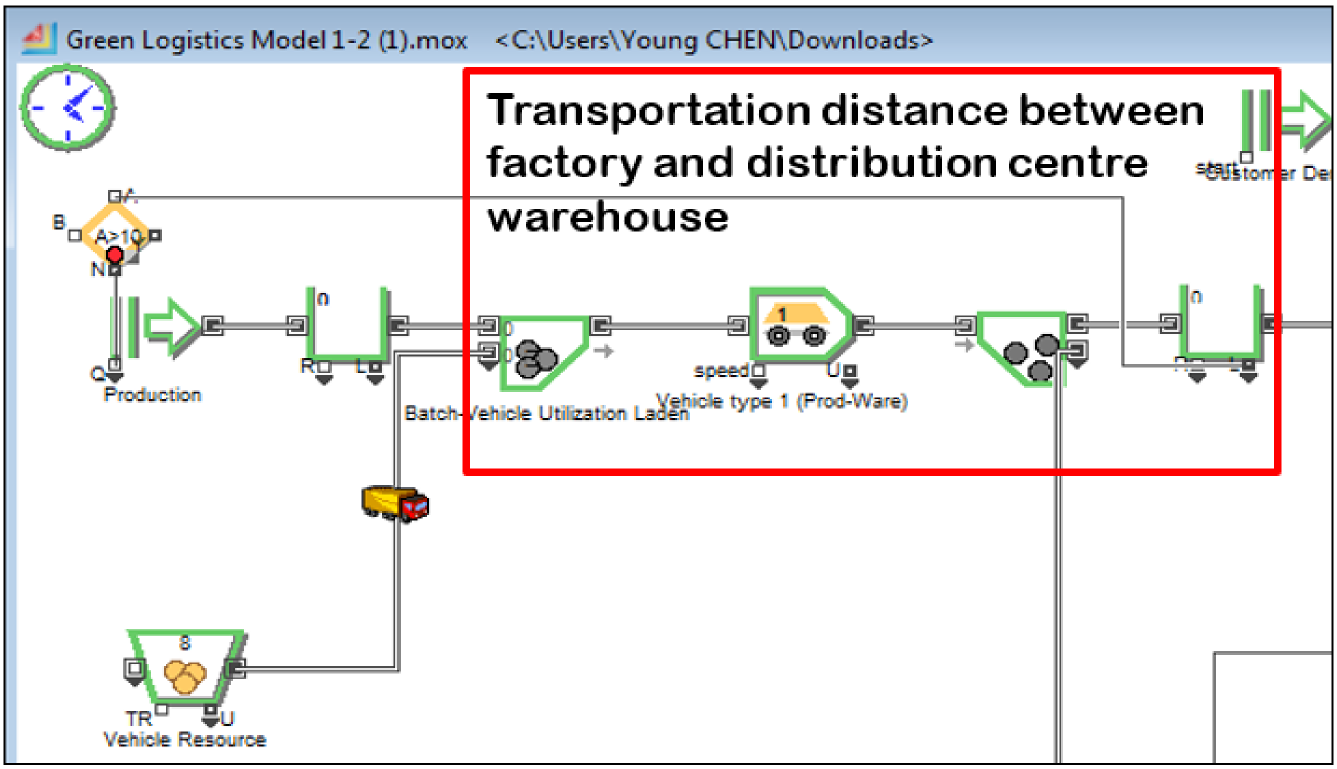
The batching process is equivalent to the truck loading, which usually happens in the production warehouse (factory). Batch size can be utilized to determine a vehicle's loading capacity, the more quantity of products can be batched with one vehicle, and more loading capacity one vehicle has. In the simulation model, it is assumed that the cargos are boat engines, each piece of engines weights two tones. If one vehicle has batch size of 10, it signifies this vehicle has loading capacity of 20 tones equivalently in the simulation model.

Table 12. Batch size input

Batch input (quantities or tons)	Batch in Factory		Batch in Warehouse	
	Quantity needed	Quantity in Block	Quantity needed	Quantity in Block
Queue: batch size	10	1	5	1
Vehicle Resource	1	1	1	1

2) The transportation process and input

The total distance what a vehicle fleet has transported plays a significant role in carbon emission calculation. The transport distance is always the most important factor to determine whether a distribution system is cost and ecological efficient. In the simulation model, total transport distance has been segmented into different transport routings as the different transport events. For instance, the transport events in the distance from production site to central warehouse, in the distance from central warehouse to customers' retailer stores and vice versa. The input of different transport routings are shown in below figure 12-13.



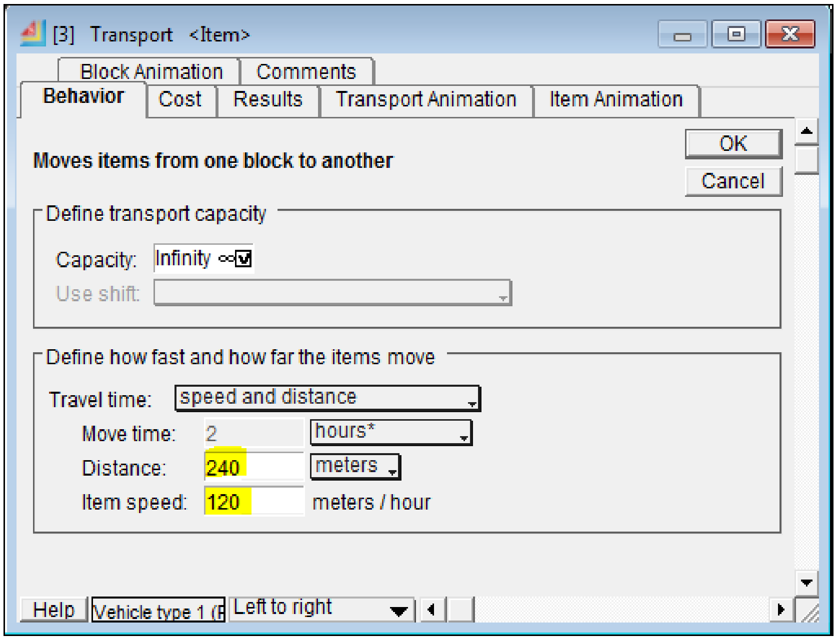


Figure 12. Input transport distance (for all of different transport paths)

In the simulation model, the input of transport distances in the different routings are only assumptions, the simulation model aims to develop an simple and practical platform first, in order to provide a foundation to further model extension. The model can be developed to be more realistic by the extension and by inputting more validated data from real cases.

Table 13. Distance and vehicle speeds input in different distribution paths

Transport Path / Transport distance	Factory to Central Warehouse	Central Warehouse to Factory	Central Warehouse to Retailers	Retailers to Central Warehouse
Move Time (hours)	2	3	1.5	2.5
Distance (meters)	240	300	150	250
Item speed: Vehicle Speed (Meters / hours)	120	100	100	100

Beside transport distance, there are many other intangible but important factors impacting on the transport emission level. These factors are weather condition, traffic density, number of stops and road conditions.

3) Un-batching process

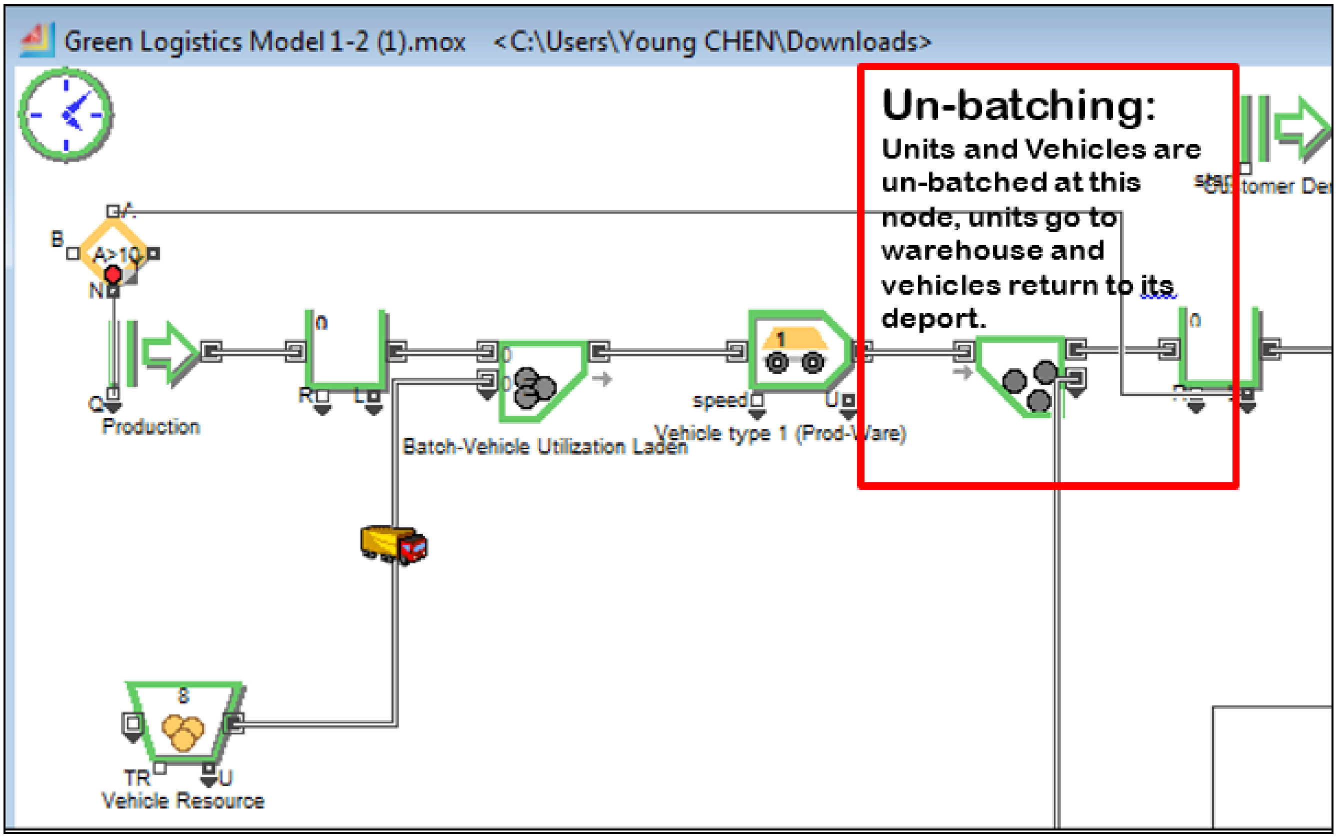


Figure 13. An un-batching process

In the simulation model, the un-batching process represents the cargo unloading in the central warehouse (distribution center), where the cargo is arrived and stored, until the unloading process has finished, the transport vehicles depart and return to the original deport. The return trip is very crucial, because the backload level determines the empty trip factor, which is one of the most important carbon emission factors. In usual manner, this process is given the name as Reverse Logistics. The tradeoff analysis can be carried out that as far as the distribution planning dedicates to enhance the backload level in order to decrease the empty trip factor which leads to less transport emission and cost, however, backload "picking-up" locations might be scattered far away from each other and far away from the initial delivery point (which is the factory in this case in the simulation model), so inevitable escalation of the backload transport distance generates more transport emission. In this scenario, the simulation model plays a significant role, because with its aids, the transport emissions in deferent distribution models can be measured comparatively. For example, correlation between the key factors “transport distance” and “empty trip factor” can be researched in tradeoff or sensitivity analysis to maximize carbon emission in the design of a distribution network.

4) The demand gate and demand input

The demand gate in the simulation model represents whether these is a customer order or not, if the customer places an order, the demand gate opens, the products can go through demand gate and they are able to be batched with transport vehicle, which means the cargo are ready to be transferred to customer sites. If there is no any order from a customer, the demand gate closes. No vehicle will batch any goods to customer because there is no demand.

The customer demand is always unpredictable. In the simulation model, the demand input is simplified and given as fixed numbers. A fixed seasonal demand has been introduced in the simulation model. Firstly, it simulates reality better and more simply. Secondly, for further scenario or sensitive analysis, the demand needs to be set-up in front. The demand input more likely to become invalid if one simply applies a statistical distribution type to the input values. For example, to be considering a more realistic model, the demand level is always correlated with warehouse and production capacities. For instance, the stock level in the warehouse can be dynamic to a set-up OTD level with demand fluctuations, it also relates back to the production rate, that, for the target of the OTD, these particular items drive the way how the production capacity should be planned as well as to know how the outbound logistics system should be designed and organized. The transport vehicles, designed batching size and transport routings, all of these OTD determiners are impacting on the total transport emission equivalently and significantly.

Nevertheless, the simulation model can be extended with inputting the demand better. For instance, by a combination of a seasonal demand practice from industry and a statistical distribution type from history demand data research.

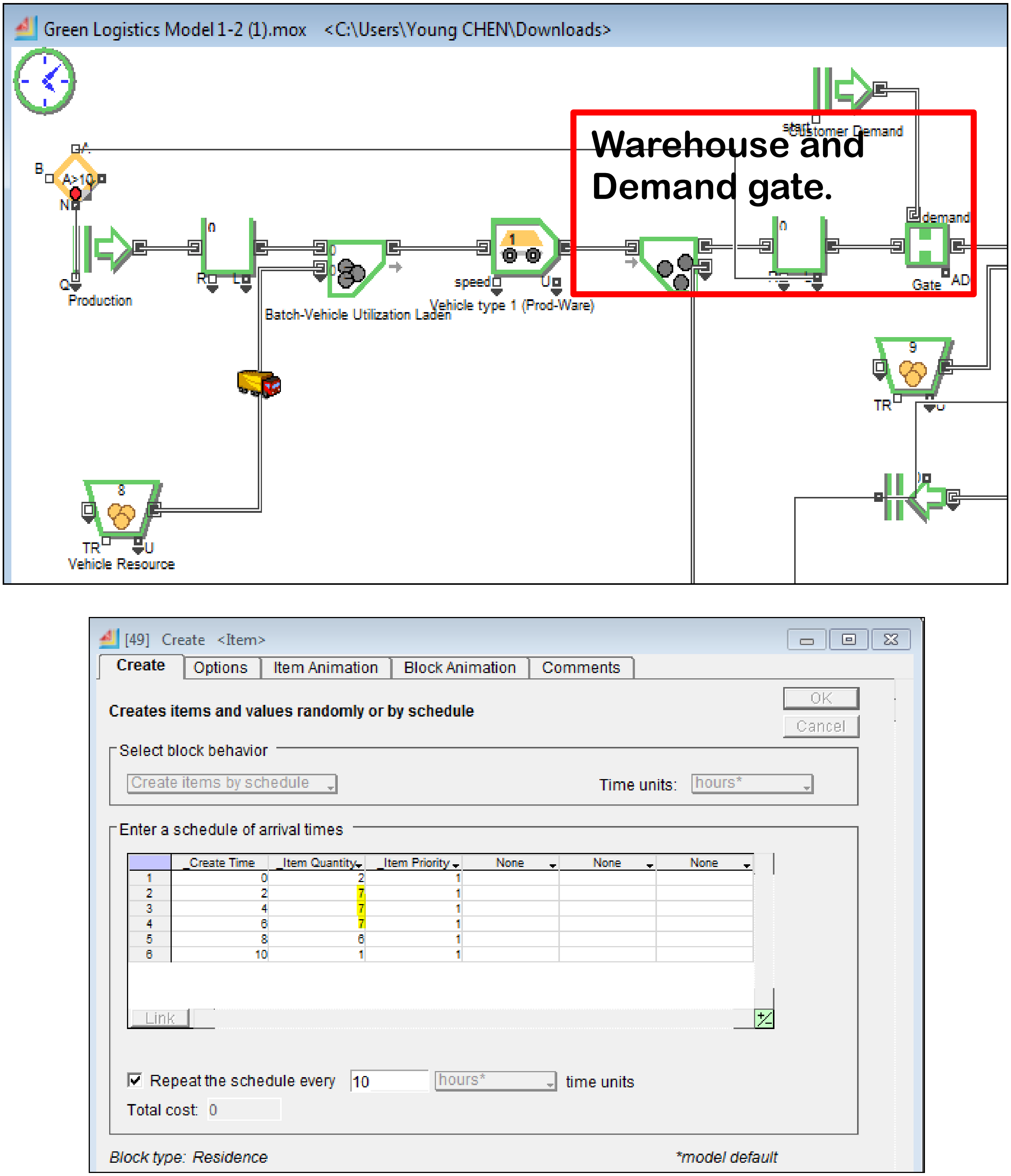


Figure 14. Demand gate in simulation model and its input value

In industry, the demand is one of the most important determining factors about how the warehouse is to be organized; usually goods in warehouse have been categorized into fast-moving, average-moving and slow-moving by the matrix of sales history and sales values. For the slow-moving goods, unless the goods have great value to the company to serve important customers, usually the company does not provide any stock for these slow-moving (no-selling) items, neither to give the forecast necessarily. For fast and average-moving goods, in general, the demand trend is very seasonal, which is also impacted by the marketing input. (e.g. sales promotions, new projects). The demand planning team, stock planning team (supply planning team) and logistics customer service team are working together very close and hard to enhance OTDs and fix many other logistics issues in order to optimize stock level to save the cost and maximize on-time delivery to satisfy customer requests.

Table 14. Demand input in the simulation model

Demand Input	Create Time (Discrete time point)	Item Quantity (Scheduled demand quantities)	Item Priority (All items have same priority to be scheduled)
1	0	2	1
1	2	7	1
1	4	7	1
1	6	7	1
1	8	6	1
1	10	1	1
Repeat the schedule every 10 houses time units (Periodic demand type)			

4.3. A Hybrid "Push and Pull" System

By the help of simulation, a complex outbound logistics system can be designed and simplified. A hybrid "Push and Pull" system has been developed in the simulation model, which provides realistic process demonstration how the material from production to center warehouse flows. The "Push and Pull" mechanism is showed in the built-up ExtendSim model below.

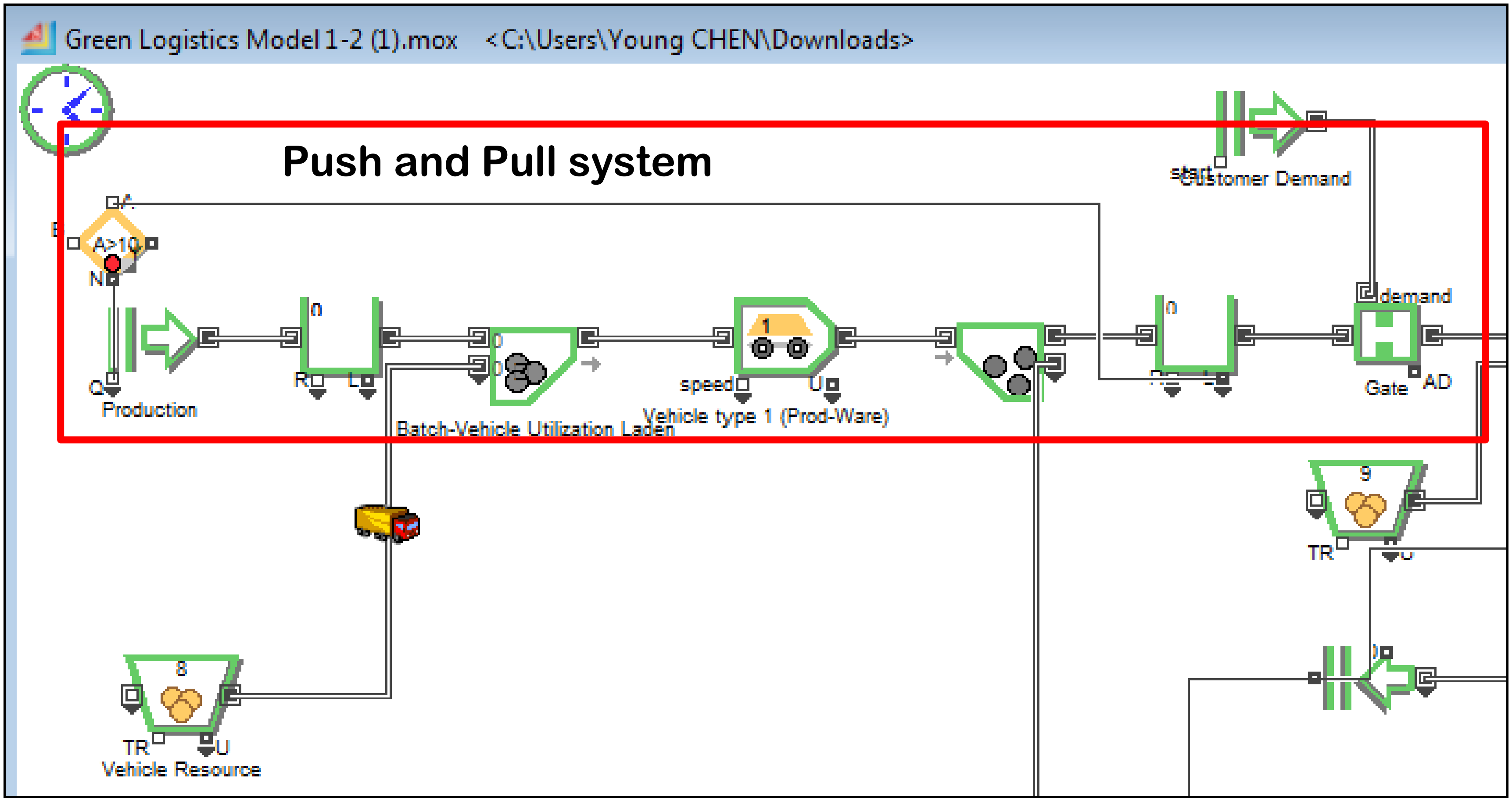


Figure 15. A push and pull hybrid system

In **Figure 15**, when the customers have demands and they place the orders, the “demand gate” opens; the produced items stocked in the DC warehouse give the supply to customer demands. After customer demands have been satisfied and no more orders are placed, the “demand gate” closes, in other words, no more items will go through demand gate. If there is not enough stock (with a set-up stock level) in the DC warehouse, it immediately sends the signal to the “production (factory)”, and the items will be produced and later transferred to the DC warehouse in order to compensate the backlog situation that there is demand but no stock.

If the pace of demand coming from customers is less than the pace of the items, which are being produced and transported to the DC warehouse, there will be quite enough stock accumulated in DC warehouse. For the time being, if the demand gate is closed, no more items will pass through it. As far as the maximum stock level is reached, DC warehouse sends the message back to the “production (factory)” with the signal “Stop producing”. The production will be terminated until the demand gate opens again. In conclusion, the “demand gate”, “maximum stock level”, “production rate” and “transport time” compose and configure how the material flow mechanism is developed in this discrete event simulation. This correlation and impacts from these factors can be formulated into the mathematic functions to investigate and calculate the transport emission as the output. Not only does the simulation model reveal the transport emission footprint by the numerical outputs, but also, by the “sensitivity analysis” the most impacting factors can be revealed and identified with the purpose of designing a greener system in terms of more transport efficiency and low carbon emissions.

4.4. Emission Footprint Mapping and Calculation Output

By using the simulation model, carbon emission values in different transport paths can be measured and compared. A distribution simulation model provides visible graphs and values to show how carbon emissions are accumulated in the simulation progress. The emission footprint and output values are shown in blow figures 16-17.

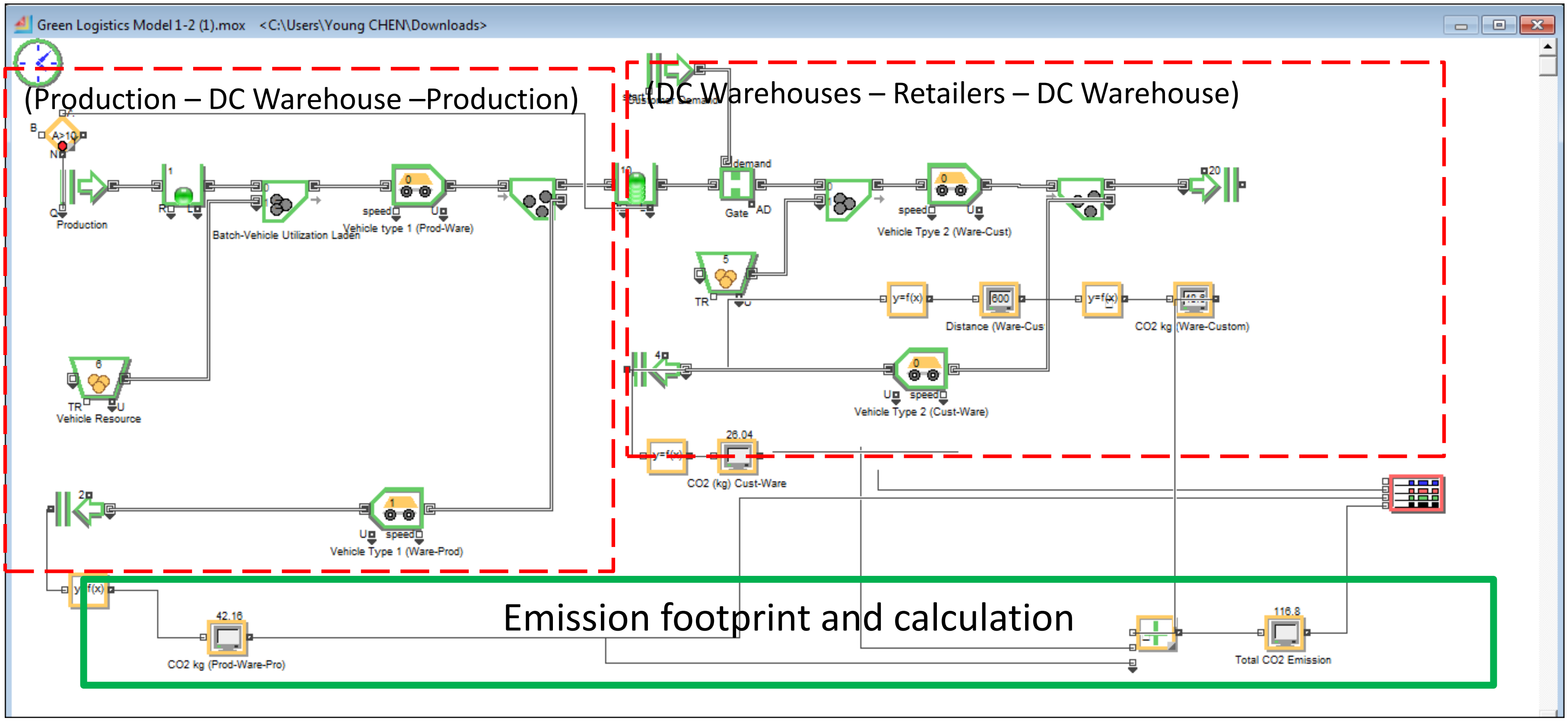
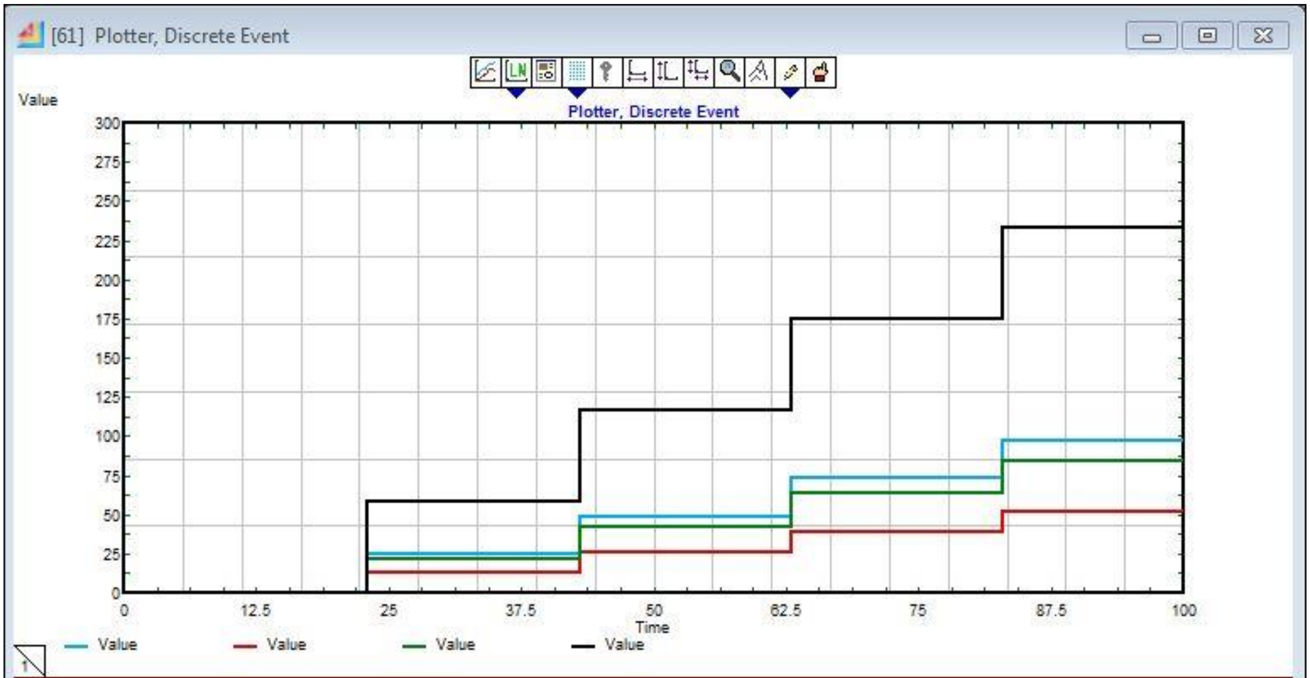


Figure 16. The emission footprint is mapped in different transport paths



Point Number	1 Time	1 Value	2 Time	2 Value	3 Time	3 Value	4 Time	4 Value
0	0	0	0	0	0	0	0	0
1	23	12.15	23	6.51	23	21.08	23	21.08
2	23	24.3	23	13.02	23	21.08	23	39.74
3	43	36.45	43	19.53	43	42.16	23	46.25
4	43	48.6	43	26.04	43	42.16	23	58.4
5	63	60.75	63	32.55	63	63.24	43	79.48
6	63	72.9	63	39.06	63	63.24	43	85.99
7	83	85.05	83	45.57	83	84.32	43	98.14
8	83	97.2	83	52.08	83	84.32	43	104.65
9	100	97.2	100	52.08	100	84.32	43	116.8
10							63	137.88
11							63	144.39
12							63	156.54
13							63	163.05
14							63	175.2
15							83	196.28
16							83	202.79
17							83	214.94
18							83	221.45

Figure 17. The emission footprint mapping in terms of emission output values

The simulation model provides a great level of visibility and simplicity in mapping emission footprint and calculating emission results in different transport paths. For simplicity, a setup time of 100 hours has been utilized in this foundational model. (The choice of simulation duration 100 hours is based on estimation that vehicle fleet has two shifts and in each shift the vehicle drives 8 hours per day, so approximately 1 week shipping time is set up in this model). The plotter chart above indicates how the transport emissions in the different transport paths have been accumulated and plotted during each transport event is completed. For instance, the blue line in the plotter chart represents transport path of the trucks travelling from production site to central warehouse and then return to original production site. It is showed in the chart that when each of these discrete transport events (tasks) is finished, the value of emission is calculated and plotted in ExtendSim. The calculation and result-plotting applies to other transportation paths as well. For instance, accordingly, the green line indicates accumulated emission values of tracks travelling from central warehouse to customer retailer site 1 and return to the central warehouse; the red line indicates accumulated emission values of the tracks travelling from central warehouse to customer retailer site 2 and then return to original site. The black line illustrates the total emission values accumulated in all transport paths, which represents the total emission values and how the values are accumulated in this distribution network model.

The principle of the carbon emission calculation is based on the transport distance multiples the different emission factors categorized in the different transport paths. These emission factors are primarily determined by the load factor, empty trip rate and vehicle type, and each of these factors are also impacted by the batch size, transport routing, vehicle fuel consumption rate and many other equivalent but less-significant parameters. The software ExtendSim, in this case, provides a great simulation environment for users to build up and improve the model in the most systematic and visible way.

Table 15. The emission output chart for crosschecking total emission values.

Transport paths	Warehouse - Customers		Retailer - Warehouse		Factory-Warehouse-Factory		Sum Crosscheck	Total	
Point	Time 1	Value 1	Time 2	Value 2	Time 3	Value 3	Value	Time 4	Value 4
1	0	0	0	0	0	0		0	0
2	23	12,15	23	6,51	23	21,08	**39,74**	23	21,08
3	23	24,3	23	13,02	23	21,08	**58,4**	23	**39,74**
4	43	36,45	43	19,53	43	42,16	**98,14**	23	46,25
5	43	48,6	43	26,04	43	42,16	**116,8**	23	**58,4**
6	63	60,75	63	32,55	63	63,24	**156,54**	43	79,48
7	63	72,9	63	39,06	63	63,24	**175,2**	43	85,99
8	83	85,05	83	45,57	83	84,32	**214,94**	43	**98,14**
9	83	97,2	83	52,08	83	84,32	**233,6**	43	104,65

10	100	97,2	100	52,08	100	84,32	**233,6**	43	**116,8**
11								63	137,88
12								63	144,39
13								63	156,54
14								63	163,05
15								63	**175,2**
16								83	196,28
17								83	202,79
18								83	214,94
19								83	**221,45**
20								83	233,6
21								100	**233,6**

4.5. A Simulation Dashboard

A “dashboard” user interface has been developed in the simulation model to facilitate the “what-if” scenario analysis, it intends to characterize the most impacting and sensitive parameters, which lead to the design and develop a “Green Logistics System” and demonstrate the gaps and constraints in reality.

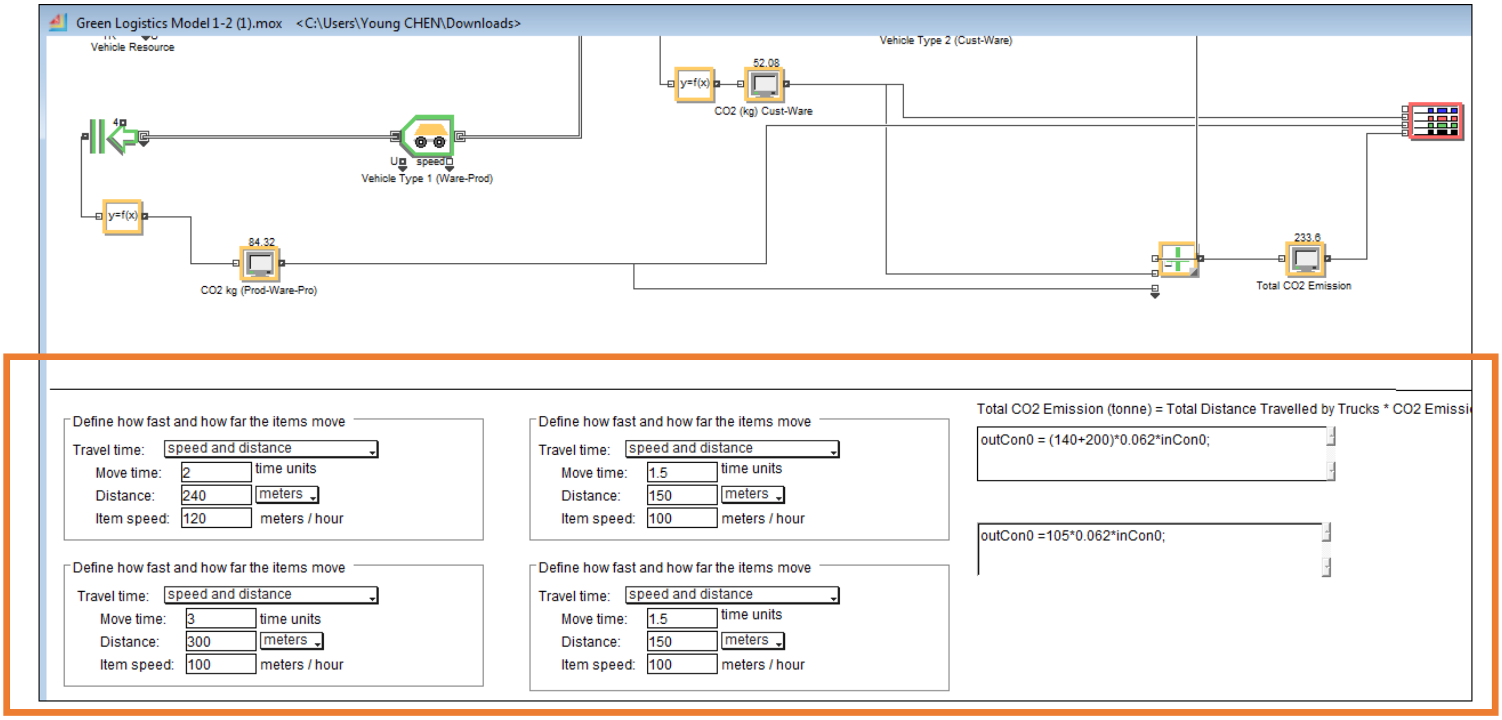


Figure 18. To develop a simulation dashboard

The figure 18 illustrates that a dashboard section has been also developed in this simulation model for giving better visibility and accessibility to the parameter adjustments. The goal is to utilize and adjust these key parameters to monitor and optimize transport emission values in different transport paths until a certain emission target towards designing a green distribution system. Utilizing this dashboard, with aid of this existing model, can carry out further “trade-off” or “scenario” analysis; a more complex and realistic simulation can be done by the model extension. The scenario analysis can be proposed as “Emission vs. Cost”, “Emission vs. OTD” as well as “Emission vs. A Theoretically Optimized Distribution Network Design”.

5. SCENARIO ANALYSIS

Simulation is able to evaluate complex systems that cannot be solved by using usual methods or without disturbing ongoing operations of a real system. Although simulation cannot predict outcomes of a system, it allows one to explore different scenarios, analyze and recognize the effect of all variables in the system such as constrains or bottlenecks, and minimize negative consequences to improve a system.

5.1. A Centralized Distribution Centre versus Decentralized Distribution Centers

By the aid of discrete event simulation in ExtendSim, a scenario research can be established to exam total carbon emission in two different distribution network designs, they are centralized DC and decentralized DC models. The aim of the scenario analysis is to find which distribution network design is better in terms of transporting all cargos (customer orders) from factory in Vaasa to other four customer cities in Tampere, Oulu, Turku and Helsinki with minimal carbon emissions generated by the transportation accordingly.

5.1.1. Simulation Model 1 - A Centralized Distribution Center in Vaasa

In the first model, Vaasa is the central warehouse and distribution center, which is in charge of delivering all orders to the customer cities Tampere, Turku, Oulu and Helsinki, the map is showed in figure 19.

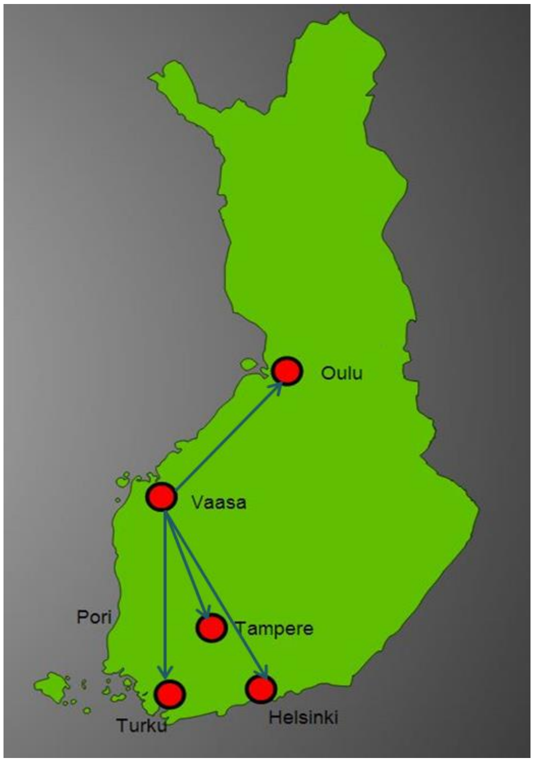


Figure 19. Simulation cities (Model 1)

If there is a demand in any of the customer cities, the Vaasa central warehouse will send the cargo by trucks to customer cities directly and separately without taking any middle stops. After the orders are delivered, the trucks in each different transport routine go back to Vaasa Warehouse directly without passing by any other customer cities. Ten items (products) per truck is the minimal batch size for the economics of scale.

The below figure illustrates a built-up model in ExtendSim, a centralized distribution center in Vaasa, it delivers all orders to other four customer cities in Finland.

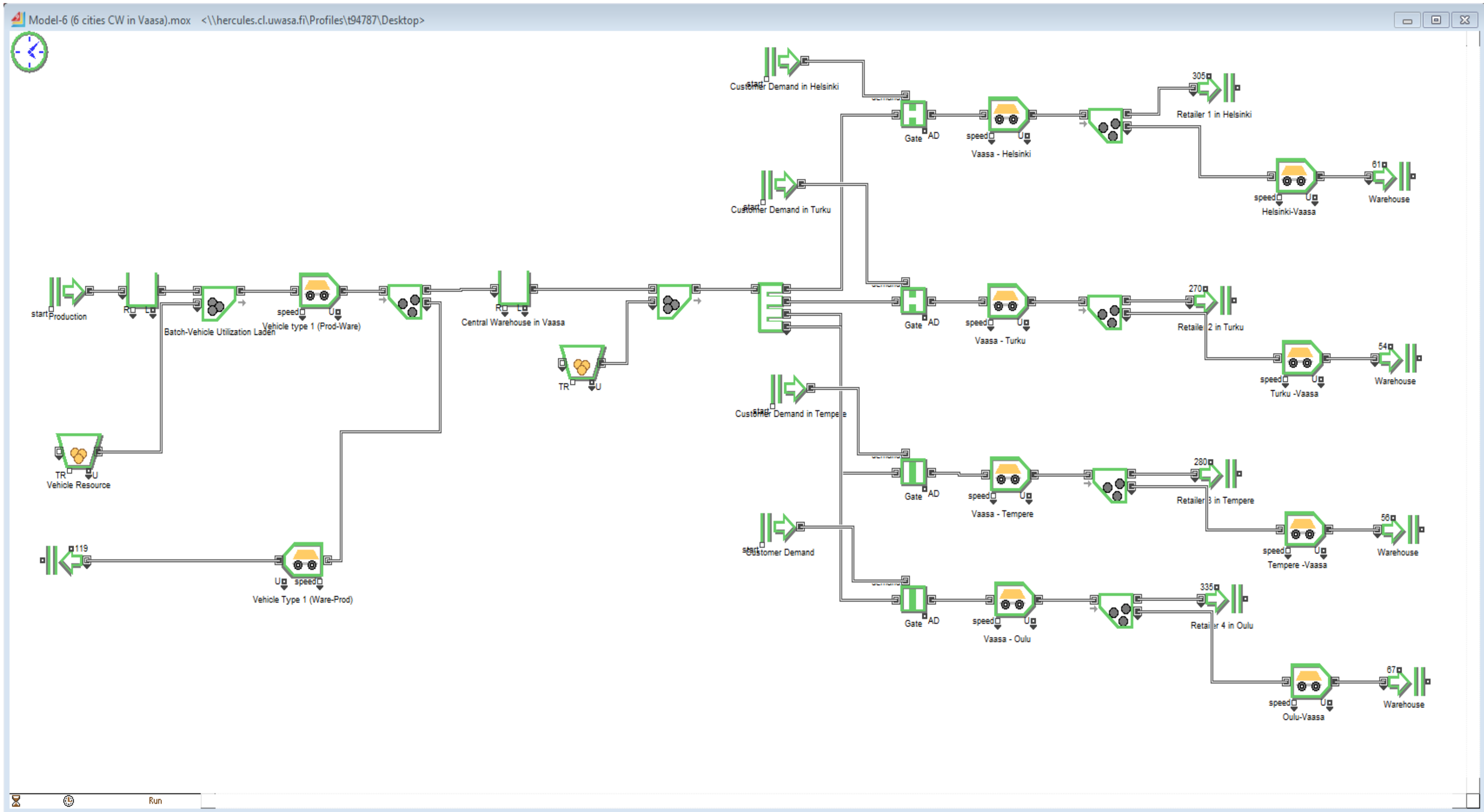


Figure 20. A distribution network simulation model in ExtendSim: central warehouse in Vaasa and customer cities in Oulu, Tempere, Turku and Helsinki.

1) The parameters setup in simulation model 1 in order to calculate the total CO2 emissions

In the built-up simulation model, the research has limitation to access empirical data from a real case company. Most of parameters in the simulation model are set up by the assumptions coming from the research of literature reviews. For instance, the "Euro-V" is the emission standard in Europe union but this emission standard does not apply to other countries such as the United States and Japan. Most manufacturing or 3PL companies commonly utilize truck type of 40-44 tones in their outbound logistics transportation but it does not apply to all companies. Other important parameters such as load and empty trip factors are extracted from empirical researches in EcoTransIT (2003); the parameters are mostly tested and utilized in industry.

Table 16. Input values of scenario analysis (model 1)

Freigt Type	Average good
Tranport Media	Truck
Vehicle type	40–44 ton
Vehicle Resourse Avaliablity	Unlimited
Emission standard	Euro-V
Load Factor (Truck)	60 %
Empty Trip Factor (per routing)	50 %
Batch size (Cargo per truck)	10 PEC/Truck
Cargo Weigt	1 PEC=1000 kg=1 ton
Distribution Node Distrance	
Vaasa-Tempere	240 km
Vaasa-Helsinki	420 km
Vaasa-oulu	320 km
Vaasa-Turku	344 km

Simulation Duration: 1000 Time units (1000 hours in 3 month transport schedule span)

The choice of simulation duration 1000 hours is assumed by approaching transport schedules in reality. It is assumed that the vehicle fleet has two shifts and in each shift the vehicle drives 8 hours per day, 5 working days in a week, so 80 hours driving time in one week is proceeded and organized in the vehicle fleet. Numerically, 1000 driving hours equalizes 12.5 weeks; in the foundation of simulation modeling, 12.5 weeks provides a 3 months transportation span to approach reality.

Simulation Runs: 1

Demand Input (A random seasonal demand is assumed and repeated for the scenario analysis, the demand can be input better by accessing empirical data from industry in the further model extension):

Table 17. Demand values input (model 1)

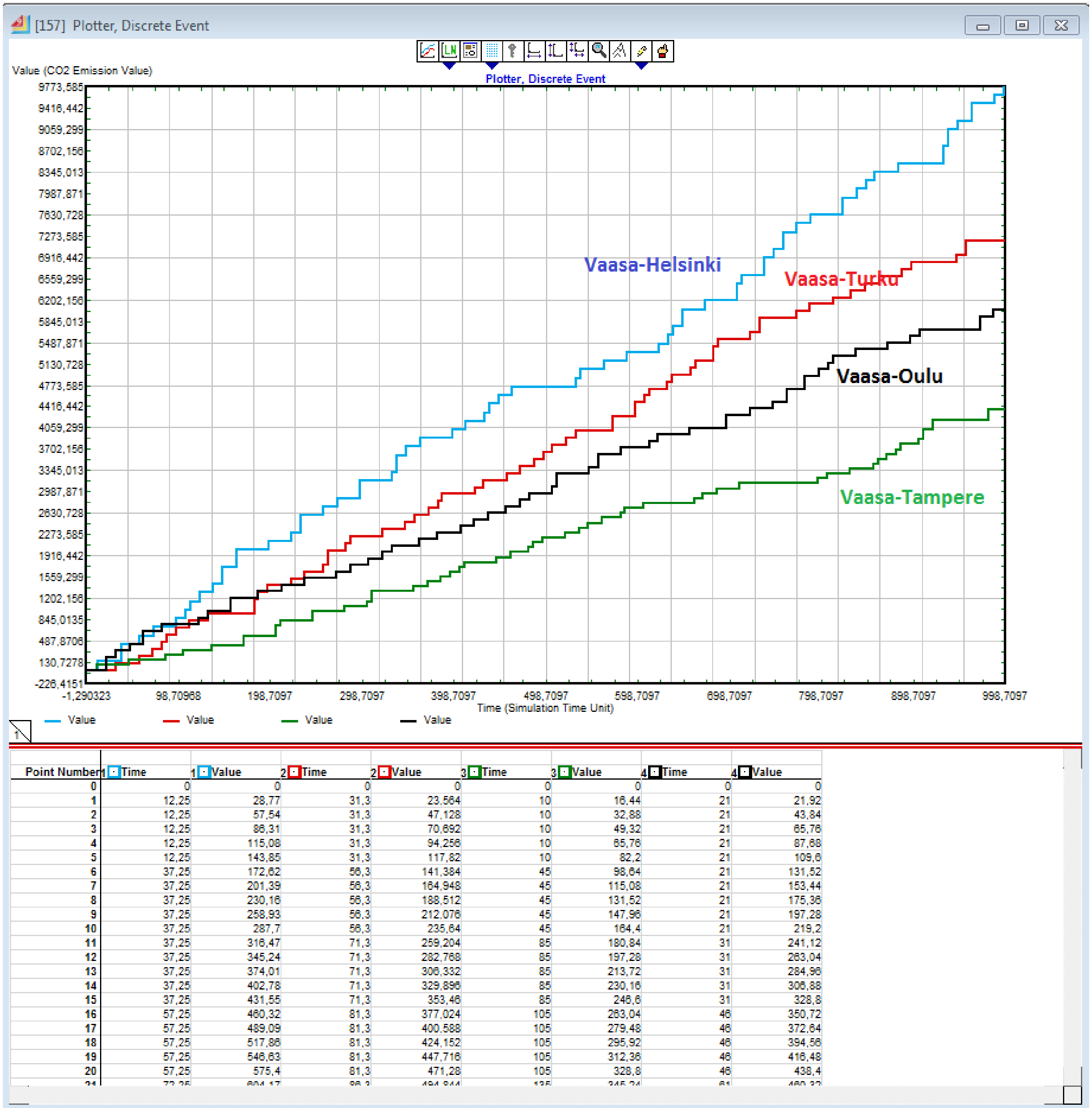
	Demand in customer cities	Tampere	Oulu	Turku	Helsinki
	Create Time	Item quality	Item quality	Item quality	Item quality
1	0	1	0	0	2
2	5	0	1	0	0
3	10	1	0	0	0
4	15	1	1	1	1
5	20	1	0	0	0
6	25	1	1	1	0

Production Rate in the Vaasa Factory:

Table 18. Production rate input (model 1).

Production rate in the factory	Create Time	Item Quantity
1	0	5
2	5	5
3	10	5
4	15	5
5	20	5
6	25	5
	Repeat schedule every 25 time units	

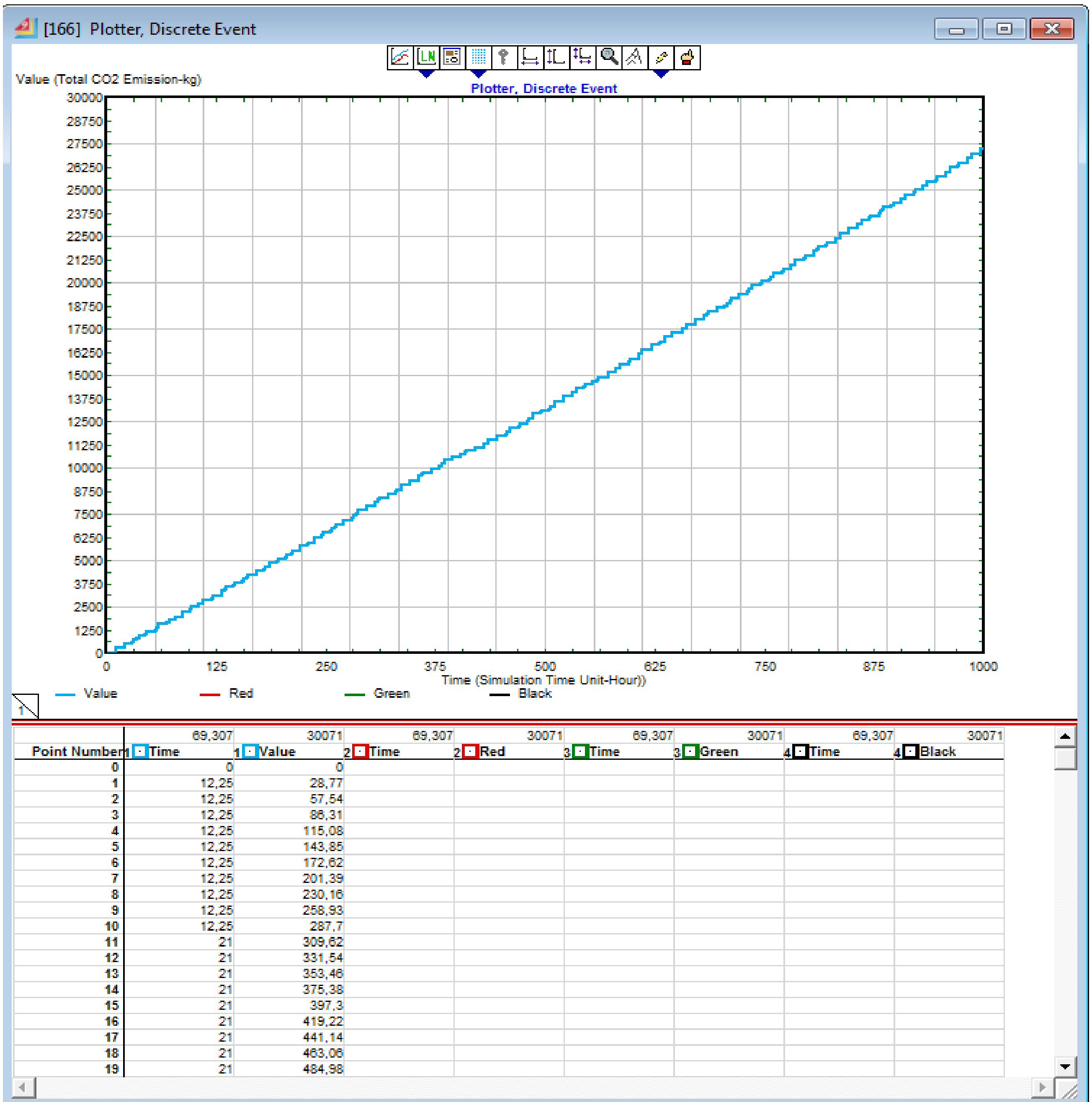
2) Simulation result in plotter chart



Point Number	1 Time	1 Value	2 Time	2 Value	3 Time	3 Value	4 Time	4 Value
0	0	0	0	0	0	0	0	0
1	12,25	28,77	31,3	23,564	10	16,44	21	21,92
2	12,25	57,54	31,3	47,128	10	32,88	21	43,84
3	12,25	86,31	31,3	70,692	10	49,32	21	65,76
4	12,25	115,08	31,3	94,256	10	65,76	21	87,68
5	12,25	143,85	31,3	117,82	10	82,2	21	109,6
6	37,25	172,62	56,3	141,384	45	98,64	21	131,52
7	37,25	201,39	56,3	164,948	45	115,08	21	153,44
8	37,25	230,16	56,3	188,512	45	131,52	21	175,36
9	37,25	258,93	56,3	212,076	45	147,96	21	197,28
10	37,25	287,7	56,3	235,64	45	164,4	21	219,2
11	37,25	316,47	71,3	259,204	85	180,84	31	241,12
12	37,25	345,24	71,3	282,768	85	197,28	31	263,04
13	37,25	374,01	71,3	306,332	85	213,72	31	284,96
14	37,25	402,78	71,3	329,896	85	230,16	31	306,88
15	37,25	431,55	71,3	353,46	85	246,6	31	328,8
16	57,25	460,32	81,3	377,024	105	263,04	46	350,72
17	57,25	489,09	81,3	400,588	105	279,48	46	372,64
18	57,25	517,86	81,3	424,152	105	295,92	46	394,56
19	57,25	546,63	81,3	447,716	105	312,36	46	416,48
20	57,25	575,4	81,3	471,28	105	328,8	46	438,4

Figure 21. The simulation result of CO2 emission accumulation in different transport paths

In figure 21, X-axial represents simulation time unit running from 1 to 1000 hours; Y-axial represents CO2 emission in different transport paths such as from Vaasa to Helsinki, Turku, Oulu and Turku. The largest part of CO2 emission is generated in the transport path from Vaasa to Helsinki, the transport distance is the most important impact on generating carbon emissions.



Point Number	1 Time (69,307)	1 Value (30071)	2 Time (69,307)	2 Red (30071)	3 Time (69,307)	3 Green (30071)	4 Time (69,307)	4 Black (30071)
0	0	0						
1	12,25	28,77						
2	12,25	57,54						
3	12,25	86,31						
4	12,25	115,08						
5	12,25	143,85						
6	12,25	172,62						
7	12,25	201,39						
8	12,25	230,16						
9	12,25	258,93						
10	12,25	287,7						
11	21	309,62						
12	21	331,54						
13	21	353,46						
14	21	375,38						
15	21	397,3						
16	21	419,22						
17	21	441,14						
18	21	463,06						
19	21	484,98						

Figure 22. The total CO2 emission accumulation result in the model of centralized distribution model.

The above figure illustrates in time unit of 1000 hours, total CO2 emission generated by all transport paths accumulated from 0 to 27000 kg gradually.

5.1.2. Model 2 - Decentralized Distribution Centers both in Vaasa and Tampere

In model 2, Vaasa warehouse delivers to Oulu and Tampere and Tampere warehouse delivers orders to Turku and Helsinki.

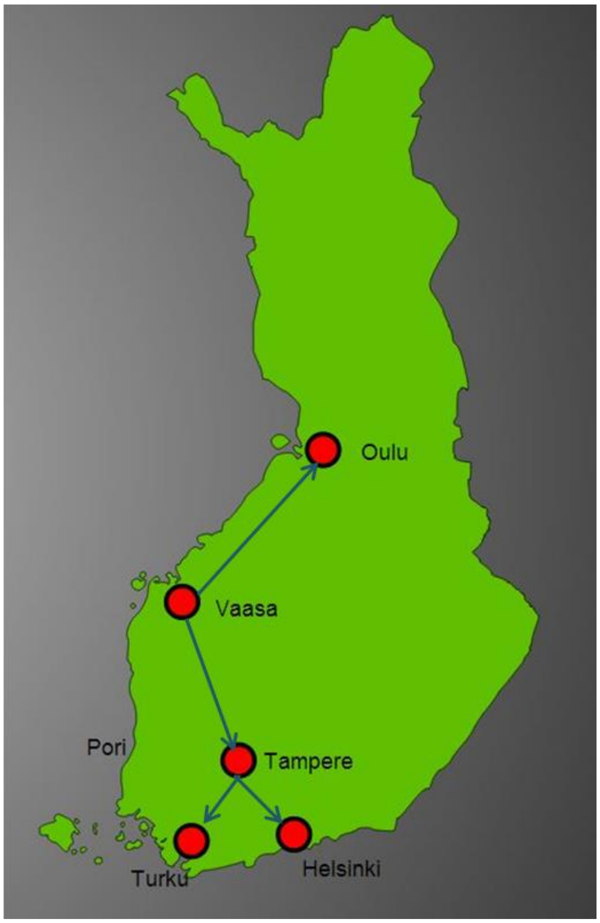


Figure 23. Simulation cities 2

In the second model, two truck fleets are used in the simulation and two main warehouses are located both in Vaasa and Tampere. Vaasa warehouse only delivers customer orders to Oulu and Tampere, and Tampere warehouse delivers orders to Turku and Helsinki. The truck fleets in each transport routing go back to Vaasa and Tampere warehouses accordingly without passing by any other customer cities. Ten pieces (products) per truck is the minimal batch size in the model for the economics of scale.

In the figure below, a second model has been built up in ExtendSim to simulate a decentralized distribution network with warehouses in Vaasa and Tampere delivering orders to other four customer cities in Finland.

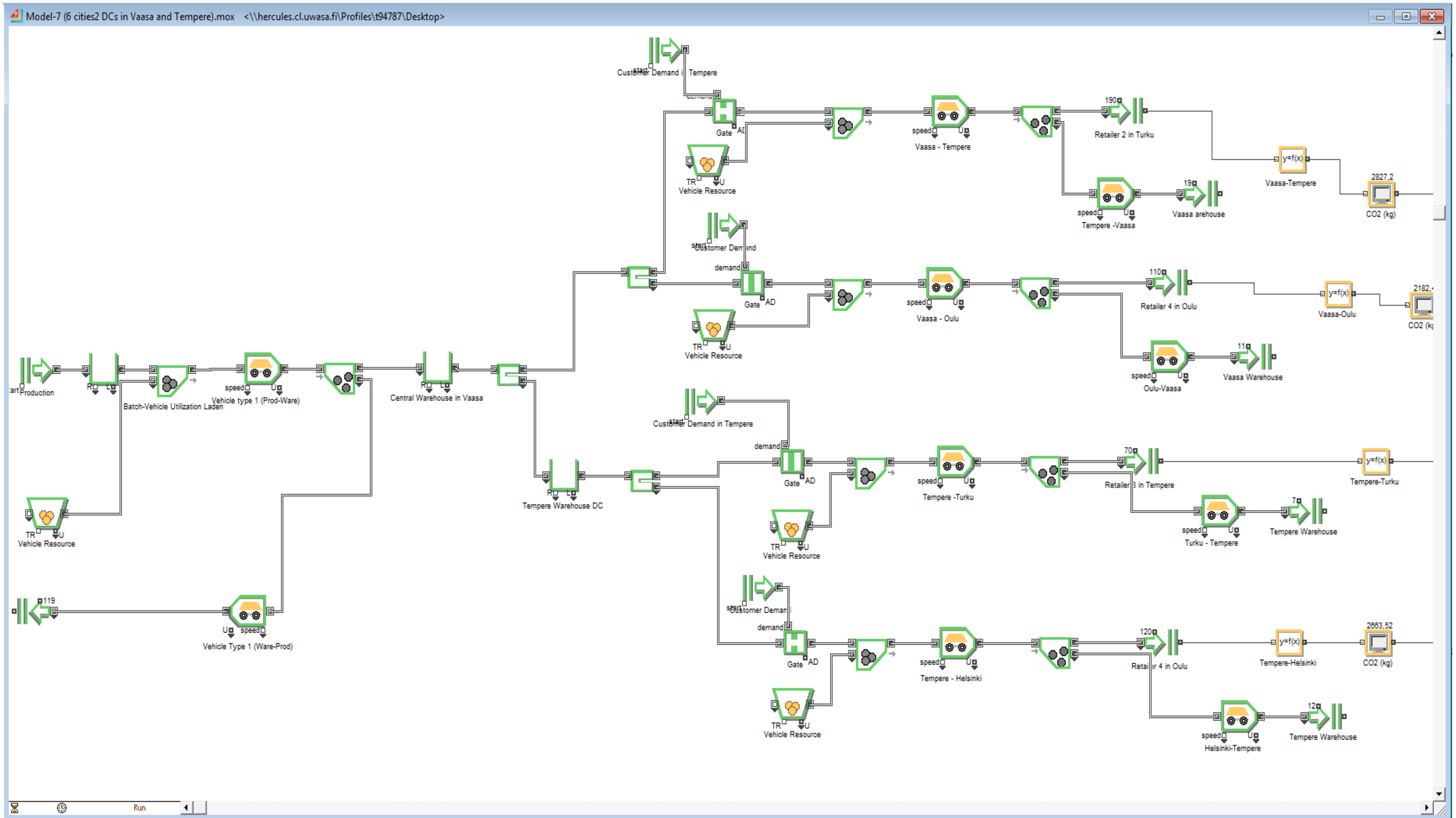


Figure 24. A distribution network model built in ExtendSim

Two warehouses in Vaasa and Tampere are showed in the model. Two distribution paths in the simulation model shows that the trucks in Vaasa warehouse deliver cargos to Oulu and Tampere and the trucks in Tampere warehouse deliver cargos to Turku and Helsinki.

1) The parameters setup in simulation model 2 in order to calculate the total CO2 emissions

According to the scenario analysis, in order to find which distribution network generates less carbon emissions in total, simulation model 1 and model 2 have same input values. All explanation of inputs is given before in the scenario simulation model 1.

Table 19. Input values of scenario analysis (model 2)

Freigt Type	Average good
Tranport Media	Truck
Vehicle type	40-44 ton
Vehicle Resourse Avaliablity	Unlimited
Emission standard	Euro-V
Load Factor	60 %
Empty Trip Factor	50 %
Batch size (Cargo per truck)	10 PEC / Truck
Cargo Weigt	1 PEC=1000 kg=1 ton
Distribution Node Distrance	
Vaasa-Tempere	240 km
Vaasa-oulu	320 km
Tempere-Helsinki	179 km
Tempere-Turku	163 km

Simulation Duration: 1000 Time units (1000 hours, the choice of simulation duration is explained in the simulation model 1)
Simulation Runs: 1
Demand Input:

Table 20. Demand input values (model 2)

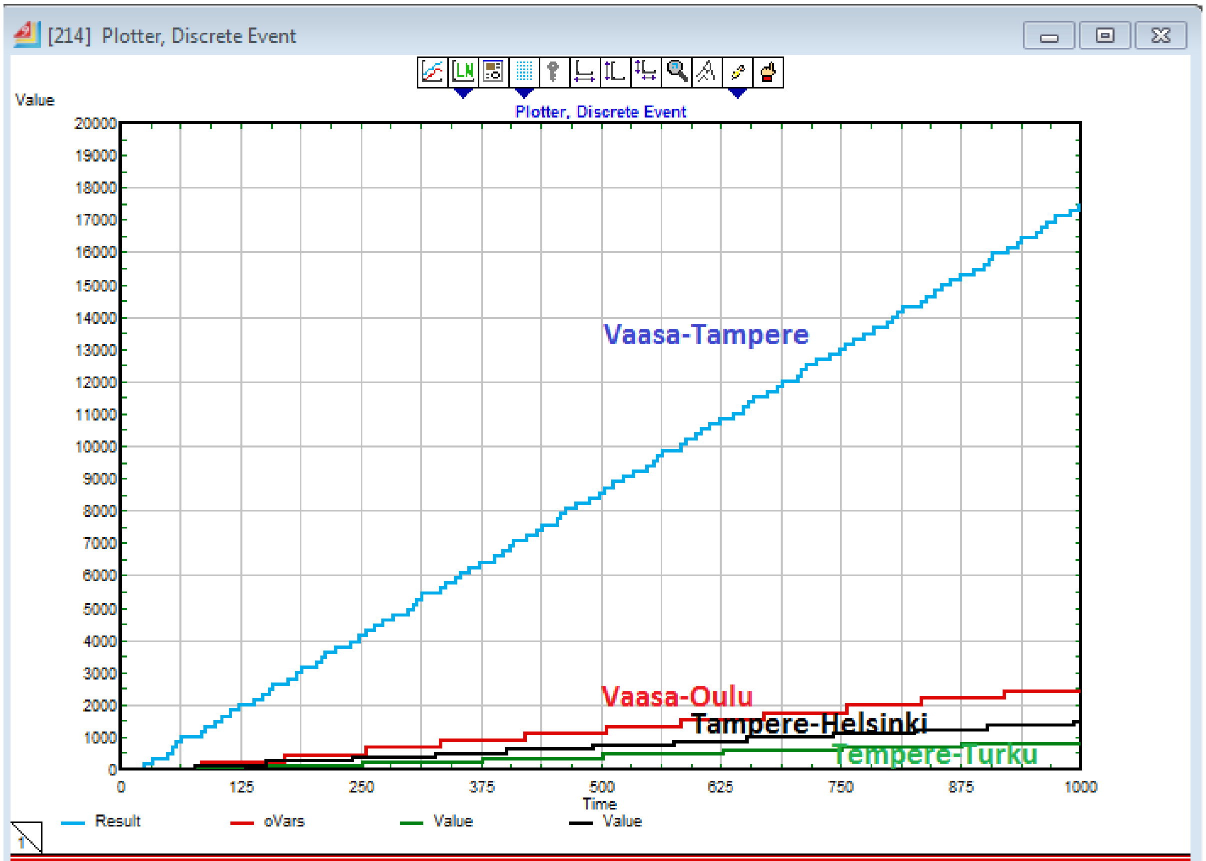
	Demand in customer cities	**Tampere**	**Oulu**	**Turku**	**Helsinki**
	Create Time	Item quality	Item quality	Item quality	Item quality
1	0	1	0	0	2
2	5	0	1	0	0
3	10	1	0	0	0
4	15	1	1	1	1
5	20	1	0	0	0
6	25	1	1	1	0

Production Rate in the Vaasa Factory

Table 21. Production rate input (model 2)

Production rate in the factory	**Create Time**	**Item Quantity**
1	0	5
2	5	5
3	10	5
4	15	5
5	20	5
6	25	5
	Repeat schedule every 25 time units	

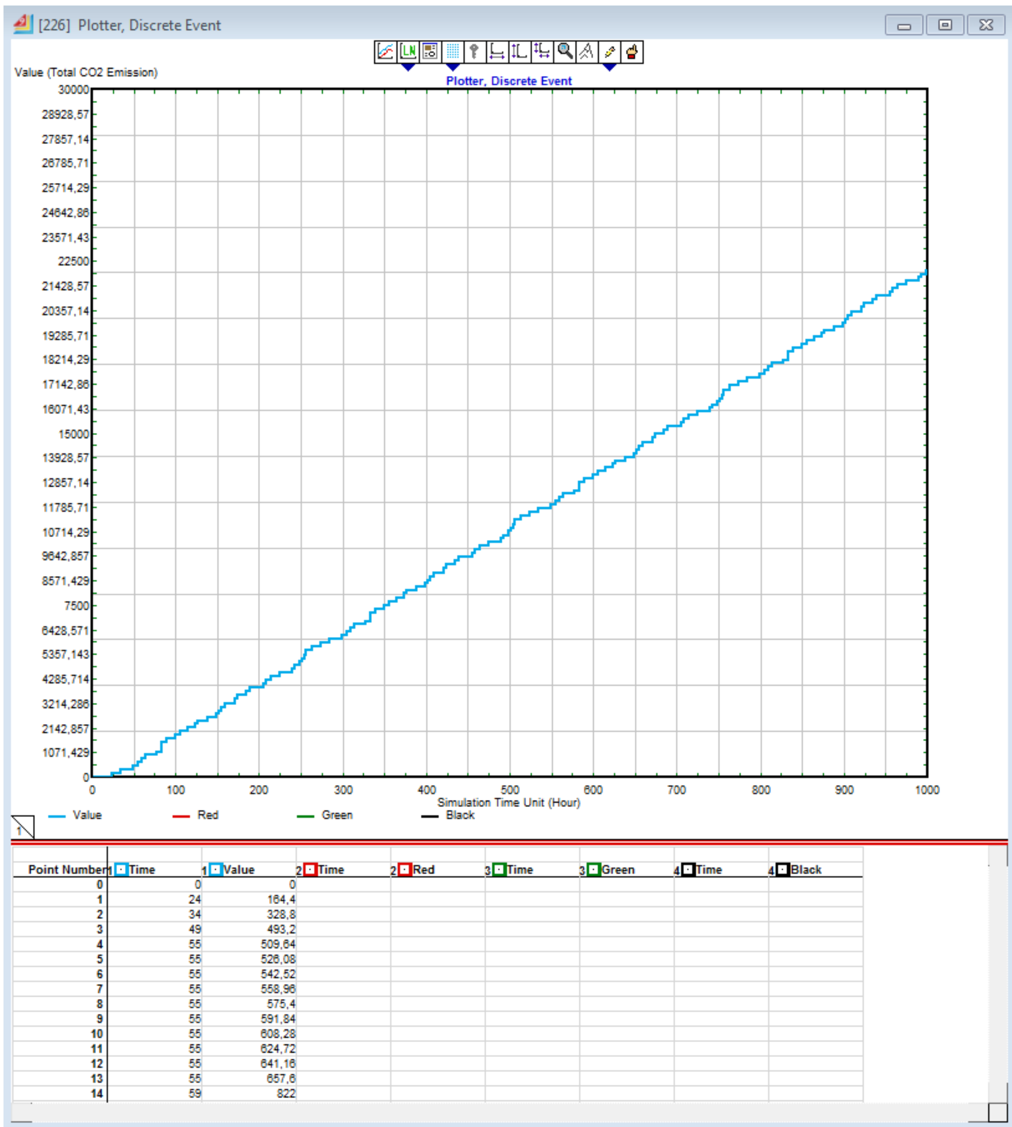
2) Simulation result is shown below:



Point Number	1 Time	1 Result	2 Time	2 oVars	3 Time	3 Value	4 Time	4 Value
0	0	0	0	0	0	0	0	
1	24	164,4	84	21,92	127,0375	11,1655	77,2375	12,261
2	34	328,8	84	43,84	127,0375	22,331	77,2375	24,52
3	49	493,2	84	65,76	127,0375	33,4965	77,2375	36,784
4	55	509,64	84	87,68	127,0375	44,662	77,2375	49,04
5	55	526,08	84	109,6	127,0375	55,8275	77,2375	61,307
6	55	542,52	84	131,52	127,0375	66,993	77,2375	73,56
7	55	558,96	84	153,44	127,0375	78,1585	77,2375	85,830
8	55	575,4	84	175,36	127,0375	89,324	77,2375	98,09
9	55	591,84	84	197,28	127,0375	100,4895	77,2375	110,353
10	55	608,28	84	219,2	127,0375	111,655	77,2375	122,61
11	55	624,72	171	241,12	252,0375	122,8205	152,2375	134,876
12	55	641,16	171	263,04	252,0375	133,986	152,2375	147,13
13	55	657,6	171	284,96	252,0375	145,1515	152,2375	159,399
14	59	822	171	306,88	252,0375	156,317	152,2375	171,66
15	64	986,4	171	328,8	252,0375	167,4825	152,2375	183,922
16	84	1150,8	171	350,72	252,0375	178,648	152,2375	196,18
17	89	1315,2	171	372,64	252,0375	189,8135	152,2375	208,445
18	99	1479,6	171	394,56	252,0375	200,979	152,2375	220,70
19	105	1496,04	171	416,48	252,0375	212,1445	152,2375	232,968
20	105	1512,48	171	438,4	252,0375	223,31	152,2375	245,2
21	105	1528,92	256	460,32	377,0375	234,4755	242,2375	257,491
22	105	1545,36	256	482,24	377,0375	245,641	242,2375	269,75
23	105	1561,8	256	504,16	377,0375	256,8065	242,2375	282,014
24	105	1578,24	256	526,08	377,0375	267,972	242,2375	294,27
25	105	1594,68	256	548	377,0375	279,1375	242,2375	306,537
26	105	1611,12	256	569,92	377,0375	290,303	242,2375	318,79
27	105	1627,56	256	591,84	377,0375	301,4685	242,2375	331,060

Figure 25. The Simulation result of CO2 emission accumulation in different transport paths

In figure 25, X-axial represents simulation time unit running from 1 to 1000 hours; Y-axial represents CO_2 emission in different transport paths. In this model, the largest part of CO_2 emission is generated in the transport path from Vaasa to Tampere. Due to Tampere is the second warehouse and distribution center, the cargo first goes to Tampere warehouse to compensate the inventory, then the orders coming from Helsinki and Turku are delivered from Tampere warehouse and not from Vaasa.



Point Number	1 Time	1 Value	2 Time	2 Red	3 Time	3 Green	4 Time	4 Black
0	0	0						
1	24	164,4						
2	34	328,8						
3	49	493,2						
4	55	509,64						
5	55	526,08						
6	55	542,52						
7	55	558,96						
8	55	575,4						
9	55	591,84						
10	55	608,28						
11	55	624,72						
12	55	641,16						
13	55	657,6						
14	59	822						

Figure 26. Total CO 2 emission accumulation result in the model of decentralized distribution network (both warehouses in Vaasa and Tampere).

The figure 26 illustrates in time unit of 1000 hours, the total CO_2 emission generated by all transport paths is accumulated from 0 to 27000 kg gradually.

5.1.3. The Conclusion of Scenario Analysis

Base on the emission calculation methodology and calculation rules, the most important and determining parameters and factors are transport distance, mass of freight transported and carbon emission factors.

Carbon emission factors are mainly determined by the transport vehicle type, emission standard, load and empty trip factors. The transport vehicle type determines payload capacity and load factor determines capacity utilization, which means how much weight of cargo can be maximally transported and what is mass of cargo has been transported in the designed model.

In the scenario analysis, the two models have same demands in all four customer cities, same production rate in Vaasa factory and same simulation time duration 1000 hours, same Truck type 40-44 ton with 60% load factor and 50% empty runs.

The discrete event simulation in ExtendSim illustrates the result that the decentralized distribution model (both warehouses in Vaasa and Tampere) generates less total CO2 emission than centralized distribution model (Only warehouse in Vaasa). The root reason by the scenario analysis is that the empty trip distance is dramatically reduced in decentralized distribution model. As far as second distribution center is located in Tampere, the trucks forwarded to Helsinki and Turku only returns to Tampere rather than they have to go back to Vaasa to load the cargos, which mean huge empty trips have been eliminated. Furthermore, due to the different transport paths in the system of decentralized warehouses, the mass of cargos transported in the distribution network are able to be more optimally organized in terms of batching process can be done in the different transport nodes.

6. CONCLUSION AND RECOMMENDATIONS

How to design a “Greener” logistics system is becoming vital to many enterprises due to their responsibilities in new environmental regulations and increasing number of customers start requiring and buying the products with green footprints. Supply chain and logistics planners always have the initiatives to design a greener logistics system but environmental impacts generated by their logistics network systems have always been intangible and not traceable. In the thesis research, a discrete event based simulation model has been built up that provides a simple and visible solution to reveal and map total carbon emission footprints in a complex logistics network system, and this simulation model also provides calculated results to show how exactly the carbon emission values in different transport paths have been generated.

To conclude the simulation modeling analysis, the carbon emission level in a simplified logistics distribution system is primarily determined by the total transport distance and different emission factors categorized by many other important parameters such as load factor, empty trip rate, batch size, vehicle type and fuel consumption rate, and so on. When designing a distribution network with aim of reducing carbon emissions, it becomes vital to supply chain and logistics planners with understanding, categorizing and prioritizing all the carbon emission factors under working mechanisms of their distribution systems. The simulation methodology and models are able to provide a very practical research platform and testing tools to the decision makers to diagnose problems or bottlenecks of their existing systems, which importantly leads to a greener logistics system design.

For research recommendations in the future, industry practicalities with valid data input from a case company logistics sector is very much needed, the whole simulation model is meant to be extended and improved to provide realistic simulations for the industry use. Moreover, a feasibility research is also recommended to proceed in the case company to exam and know explicitly how much a discrete simulation model can make the contributions and improvements to build up a greener logistics system. The optimal goal is to develop a web-based software prototype in the case company for realistic industry uses.

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