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REVERSE LOGISTICS NETWORKS WITH THE GATEWAY-CORRIDOR COMPONENTS: A CASE OF WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT

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Reverse Logistics Networks with the Gateway-Corridor Components: A Case of Waste Electrical and Electronic Equipment

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Abstract: The paper presents a reverse logistics network for the end-of-life management of waste electrical and electronic equipment for the province of Ontario and develops a dynamic simulation model that describes the behavior of the presented system and incorporates distance, cost, time and quantity variables associated with the system. Using the simulation model, the paper explores different strategic decisions and potential improvements to the system by developing scenarios on the future collection loads and the structure of the network using gateway and corridor components.

Keywords: Reverse Logistics, Simulation, Gateway-Corridor Network

1- Introduction

Today, manufacturing firms are faced with environmental rules and regulations that force them to use recyclable materials, incorporate environmental friendly practices, implement end-of-life treatment for their products, or in general "go green". These actions are usually considered as additional cost bearing burdens that are being legally imposed. However, a closer look might reveal that by making the right decisions and implementing the correct solutions, these so called burdens can be turned into new revenue streams that not only discharge legal obligations of these companies, but also act as a competitive advantage and help the organizations gain a higher market share, explore new markets, and keep a good public image. In the early environmental management frameworks, separate organizational units were responsible for complying with environmental regulations and expectations within their own area. But after the quality and supply chain revolution in 1980s and 1990s, it has become clear that today the best practices call for integration of environmental management with ongoing operations (Srivastava 2007).

Green Supply Chain Management (GrSCM) is defined as 'integrating environmental thinking into supply chain management, including product design, material sourcing and selection, manufacturing processes, delivery of final product to the consumers as well as end-of-life management of the product after its useful life'(Srivastava 2007). As one of the most important operational factors of a green supply chain system, reverse logistics (RL) is defined as a process in which a manufacturer systematically accepts previously shipped products or parts from the point of consumption for possible recycling, remanufacturing, or disposal (Dowlatshahi 2000). Manufacturers worldwide are increasingly facing responsibility for their products at the end of life and must provide collection and product recovery or proper disposal (Klausner & Hendrickson 2000). By implementing RL practices, new products and new market segments can be explored. Entities engaged in RL operations can benefit from the opportunities created by high quality remanufactured, refurbished, or recycled products with usually lower prices (Dowlatshahi 2005).

In general, RL networks are usually harder to analyze because of the uncertainties in quantity, quality, and variety of collected products and different administrative and operational costs. This complexity stems from a high degree of uncertainty due to quantity and quality of the returned or collected products (Gungor & Gupta 1999). The quality of collected products, the availability of proper infrastructure and the potential fixed and variable costs drive the decision on reusing, refurbishing, recycling or disposing the collected products. Most of the theoretical approaches require many restrictive assumptions and are unable to model complex systems. That is why in the context of supply chain and logistics modeling, simulation is considered a useful tool. Due to the complexity of many logistics networks, one may say that a simulation model is one of the few tools that can capture the dynamic nature of a system in a realistic manner (Vieira & Junior 2005). Moreover, advances in recent simulation modeling software packages provide the power of incorporating various real world dynamics and performing simulation optimization.

This paper presents a reverse logistics network for the end-of-life management of waste electrical and electronic equipment (WEEE) for the province of Ontario, Canada. The aim of this paper is to develop a dynamic simulation model that describes, with a proper level of abstraction, the behavior of the presented RL system for WEEE management and incorporates stochastic and deterministic cost, time and quantity variables associated with the system. The simulation model is then used to analyze different operational, tactical, and strategic aspects of the RL system which include measuring the system performance indicators, analyzing the system costs and benefits, gaining insight on the behavior of the system over time, and finding the effect of different network structures on the performance of the system. Moreover, the paper will try to find out how the downstream trade of the recovered material can affect the whole network structure. It will analyze the effect a specific alignment called the Gateway & Corridor Network which can be formed to facilitate the flow of the material towards a gateway city.

Next section will provide some background and describe the structure of the current WEEE management network in Ontario which will be used to develop a basic conceptual model for simulation analysis. Section 3 will provide a more detailed specification model and define the computer simulation model and its elements. In section 4, the simulation results are presented and the proposed analyses are performed. Finally section 5 makes some conclusive remarks and discusses the managerial insights and future research.

2- The Conceptual Model

EOL treatment is of great importance for electrical and electronic equipment since there are many opportunities in reusing and remanufacturing some of the parts, and specific requirements for recycling and disposing some of the parts and material (i.e. batteries) included in these products. Additionally, since the environmental risks of electronic products can be very high, there are governmental legislations and consumer expectations that require electronic manufacturers to implement recycling and remanufacturing plans. For example, the EU legislation[1] on electronic waste management restricts the use of hazardous substances in electrical and electric equipment to promote the collection and recycling of such equipment. The legislation provides for the creation of collection schemes where consumers return their used e-waste free of charge.

Canada has recently introduced e-waste regulations similar to European Union's WEEE Directive. The aim is to cut the amount of waste in landfills and to move the burden of disposal costs to producers (Feszty & Calder 2007). In June 2004, the Canadian Council of Ministers of the Environment adopted twelve principles to provide a framework to develop and set up WEEE management programs in each province. The e-waste legislations are already in place in Alberta, Saskatchewan, British Columbia, New Brunswick, Nova Scotia, and Ontario. The Ontario WEEE program is designed as a plan for collection and EOL treatment of WEEE through an extensive RL network. The first phase of the WEEE program has been operating since April 2009 and the complete phase 1 and 2 started from April 2010. Directed by the Ministry of Environment and managed and funded by Ontario Electronic Stewardship (OES), the objectives of the program include the promotion of reduction, reuse and recycling of the generated WEEE, the support and expansion of a WEEE collection system of depots and collection services, diverting significant quantities of toxic materials from landfills and the environment and increasing the current WEEE recycling rate, and shifting the cost of managing WEEE from generators and the general tax base to the producers and distributors.

A graphic overview of proposed WEEE material flow is presented in figure 1. In general, there are six functional areas that make up the WEEE management activities in Ontario:

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[1] http://ec.europa.eu/environment/waste/weee/

1. *WEEE Generation* which includes the making of WEEE materials available for reuse, recycling or disposal by the final users.
2. *WEEE Collection* which deals with the collection of material through different channels of commercial retailers, non-profit or municipal organizations, reuse and refurbishment organizations, as well as special one-time, full service, ‘turnkey’ collection events (round-up events) that are fully sponsored and supported by the WEEE program. The collected materials are sorted and packaged into 4 management groups of desktop and portable computers, display devices (monitors and televisions), other phase 1 and 2 WEEE, and floor standing copiers and printers.
3. *Consolidation* which includes the receiving of the bulk WEEE from collection agents for subsequent transport to processing centres. It is important to note that the simulation model only takes into account the materials that travel into the consolidation centres. These materials are destined for recycling and processing. Ontario is divided to four consolidation regions: East, West, Central, and North.
4. *Reuse and Refurbishment* which deals with the provision of functioning WEEE to another user for its original intended purpose or any disassembly of WEEE for the purpose of internal testing, troubleshooting or replacement or repair of non-functioning or obsolete parts. The reuse and refurbishment operations are not funded by the OES and constitute a smaller part of material flow, and therefore not considered in the simulation model.
5. *Processing and Recycling* which include the separation of a product’s component materials in preparation for recycling or disposal. The processing and recycling system can be further broken down into two functional areas: Primary Processing, and Downstream Processing and Recycling. The primary WEEE processing is the first point in the WEEE EOL management chain and includes functions like receiving for OES, sorting, dismantling, disassembly, shredding or any other material processing activity, preparing material for further downstream processing, and disposal. Downstream WEEE processing is the further manual or mechanical separation of materials by another vendor or vendors after the recovery of recyclable and non-recyclable components. Downstream processing may include the following types of activities: shredding, grinding, smelting, incineration, energy recovery, and landfill disposal. It is important to note that a great portion of the processed material end of other countries including US, China, and EU.
6. *Steward WEEE Self-Management Channel* which includes the self-managed programs that are directed by stewards (i.e. brand owners, first importers and/or assemblers of non-branded products for sale and use in Ontario that result in WEEE). This function is also not included in the simulation modeling due to its private cost structure and the lack of significance in terms of the quantity of materials.

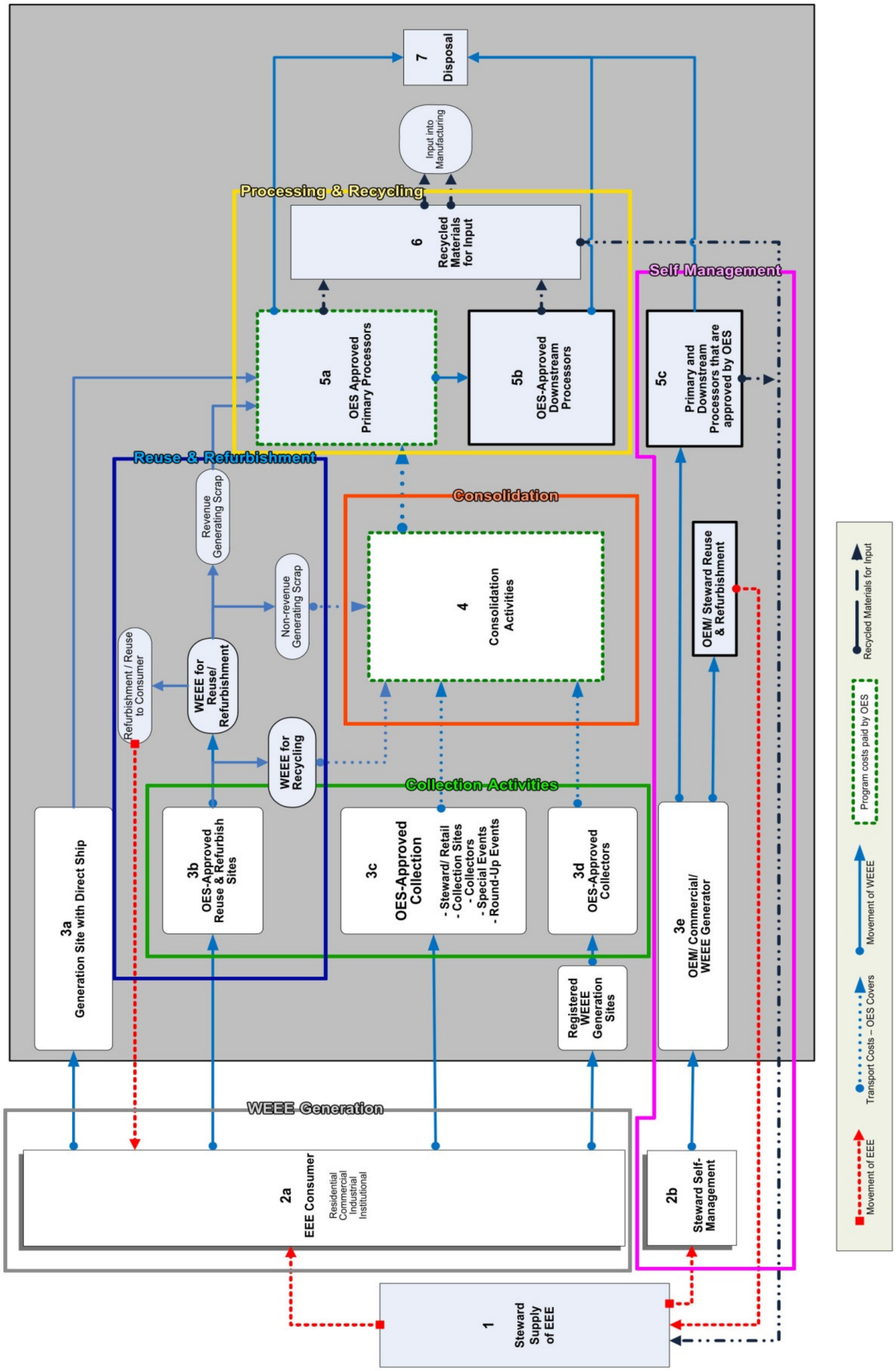

Figure 1: WEEE Material Flow and OES Funding

Accordingly, the main players in the network funded by the OES are the WEEE collectors that collect the material from the users and prepare it for consolidation, consolidators that store, inspect, and report the information about the collected WEEE, processors that dismantle and recover the valuable raw materials from collected WEEE, and transporters that move the material from collection to consolidation and from consolidation to processing. OES compensates the collectors for the collected material, pays for the transportation and consolidation costs, and closely tracks the recycling processes to make sure that they meet the required standards.

Figure 2, demonstrates the conceptual model that would be used as the basis for simulation modeling of the WEEE management in Ontario. The main functional areas considered are collection, consolidation, and processing which includes upstream processing and downstream recycling. Up to the processing function, the logistics network is divided into 4 physical regions of east, central, west, and north. For instance, the collected material from eastern Ontario only travel to the consolidation centres in the East. On the other hand, most of the processors in Canada are concentrated in the central region (GTA) and therefore there is no regional distinction between the different processing plants. Based on the type of the collected WEEE (the four packaging groups described before) the recycled material mostly consist of metal, plastic, glass, and epoxy resins (circuit boards). These materials might travel a long distance into US, Europe, or China for further processing. Of course a proportion of the collected material is not suitable for recycling and ends up in landfills.

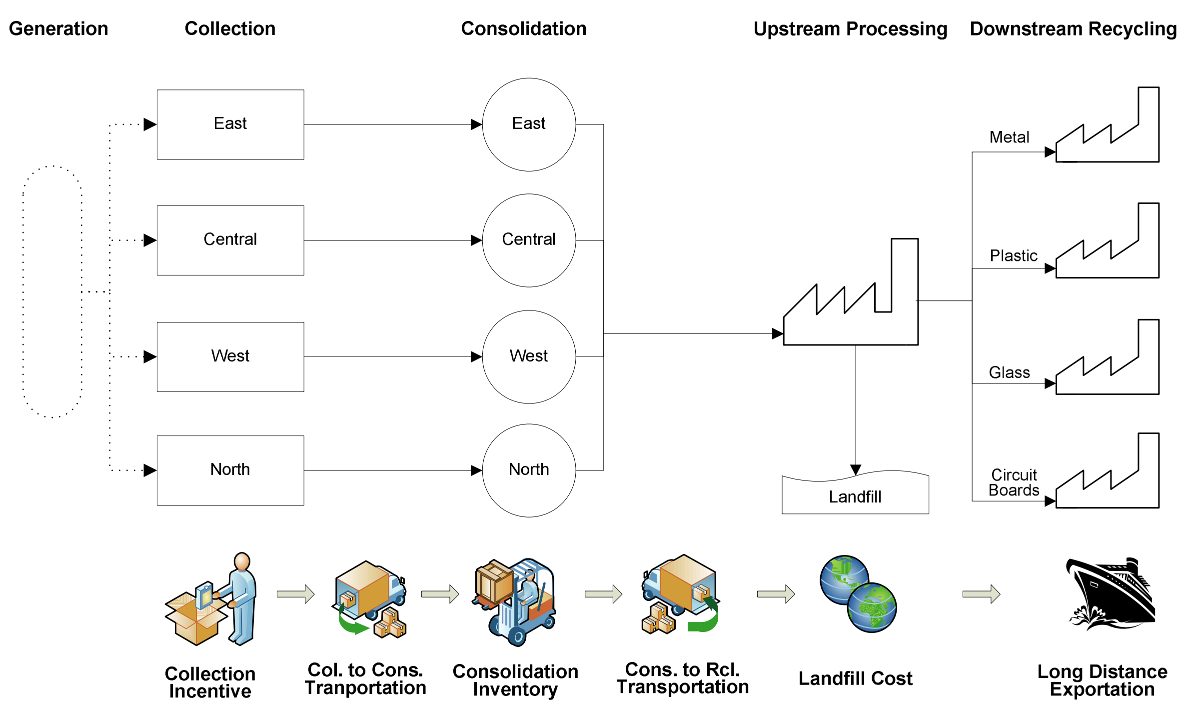

Figure 2: Ontario WEEE Management Conceptual Model

Also at the bottom of Figure 2, different cost bearing operations in the network are demonstrated. These costs are essentially covered by OES and should be considered in the simulation model. It is important to know that a hypothetic landfill cost is also taken into account as a representative for environmental damage caused by dumping the unrecyclable material into landfills. Moreover, for further analysis of transportation costs and environmental footprints, the fate of the recovered material will be considered as a part of the output analysis. This is where the long distance transportation costs for exporting the material to their different destinations might be of special interest since those materials should be hauled to the export gateway.

In the next section, we will further break down the elements of the conceptual model deriving the specification and computer models.

3- Simulation of the WEEE flow

The specification model is the corner stone for the development of the final computer model. It includes the main processes to be modeled and identifies the data requirements for each process. It also pins down the main outputs that should be measured at each stage. Having defined the specifications of the model and refined the data, the computer model reflects the behavior of the system in a specific simulation platform and provides the possibility of changing the variables and redefining the system structure to generate and analyze different scenarios.

Figure 3 demonstrate the specification model for simulation of the Ontarian WEEE management network. Four main functions are considered in the specification model. Collection, consolidation, and processing will be modeled as interactive sub-models in the computer model. Transportation is considered as an independent function due to its importance in cost analysis. Below, we will discuss each of these functions and present the assumptions and the input data. The sources for the input data are the OES WEEE program plan, expert opinions (OES professionals), and site visits (consolidation).

3-1- Collection

Collection is the starting point for the flow of material in the simulation model. According to the OES professionals, there are more than 600 collection centres all around Ontario that include private, non-profit, and municipal organizations. Modeling 600 nodes would make the simulation model very complex and heavy. Furthermore, there are no detailed data available on the flow of material from each of these collection centres. The most detailed collection data available breaks down the collection estimates into 4 Ontarian regions. To find the collection estimates for different geographical locations across the

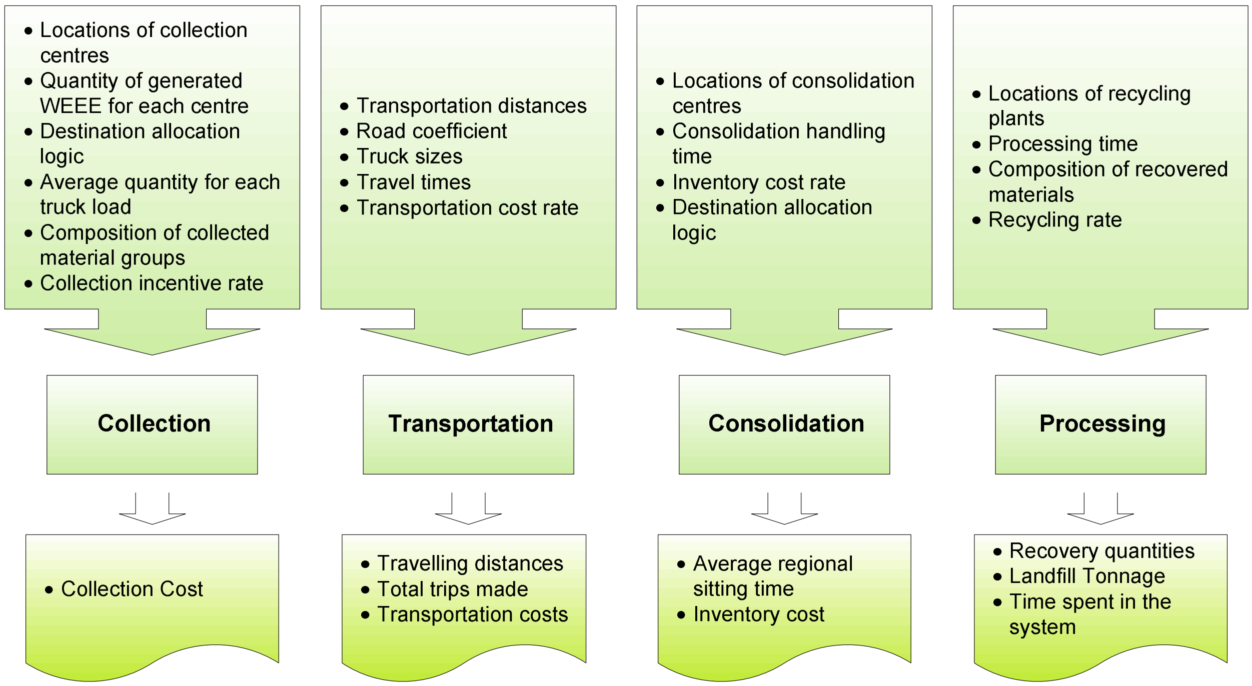

Figure 3: Specification Model for Simulation

province, 48 counties, divisions, and districts in Ontario are considered as collection nodes. The aggregated collection data for each of the four regions are then broken down based on the population of each county, division, or district. For each of these counties, the geographical location of the collection node is considered as the centre of population in each county. The resulting collection estimates in tonnages are then converted to the estimated number of pallets since the number of pallets is the counting unit used in the real system. Each pallet is considered to weigh 330 kilograms which is the number presented in the program plan and confirmed by the operating consolidation centres. Each collection centre should have at least 6 pallets available, before it would be able to schedule a pick up by a consolidation centre. However, according to the expert opinion of consolidation centre employees, the average truckload is usually around 12. Using the yearly estimate of the number of collected pallets, the average truckload, and 260 operating days in year 2009 with single 8 hour shifts, the average time between pickups from each of the collection nodes is simply calculated by:

$$\frac{260 \times 8 \times 12}{\text{collection estimate}}$$

The resulting pick up/dispatch mean frequencies are used as the mean for the exponential distributions that create the material flow in the computer model. The detailed collection data for different Ontario counties and different material groups are presented in Appendix I.

Table 1 summarizes the basic collection information for the baseline year of 2009. This baseline year data will be used as the baseline input to the computer model. It is important to note that a compensation of 165 dollars for each tonne of collected material is paid to each of the recycling centres.

The geographical positions for each of the collection counties, divisions, and districts are presented in Appendix II. These numbers will be used to calculate the distance between the collection nodes and consolidation centres. The destination of the trucks dispatched from each of the collection nodes would be the closest consolidation centre within the region. The calculation method for the distance between two geographical positions will be described in the next section. The only calculated output in the collection sub-model would be the collection cost. It would be measured by multiplying the collection rate by the tonnage of collected material (approximately one third of the number of dispatched pallets).

Table 1: Basic Collection Information for the baseline year of 2009

Baseline Year (2009) Summary	
2009 Population Est.	12852220
Collection Est. (Ton.)	39552
Collection Est. (Pallets)	118656
Average Truck Payload (Pallets)	12
Average pallet weight (Kg.)	330
2009 Business Days	260
Daily Working Hours	8
Collection Incentive (CAD)	165

3-2- Transportation

Ontario WEEE program covers the cost of transportation from the collection nodes to consolidation centres and the consolidation centres to processing plants. As mentioned before, the trucks from collection to consolidation hold an average of 12 pallets. The trucks that are used to send the consolidated material to processing plants are bigger and take up to 24 pallets. There are two systems that can be used to calculate the distance between the collection nodes and the destination consolidation centres by using coordinates of the two nodes: Universal Transverse Mercator (UTM), and Geographic Positioning System (GPS). Since Ontario is extended within more than one UTM zone[2], it is preferable to use the GPS method in order to get more accurate results. Because of the near-spherical shape of the Earth, GPS method calculates the distance by using spherical geometry and trigonometric math functions. Therefore the following formula is used to calculate the accurate distance:

[2] UTM is a practical application of a 2-dimensional Cartesian coordinate system and divides the surface of the Earth into 60 longitude zones. It provides near accurate results when the two points are in the same zone.

$$\mathbf{r} \times \mathbf{acos}[\mathbf{sin}(\mathbf{lat1}) \times \mathbf{sin}(\mathbf{lat2}) + \mathbf{cos}(\mathbf{lat1}) \times \mathbf{cos}(\mathbf{lat2}) \times \mathbf{cos}(\mathbf{lon2} - \mathbf{lon1})]$$

where r is the radius of earth in whatever desired units and latitudes and longitudes are in radians which are calculated by dividing the decimal degrees by 180/pi. For the purpose of simulation modeling, r in this formula is considered to be equal to 6378.7, which makes the resulting distances in kilometers. Moreover, to find the actual road distance, the calculated distances are multiplied by a road coefficient of 1.5. This coefficient was derived by comparing the calculated distance between some sample pairs of nodes and the actual road distances available in Google Maps. The transportation time is calculated by considering an average speed of 85 kilometers per hour which is used as an input to a normal distribution with a standard deviation of 5 minutes, assumed to capture the uncertain nature of the travelling times.

The measured outputs from this sub-model are the total covered millage by the whole transportation fleet during the baseline year, the average travelling distance per pallet from collection to consolidation and from consolidation to recycling, the total number of trips made (truck calls) and the per pallet and total transportation cost. Transportation rates of $ 3.5 per kilometer for trucks from collection to consolidation and $ 5 per kilometer for trucks from consolidation to recycling are assumed as the industry norm.

There are no limitations on the number of available trucks. Since the transportation is outsourced to some huge transportation companies all across Ontario (including Cardinal Couriers and Manitoulin Transport), the trucks are usually available whenever needed. However, it is possible that in the future for higher system loads, truck capacity would become an issue. The simulation model assumes unlimited number of trucks available but imposing actual trucking limitations is easily possible if regional data is acquired.

3-3- Consolidation

Figure 4 illustrates the geographical positions for the 15 consolidation centres currently active in Ontario. The coordinates for these centres are presented in Appendix III. These coordinates are used to calculate the distances between these centres and the collection nodes, as well as the recycling plants.

An average time of 3 hours is assumed for unloading, inspection, weighing and reporting of the WEEE received at each consolidation centre. It is also assumed that each consolidation centre has 3 people that would work on the received material at each time. Obviously, different consolidation centres might have different processing times based on the capacity and staffing. More detailed information can be further added to the model to improve the results. It is important to note that the 3 hour processing time does not include the processing queue waiting time and the time that each pallet has to wait until a batch of 24 pallets is processed and send out to the processing plants. The sum of the processing time, queue waiting time and the batch waiting time is calculated as the aggregated sitting time in consolidation and measured as one of the outputs in this sub-model. The other output at this stage would be the inventory cost which is calculated by multiplying an assumed rate of $5 per pallet per hour by the sitting time in hours.

Unlike the collection to consolidation route, the destination allocation logic at this stage is not merely based on a regional minimum distance logic. The logic used in the simulation model is based on a random semi regional decision making weighted by the route distance. The consolidation centres in Eastern Ontario send their trucks randomly to one of the processing plants in Eastern or Central Ontario. The closest recyclers have a higher chance of receiving the material. Since there are no processing plants in north, the northern consolidators send their material to central processors. For western Ontario, the recipients are western and central processors and for the central Ontario itself, the material is obviously sent to central processors.

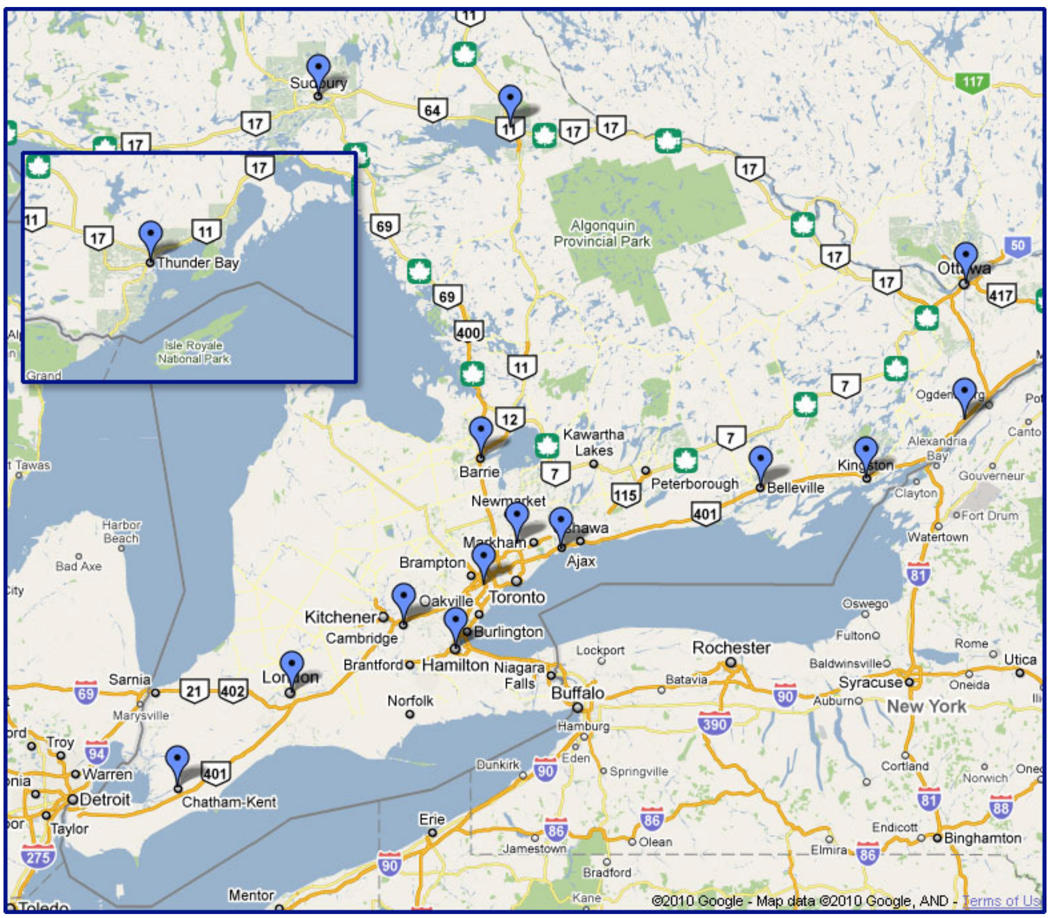

Figure 4: Map of WEEE consolidation centres in Ontario

3-4- Processing

Figure 5 illustrates the geographical locations for the recycling plants in Ontario. The coordinates for these plants are also presented in Appendix III. These coordinates are used to calculate the distances between consolidation centres and the recycling plants. Also it is assumed that an average time of 24 hours (3 business days) is required for each truckload to be dismantled, processed and broken down into the main composing materials which can be metal, plastic, glass, and epoxy resins. The given average processing time is used as a mean to a normal distribution that represents the uncertain processing time in the simulation model. The standard deviation to the normal distribution is assumed to be 3 hours. These two numbers are just sound assumptions that had to be made due to the lack of data on processing stages and time.

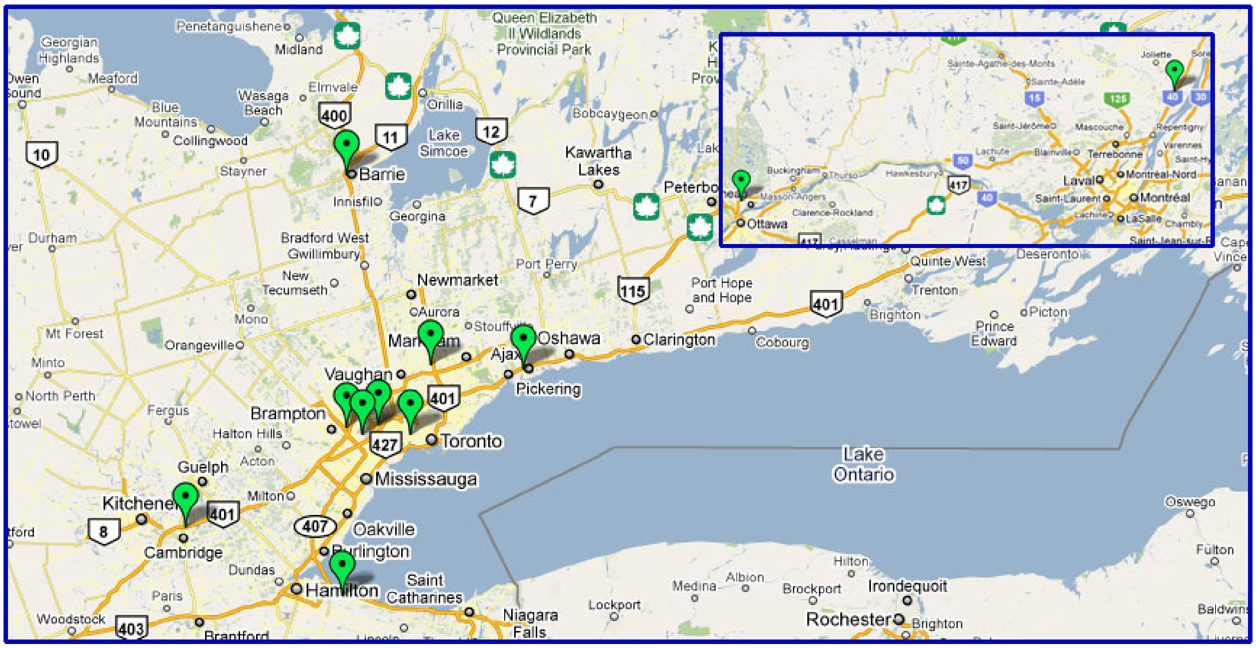

Figure 5: Map of WEEE processing and recycling centres in Ontario

Table 2 shows the decomposition ratios for each of the material groups that identify the ratio of the recovered material from each WEEE group. These ratios are acquired from the OES phase 1 WEEE management program plan. Using these ratios, the simulation model calculates the total tonnage of recovered material types during the baseline year.

Also according to the OES final phase 1 and 2 WEEE management program plan, the processing plants have an average recovery rate of 77.5 percent. This percentage is used to measure the total amount of material that end up in the landfills. Clearly having the specific recycling rate for different recycling plants can provide more accurate outputs on the WEEE that end up in landfills of each Ontarian region.

Table 2: The decomposition of recovered material for different WEEE material groups

Collected Material Groups	Decomposition of Recovered Material			
	Metal	Plastic	Glass	Epoxy Resins (Circuit Boards)
Desktop & Portable Computers	0.82	0.07	0.00	0.11
Display Devices	0.40	0.25	0.33	0.02
Copiers & Printers	0.14	0.85	0.00	0.01
Other WEEE	0.35	0.60	0.00	0.05

The last output that is measured in this sub-model is the total time that a pallet spends in the system. This time includes the transportation times, consolidation sitting time, and recycling processing time.

3-5- Computer Model

The following research uses Arena 12.0 as the simulation tool for modeling the WEEE RL network. Arena represents an advancement in simulation technology by enabling enterprise-wide simulation. It is a comprehensive system that addresses all phases of a simulation project from input data analysis to the analysis of simulation output data (Hammann & Markovitch 1995). Following a hierarchical structure, the WEEE management network was modeled in Arena using specific sub models for collection, consolidation, and processing. An illustration of the modeling process can be viewed in Appendix IV. In the modeling process, 22 different variables, arrays and matrices were defined to accommodate the complex modeling of the system. The model also contains 300 assign modules that define the attributes for different entities, 20 decide modules that act as if statements, 26 stations that define the physical locations for consolidation and processing, 48 create modules that create the WEEE from different locations, 32 record modules that record the output measures, and a lot more of different advanced processing and advanced transportation modules.

4- Analysis of the Results

In this section, the simulation model will be used to analyze key performance measures within the modeling scope. It will also be modified in terms of input variables or slight structural changes to incorporate the desired 'to be' state scenarios and analyze the behavior of the system given the new situation. The first step in analysis of the outputs, however, is to record the required parameters by running the 'as is' state simulation model. It is important to note that the number of simulation replications of the model should be enough to give us proper estimates within the required confidence intervals. According to Law & Kelton (2000), the number of simulation replications (n), is calculated by the following formula:

$$n = \frac{Z_{\alpha\backslash 2}^{2}\sigma^{2}}{d^{2}}$$

where d is the accuracy expressed, Z is the critical value from the standard normal table at the given confidence interval, and σ is the standard deviation desired. Therefore, 70 replications as calculated, we carried out in order to achieve a 95% confidence interval when comparing different performance measures within different system scenarios.

If there is any actual information on any of the system performance indicators, the simulation outputs can be compared to the real world data as a way of calibrating and validating the model. However, validation might be a challenge for simulation models of the systems that are not yet operative or there are no actual dynamic data on the system performance measures. In these cases, the validation is usually achieved by measuring some of the operational outputs of the system and comparing them to short-term performance indicators in the system as well as referring to the expert opinion. It is also important to note that the main role of the simulation model is to make "what if" analysis on different states of the system. As long as the model provides a fair presentation of the relevant operational aspects of the real system, it can be assumed as a good basis for making desired changes and comparing the results since all the scenarios are built upon the same model.

The final WEEE management phase 1 and 2 program has been operative since April 2009 and it has completed a 1 year period of operation. However, the actual data on the performance of the system is not out yet. Our sources of data to help us gain an idea on the accuracy of the modeling results are the yearly cost estimates available in the program plan, as well as some operational information gained from the held interviews with program officials. In the next section, we will describe our selected performance measures of the system and compare them to the real world data where available.

4-1- System Performance Measures

To provide a holistic view on different aspects of the WEEE management network simulation model, we will look at 4 types of performance indicators: Distance, Time, Cost, and Quantity. These measure would provide a good sense of how the system behaves in the real world.

Table 3 provides the distance values for the first 5 replications of the simulation model as well as the average for the total 70 replications. We measure two types of transportation performance measures. Average travelling distance per pallet demonstrates the distance in kilometers that each pallet travels from the point of collection to consolidation and from consolidation to processing. Also, we will calculate the total distance in kilometers, which is covered under the execution of WEEE management program. This total distance includes the total kilometers that all the trucks cover from collection to consolidation and consolidation to recycling.

Table 3: Distance Measures - Ontario WEEE management network simulation output

Replication #	Distance Measures (Kilometers)			
	Average Travelling Distance Per Pallet (PP)		Total Distance Covered	
	Coll. to Cons.	Cons. to Rcy.	Coll. to Cons.	Cons. to Rcy.
1	52.6426	200.64	523,008.00	982,971.00
2	52.5614	200.74	515,695.00	975,817.00
3	52.2316	201.06	524,755.00	993,873.00
4	51.1389	198.72	510,056.00	972,952.00
5	52.2692	204.61	517,910.00	998,817.00
Average (70 Reps)	51.69	198.28	508,983.17	958,516.36

In addition to being used as a basis to calculate the transportation costs, these numbers provide and interesting insight on how the transportation segment of WEEE management network actually affects the environment itself. In other words, assuming that there was no such a system and all the WEEE materials were disposed at the collection centres, the Ontario roads (and the environment) would see a total travelling distance of 1,467,499 kilometers less than what is happening with the execution of WEEE management network in year 2010. This is a very interesting issue which has recently attracted some attention especially for the case of WEEE management in Europe. For example, Barba-Gutierrez et al. (2008) show that under certain circumstances, the environmental impact of WEEE program in Europe can even be higher than non-collection.

Time is a popular performance measure in analysis of supply chain and manufacturing systems. Cycle times and lead times are usually amongst the outputs of these simulation models. In the reverse logistics network for WEEE management, we calculate the overall time that each entity (WEEE product pallet) spends in the system to provide a view on the time frame of WEEE operations. Moreover, we calculate the average time that the pallets spend in different regional consolidation centres. In addition to being used as a basis to calculate the inventory costs, these time averages provide an understanding on the fluidity of the material through the consolidation centres and can be used to analyze the impact of different material loads and material collection scenarios (for example the impact of collection events) on the consolidation processing capacity and the possibility of congestion. Table 4 demonstrates the time measures.

Table 4: Time Measures - Ontario WEEE management network simulation output

Replication #	Time Measures (Hrs)				
	Time in Consodliation (PP)				Time spent in system (PP)
	East	Central	West	North	
1	6.1946	29.2951	4.1589	8.8052	6.1946
2	6.1050	31.5987	4.2406	9.2366	6.1050
3	5.9572	18.9549	4.0094	9.1547	5.9572
4	5.8844	15.9859	4.2313	9.4784	5.8844
5	6.1140	17.0827	4.3164	8.4597	6.1140
Average (70 reps)	6.13	27.60	4.25	9.27	45.50

According to an interview with the experts from the main consolidation centre for WEEE management in Kingston, Ontario, one day is the average time that the materials spend in the warehouse before they are sent to recyclers. They also indicate that this time might become a little longer since WEEE takes up only around 20% of their activities and there might be some waiting time for identification of the recipient recyclers by OES. As we can see from table 4, the average 6 hours is a sound result considering the assumed 8 hour shift. It was also mentioned that the congestion in the consolidation centre sometimes occurs after huge round-up events in Ontario, which makes the material stay for around 1 week in the centre before they can be processed and sent out. The round-up scenario would be analyzed further ahead in the next section.

Table 5 presents the cost measures as calculated by the simulation model. Cost measures are of great importance since they are the basis for most strategic decisions. As mentioned before, the cost centres in this model are collection, consolidation inventory, transportation, and a hypothetic environmental cost of dumping the material in landfills.

Figure 6 illustrates the cost break down structure of the WEEE management operations as gained from the simulation model. We can see that collection, transportation and consolidation constitute the highest costs of the system. While collection costs are directly related to the compensation for collection centres and cannot be impacted from an structural decision making point of view, the transportation and processing costs are impacted by strategic decisions such as the locations of consolidation centres and recycling plants, flow of the material in the system, and the number of available nodes in the system. These costs are used as the main objective values for analyzing such strategic decisions in the next part of this research. It is also important to note that the resulting costs are almost close to the target estimates as proposed by the OES program plan. For example, according to the cost estimates presented in OES WEEE program plan, the transportation cost is estimated to be 6,846,000 dollars which is very close to the simulation output of 6,593,780 dollars (proximity of 3.6%).

Table 5: Cost Measures - Ontario WEEE management network simulation output

Replication #	Cost Measures (CAD)				
	Collection	Cons. Inventory	Transportation		Environmentral (Landfill)
			Coll. to Cons.	Cons. to Rcy.	
1	6,665,890	6,781,292	1,840,522	4,924,885	1,332,000
2	6,602,805	7,185,215	1,814,776	4,889,181	1,308,000
3	6,723,090	4,655,945	1,846,688	4,979,461	1,332,550
4	6,633,880	4,073,044	1,795,217	4,874,740	1,332,650
5	6,619,855	4,272,921	1,822,672	5,004,069	1,324,600
Average (70 Reps)	6,584,790.14	6,403,739.09	1,791,337.56	4,802,442.69	1,308,980.71

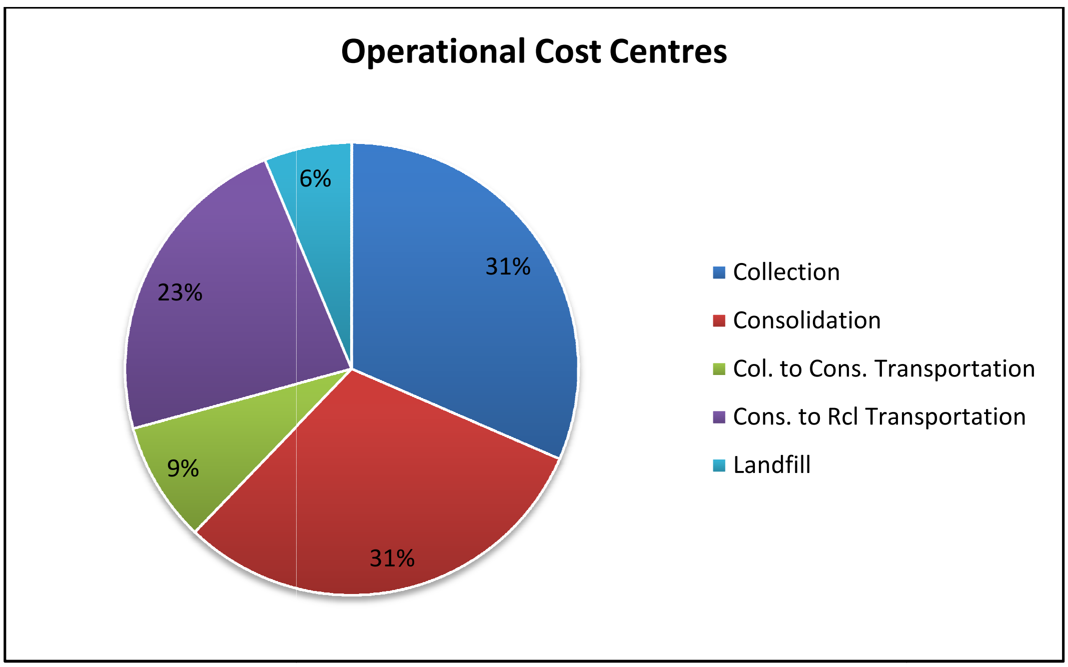

Figure 6: Cost breakdown of the WEEE management operation as measured by the simulation model

The quantity performance measure includes the recovery quantities of materials, total number of transportation trips made (table 6), and the number of allocated trucks to each recycling centre (table 7). The recovered material quantities are based on different types of collected material groups.

By looking at the recovery quantities and the truck allocation quantities to different recycling plants, we can find out how much recovered material of each type is produced at what regions of Ontario and how much material ends up in landfills in each region. This can be of special interest, since tracing these recovered material shows that they might actually end up in other countries around the globe. We will take a look at this issue when analyzing the effects of strategic decisions.

Table 6: Quantity Measures - Ontario WEEE management network simulation output

Replication #	Quantity Measures						
	Total Number of Trips Made		Recovery Quantities (KG)				
	Coll. to Cons.	Cons. to Rcy.	Metal	Plastic	Glass	Epoxy	Landfill
1	10,080	4,912	12,636,916	10,963,700	5,577,639	1,049,754	8,871,120
2	9,999	4,874	12,602,990	10,906,492	5,524,229	1,051,306	8,711,280
3	10,168	4,956	12,819,775	11,049,795	5,636,826	1,067,810	8,874,783
4	10,078	4,909	12,662,557	10,886,757	5,598,894	1,051,524	8,875,449
5	10,026	4,894	12,606,486	10,903,560	5,578,402	1,045,539	8,821,836
Average (70 Reps)	9,969	4,847	12,501,454	10,809,516	5,510,445	1,039,503	8,717,812

Table 7: WEEE allocation to different recyclers - Ontario WEEE management network simulation output

Replication #	Recycling Allocation (Trucks)										
	ADL	Artex	Ecy.	FCM	GEEP	Greentec	LaRe.	Mida	Sims	Target	Tor.
1	601	640	608	134	455	83	158	429	636	580	642
2	612	614	632	135	428	97	135	443	638	581	615
3	584	625	628	129	475	110	156	453	635	588	630
4	618	615	631	147	468	106	139	461	600	551	633
5	608	645	642	148	437	119	131	422	655	559	586
Average (70 Reps)	606	615	618	135	445	110	146	443	618	572	595

We have defined the performance measures of the system and gained an initial idea on the values of distance, time, cost, and quantity measures of the simulation model. Now having the system in a box, we can make any kind of changes and analyze the impact on the related performance measures. This is called “to be” state analysis.

4-2- Analysis of Different WEEE Collection Input Loads

The WEEE management program plan sets collection targets for the next 5 years of program operations (table 8). In developing the collection sub-model of our simulation model, we used the regional collection estimates and material group collection ratios available for the baseline year. Now, by using the same collection ratios and regional collection shares, and keeping all the other modeling parameters constant, we will increase the input collection loads using the yearly estimates and see how this increase will affect our system.

Table 8: 5 year collection targets for WEEE program in Ontario

Baseline	Year 1	Year 2	Year 3	Year 4	Year 5
39552	46617	52507	61492	72478	84732

The performance measures that we consider in analyzing the collection load scenario include the time and cost factors. Time factors can demonstrate the possible congestion in the consolidation centres and cost measures can reflect the significance of the changes in operational cost compared to each other. Of course since all the materials are assumed to be eventually processed, the quantity measure is thus not important.

When running the simulation model with the new collection loads, we encounter an interesting phenomenon. The simulation model gets overloaded when putting in the collection loads for years 3 to 5. This means that the material input frequencies in some of the consolidation centres become greater than their capacity to process the material and as a result, the centres become overloaded with tons of material that they cannot handle. Table 9 shows the average sitting time in consolidation centres for each of the Ontarian regions, given the new input loads for years 1 and 2. Also figure 7 compares the average time each pallet spends in the system for the 70 replications of the simulation model and the 2 new collection load input scenarios.

Table 9: Average sitting time (hrs) in consolidation centres for the first two years of the WEEE program

	Baseline	Year 1	Year 2
East	6.13	5.56	5.23
Central	27.60	98.88	135.93
West	4.25	3.84	3.58
North	9.27	7.97	7.16

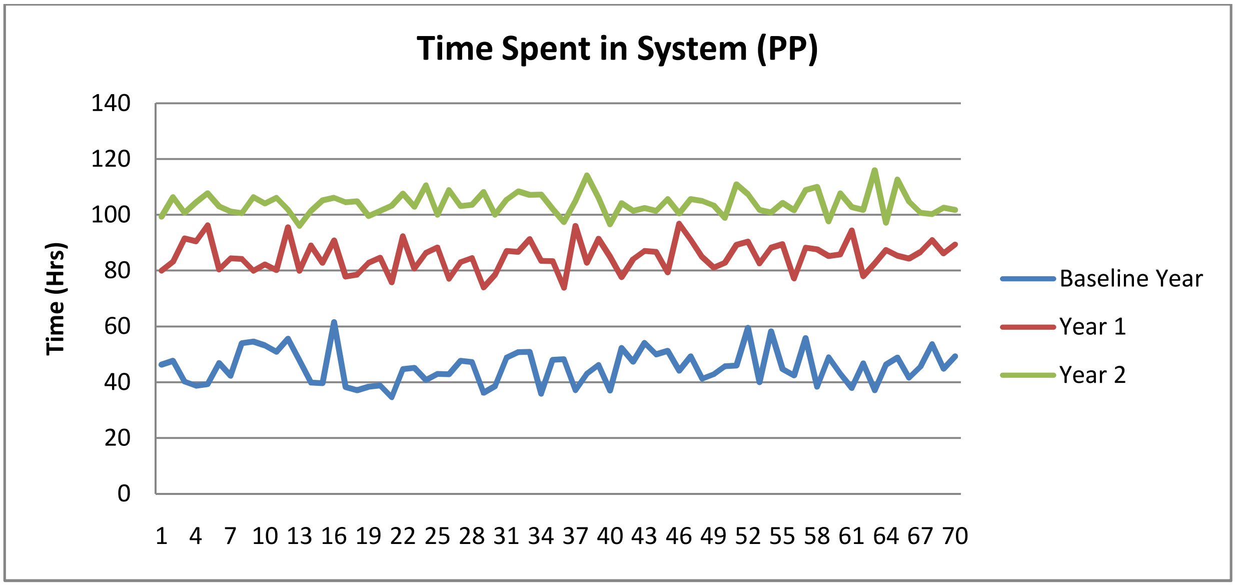

Figure 7: Average time in system for the next two years of the program

Looking at the values of sitting time in consolidation centres, we observe that increasing the system load in the regions of east, west, and north in fact decreases the consolidation inventory cost. Because of the available capacity and the low frequency of material inputs to the consolidation centres in these regions, the inventory cost mostly is incurred because of the waiting of materials sitting in these centres in order to satisfy the 24 pallet requirement so that they can be dispatched for recycling. On the other hand, we see a dramatic increase in the inventory time for the central region. Already having a higher average inventory time in the baseline year, some of the central consolidation centres deal with congestion problems and therefore increasing the system load would trigger higher congestions and inventory sitting time. By adding a couple of new record modules to the model, it is also possible to identify the specific congested centres in central Ontario.

Table 10 and figure 8 demonstrate the effect of increasing the system load on different system operational costs. We observe that the load increase does have an increasing effect on all the cost. However, taking a closer look, we can see that the collection, transportation, and landfill cost follow a natural smooth increasing slope consistent with the system load increase. On the other hand, the consolidation inventory cost follows a steep increase which is of course because of the imposed congestions on the central region.

Table 10: The effect of increasing the system load for the next 2 years on the system operational costs

	Cost Measures				
			Transportation		
	Collection	Cons. Inventory	Coll. to Cons.	Cons. to Rcy.	Environmentral (Landfill)
Baseline	6584.7901	6403.739086	1791.337557	4802.442686	1308.980714
Year 1	7735.7618	22618.84693	2104.951929	5567.746871	1466.973571
Year 2	8705.1368	32675.55589	2367.318514	6244.689829	1599.918571

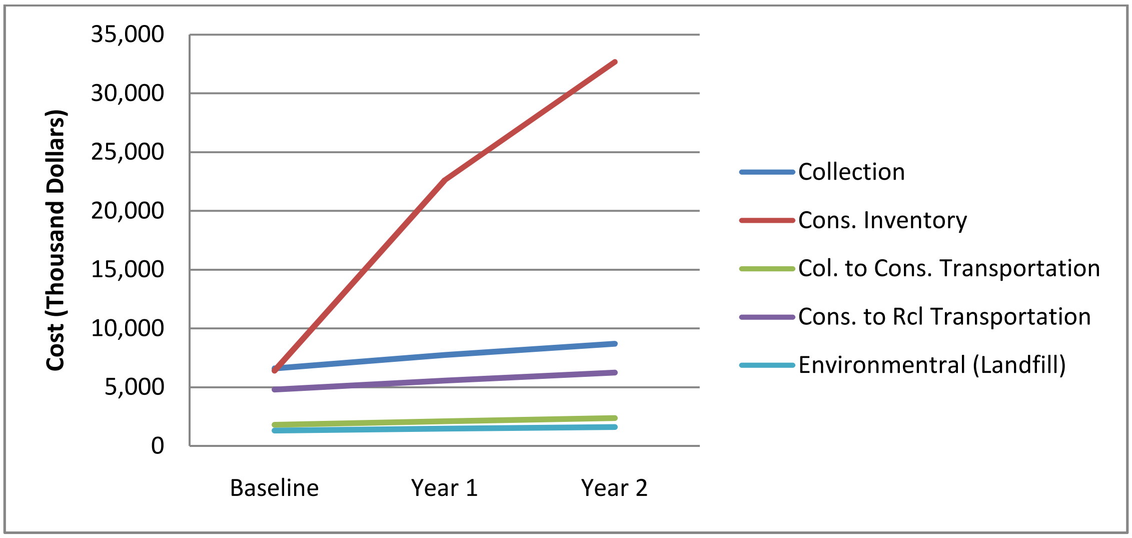

Figure 8: The effect of increasing the system load for the next 2 years on the system operational costs

5- Analysis of the Network Structure: The Gateway and Corridor Components

As the director of the WEEE management program, OES tracks the material up to the upstream processing. OES has no contractual relationship with the downstream vendors. Of course the certified upstream processors have to comply with some regulations that include their downstream network as well. For example, The OES Electronics Recycling Standard does not allow export of WEEE to countries that are not members of the Organization for Economic Co-operation and Development (OECD) or the European Union, unless the primary processor can demonstrate that any/all downstream processors meet or exceed environmental, health and safety standards equal to Ontario requirements.

Looking at the downstream processing of the recovered parts and material, we observe that most of the materials actually end-up outside the country. Figure 9 illustrates the mapping of the downstream processing activities and types of the companies involved as explained by the OES recycling standards. We can see that USA, EU, and China are the recipients of a great part of recovered parts. In fact, international trade of electronic waste has attracted the attention of several researchers in the recent years. Lepawsky and McNabb (2010) map the international trade routes of electronic waste and quantify the directions and magnitude of this trade on a global scale. Figure 10 demonstrates the global trade of E-waste in 2006 based on the information gained from the United Nations Commodity Trade Statistics Database.

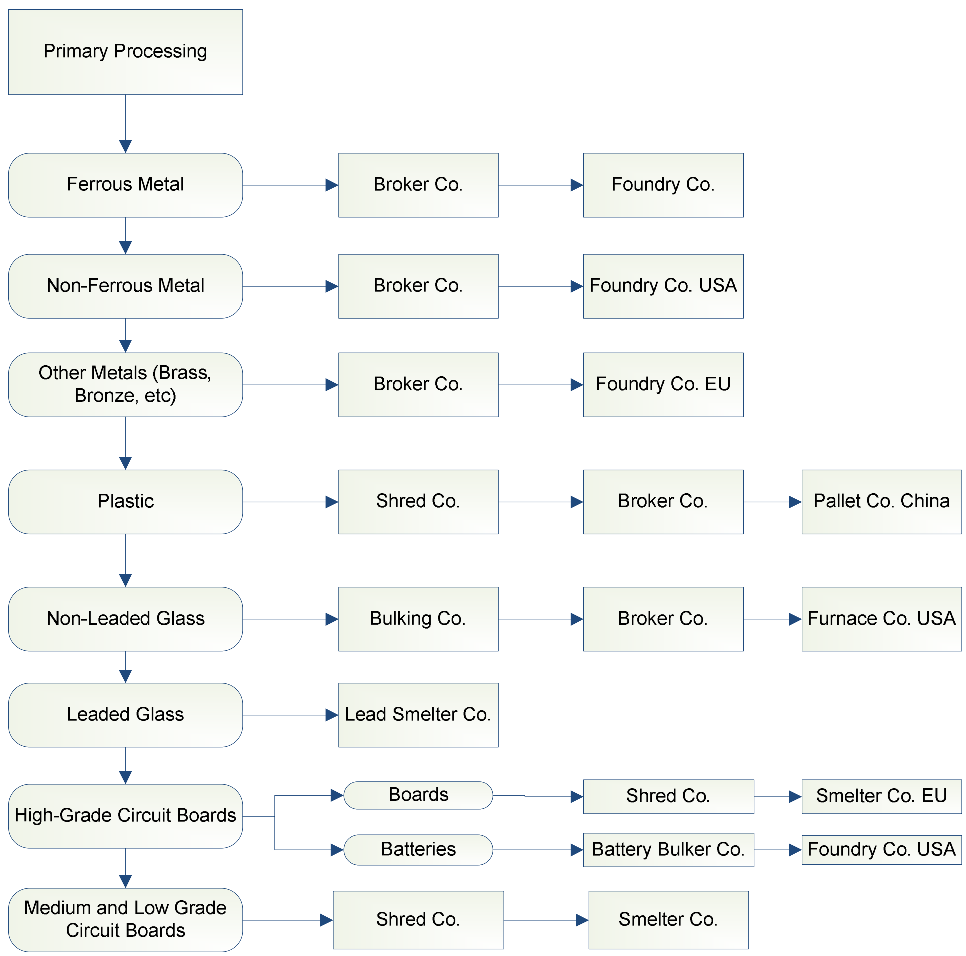

Figure 9: Mapping of the WEEE downstream processing

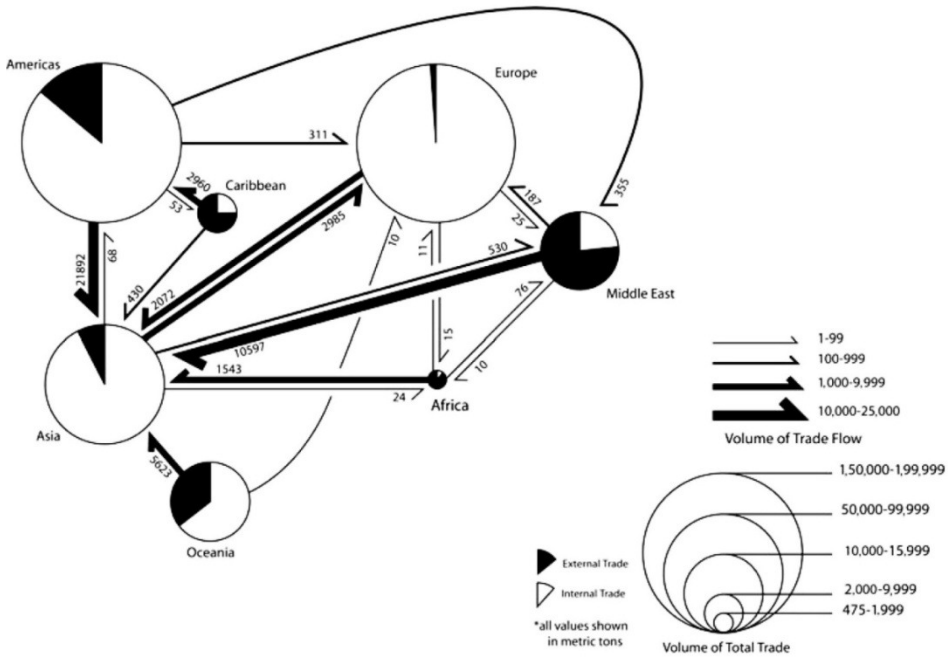

Figure 10: Global trade in e-waste 2006 (Lepawsky & McNabb 2010)

Getting back to the argument on the environmental foot prints of transportation as a downside to the WEEE management programs, it would be interesting to consider the fate of the recovered material and the transportation involved in the downstream network. We will consider one or more channels of recovered material flow and figure out how the alignment of the whole WEEE network (locations of the consolidation centres and recyclers) can affect the carbon footprints of transportation in upstream and downstream networks.

Looking at Figure 9, we see that China & Europe are the recipients of a fair amount of recovered e-waste including metal, plastic, and circuit boards. Since there are no available data on the quantities of the materials going to each of these different locations, we make a simple assumption that Europe would be the recipient of the recovered circuit boards and one third of the recovered metal, and China would be the recipient of the recovered plastic. We consider Montreal as the destination city for the exportation of these materials and consequently the next echelon in our reverse logistics planning. Therefore Montreal would be the next destination of the recovered plastic, circuit boards, and one third of the recovered metal. We also assume that the transportation trucks are the same as the trucks that are used from consolidation centres to recycling plants.

Table 11 demonstrates the transportation costs from collection to consolidation, consolidation to recycling, and recycling to the exportation city for the considered channels of recovered materials.

Table 11: Transportation costs including the downstream exportation network

Replication #	Transportation Costs		
	Coll. to Cons.	Cons. to Rcy.	Rcy to Exp
1	1,775,170	4,849,587	179,769,480
2	1,805,557	4,669,205	174,106,745
3	1,762,151	4,745,220	176,568,975
4	1,735,457	4,681,270	177,839,565
5	1,807,498	4,830,375	177,088,925
Average (70 Reps)	1,793,717	4,814,029	177,493,999

As it could be predicted, since most of the recycling plants are located in central Ontario, a huge cost for downstream transportation will be incurred considering a destination city like Montreal to act as the exportation hub. It is interesting to notice that the assumed quantities for the types of recovered material constitute more than half of the total recovered material through the WEEE collection network. Obviously redesigning the WEEE collection network or adding more recycling centres in the east region can dramatically decrease this huge amount of transportation cost and environmental footprints.

5-1- The Gateway-Corridor Network (GCN)

Trade gateways and corridors exist within broader networks of links and nodes. Cities form nodes within the network and the competing modes of transportation infrastructure for road, rail, air or water, form the links. A trade gateway or corridor is any pathway that facilitates the movement of goods and people between two or more nodes. According to Parsons et al (2007), the gateway city lies at the transition point with a “fertile” cone-shaped hinterland on the one side, and an “infertile” region on the other. The fertile side has a well developed multimodal network of transportation infrastructure. The infertile side is served by a narrow trade corridor with long haul transportation services that connect the gateway city to a distant gateway in another market. Traffic is funneled through a gateway city because it sits at a strategic location where transportation costs can be minimized along a land corridor or a sea route.

The federal government’s gateway and trade corridor strategy, outlined in the National Policy Framework for Strategic Gateways and Trade Corridors, aims to improve Canada’s integration in global supply chains through an efficient multi-modal transportation system. In 2006, the provinces of Quebec and Ontario signed a Cooperation Protocol to promote the development of a trade corridor, and improve the efficiency of all modes of transportation (Government of Canada, 2008). On July 30, 2007, the two provinces signed a Memorandum of Understanding (MOU) with the federal government for the development of the Ontario-Quebec Continental Gateway and Trade Corridor (figure12).

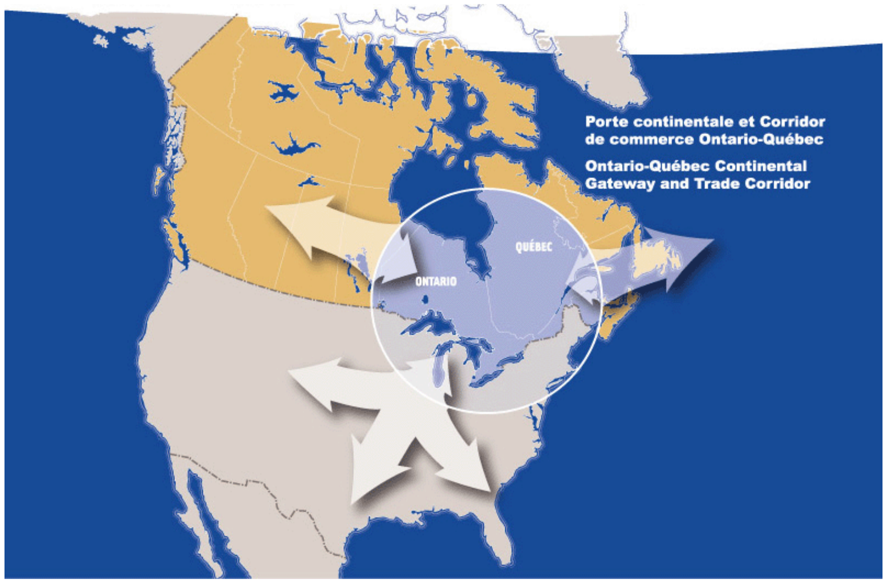

Figure 11: The structure of the Ontario-Quebec Continental Gateway

In the previous section, we acknowledged the fact a big portion of the recovered material from the Ontario's WEEE program end-up outside of the country and we made the assumption that for this to happen, Montreal can be the destination city. Looking at the structure and the role of Gateway & Corridor Networks in facilitating the flow of material meant for international trade, we notice that the Continental Gateway in the east coast can play an important role in the flow of recovered materials towards Montreal, as the gateway city. In other words, gateway and corridor initiatives can not only be used to facilitate the flow of virgin products inside or outside their covered region, but also they can be used to direct the flow of end-of-life products and the recovered materials.

Figure 12 demonstrates a restructuring of the WEEE flow network, facilitating the transportation of the recovered materials through a cone-shaped GCN with Montreal as the gateway. We can also see how this network can be embedded into the bigger picture of the Continental GCN. We have made two assumptions in constructing this network:

- The locations of the hub nodes (recycling and consolidation centres) have been selected so that they accommodate the density of collected WEEE across the province as well as to contribute to the cone-shape structure of the GCN.
- The flow of the material (allocation logic) has been defined so that it would facilitate the forward flow of recovered materials towards the gateway node.

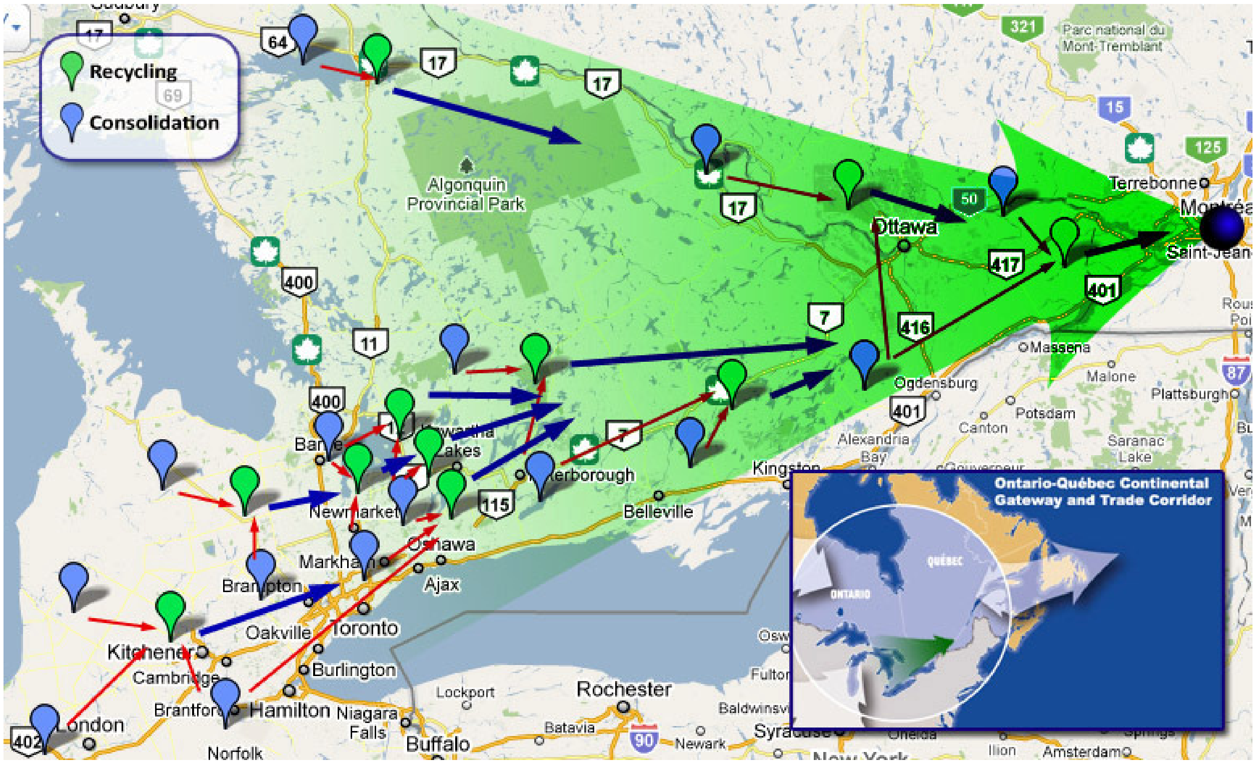

Figure 12: The Gateway-Corridor Network for WEEE Management in Ontario

Now it is possible to run the simulation model with the new GCN structure and the allocation logic in order to quantify the possible changes in the transportation costs. Table 12 presents the transportation costs for the GCN structure. Also Figure 13 shows a comparison of the total transportation cost between the as-is state of the WEEE management network and the to-be state of the restructured GCN. Savings in the total transportation costs can be clearly observed.

It is important to note that the to-be network structure was a mere assumption to demonstrate the transportation distance and cost savings when redefining the network. Obviously, it would not be feasible for OES to simply restructure its WEEE collection and consolidation network. However, the similarity of the current network structure to a GCN, as well as the potential savings in transportation costs (and presumably other management and operational costs) can be used as an insight to direct future strategic decisions in terms of network management, selection of the locations, and transportation. Moreover, as OES is currently adding new members to its network of collectors, consolidators, recyclers, and transporters, the simulation model can be used to direct these decisions.

Table 12: Transportation Costs for the to-be GCN structure

Replication #	Transportation Costs		
	Coll. to Cons.	Cons. to Rcy.	Rcy to Exp
1	2,997,644	2,096,287	165,701,280
2	3,081,569	2,142,886	168,956,760
3	3,252,306	2,081,415	164,990,640
4	3,064,341	2,069,482	163,151,760
5	3,167,476	2,085,699	164,035,440
Average (70 Reps)	3,147,267	2,100,954	165,707,761

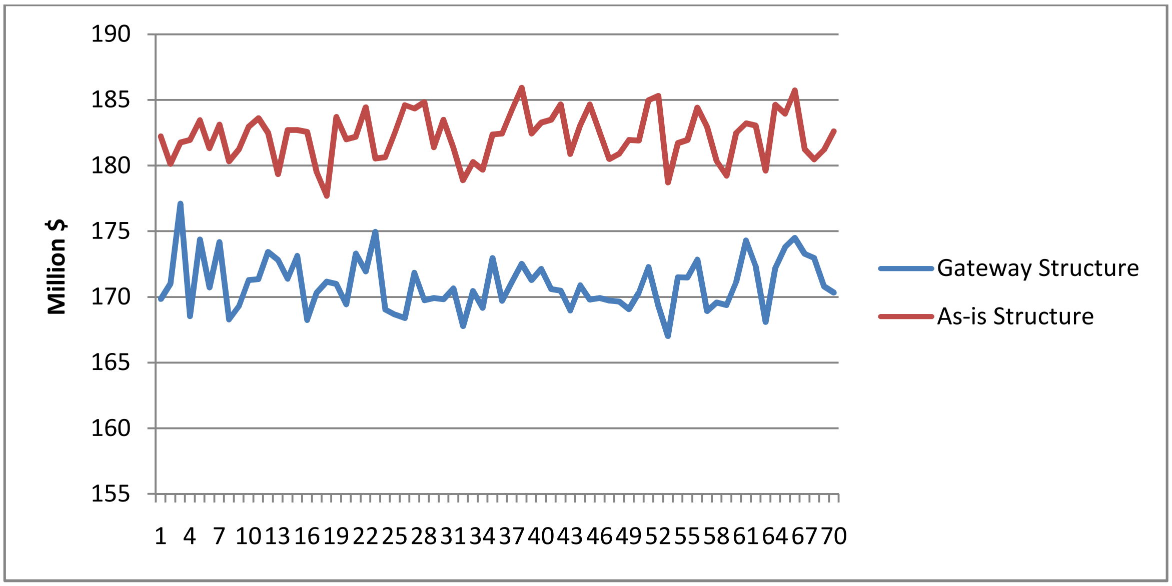

Figure 13: Comparison of the total transportation costs between the as-is and to-be structures

6- Conclusion & Future Research

Due to the importance and the increasing attention towards green supply chain management and reverse logistic networks, this research used the WEEE management in Ontario as the case to address a real world example of a massive and complex RL system using the simulation tool. The network included more than 48 collection nodes representing different counties, divisions, and districts in Ontario, 15 consolidation centres and 11 recycling and processing plants. The considered functional areas were collection, transportation, consolidation, and upstream and downstream recycling.

The simulation model analyzed some interesting issues in the management of WEEE in Ontario by measuring the performance measures and analyzing the impact of different scenarios on them. The performance indicators included the distance measures, time measures, cost estimates, and quantity values.

Using the simulation model, the capacity of the network to take in future collection estimates was analyzed and it was shown that after two years of operation, if no enhancements are made to the network, the central consolidation centres would not be able to handle the flow of material with their current capacity. Additionally, we studied the fate of the recovered material and found out that a considerable proportion of the recovered materials end up in Europe, US, and China. The paper analyzed the downstream network of recovered WEEE and showed that it is important to consider the exportation of material in downstream networks in making strategic decisions on the locations of consolidation and recycling plants. Using the simulation model, the paper then explored the possibility of restructuring the system as a gateway-corridor structure to facilitate the flow of waste and recovered materials within the Continental gateway and proved the decrease in transportation costs of the new structure.

Future research related to this paper may include improving the current model by incorporating a more detailed structure into the defined sub-models, calibration of the model using more accurate data, theoretical modeling of the different operational problems defined in the scenario analysis section, incorporating the model into steward self-management channels, analyzing the reuse and refurbishment channels, defining the system as a closed-loop supply chain, and analyzing other aspects of the gateway-corridor network facilitation that are applicable within the WEEE management system.

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APPENDIX I: The Collection Data Estimates

Baseline and Year 1 Collection Data for Different WEEE Categories

Name		Baseline Year (Ton.)	%	Year 1 (Ton.)	%
Desktop & Portable Computers	Desktop Computers	4753	12.0%	5935	12.7%
	Portable Computers	854	2.2%	1157	2.5%
	SUM	5607	14.2%	7092	15.2%
Display Devices	<= 29 inch	16261	41.1%	18198	39.0%
	> 29 inch	5909	14.9%	6862	14.7%
	SUM	22170	56.1%	25060	53.8%
Copiers & Printers	Desktop Printing, Copying	4842	12.2%	6035	12.9%
	Floor Printing	117	0.3%	146	0.3%
	Floor Copying	234	0.6%	292	0.6%
	SUM	5193	13.1%	6473	13.9%
Other WEEE	Computer Peripherals	572	1.4%	675	1.4%
	Telephones	1052	2.7%	1145	2.5%
	Cellular Devices	167	0.4%	205	0.4%
	Image, Audio & Video Devices	4790	12.1%	5967	12.8%
	SUM	6581	16.6%	7992	17.1%
TOTAL SUM		39551		46617	

Collection estimates and truck dispatch frequencies for Eastern and Central Ontario counties

	Collection Counties, Divisions, Districts	2009 Population Est.	Collection Est. (Ton.)	Collection Est. (Pallets)	Truck Dispatch Freq. (Hr)
EAST	FRONTENAC	160100	490	1470	16.98
	HASTINGS	145441	445	1335	18.7
	LANARK	72186	221	663	37.65
	LEEDS & GRENVILLE	111587	342	1026	24.33
	LENNOX & ADDINGTON	45580	140	420	59.43
	OTTAWA	894108	2737	8211	3.04
	PETERBOROUGH	145373	445	1335	18.7
	PRESCOTT & RUSSELL	88300	270	810	30.81
	PRINCE EDWARD	28762	88	264	94.55
	RENFREW	109891	336	1008	24.76
	STORMONT, DUNDAS & GLENGARRY	126506	387	1161	21.5
	SUM	1927833	5901	17703	1.41
CENTRAL	BRANT	129255	400	1200	20.8
	DUFFERIN	55650	172	516	48.37
	DURHAM	552978	1711	5133	4.86
	GREY	97170	301	903	27.64
	HALIBURTON	16456	51	153	163.14
	HALTON	409337	1266	3798	6.57
	HAMILTON	534833	1655	4965	5.03
	KAWARTHA LAKES	75467	233	699	35.71
	MUSKOKA	57933	179	537	46.48
	NIAGARA	447895	1386	4158	6
	NORTHUMBERLAND	84541	262	786	31.76
	PEEL	1078843	3337	10011	2.49
	SIMCOE	411324	1272	3816	6.54
	TORONTO	2707061	8374	25122	0.99
	YORK	795543	2461	7383	3.38
	SUM	7454288	23060	69180	0.36

Collection estimates and truck dispatch frequencies for Western and Northern Ontario counties

	Collection Counties, Divisions, Districts	2009 Population Est.	Collection Est (Ton.)	Collection Est. (Pallets)	Truck Dispatch Freq. (Hr)
WEST	BRUCE	76955	230	690	36.17
	CHATHAM-KENT	129731	388	1164	21.44
	ELGIN	98227	294	882	28.3
	HALDIMAND-NORFOLK	126071	377	1131	22.07
	HURON	71907	215	645	38.7
	LAMBTON	152931	458	1374	18.17
	MANITOULIN	15271	46	138	180.87
	MIDDLESEX	485620	1454	4362	5.72
	OXFORD	119567	358	1074	23.24
	PERTH	88738	266	798	31.28
	WATERLOO	528173	1581	4743	5.26
	WELLINGTON	225611	675	2025	12.33
	ESSEX	451642	1352	4056	6.15
	SUM	2570444	7694	23082	1.08
NORTH	ALGOMA	137858	444	1332	18.74
	COCHRANE	99117	319	957	26.08
	KENORA	71857	231	693	36.02
	NIPISSING	96399	310	930	26.84
	PARRY SOUND	46118	149	447	55.84
	RAINY RIVER	25706	83	249	100.24
	SUDBURY	207149	667	2001	12.47
	THUNDERBAY	175405	565	1695	14.73
	TIMISKAMING	40046	129	387	64.5
	SUM	899655	2897	8691	2.87

APPENDIX II: The Geographic Positions for the Collection Nodes

Counties	Geographic Positions		Counties	Geographic Positions	
	Latitude	Longitude		Latitude	Longitude
FRONTENAC	44.5797	-76.565358	TORONTO	43.6525	-79.381667
HASTINGS	44.70727	-77.681517	YORK	43.988461	-79.470388
LANARK	45.00838	-76.358924	BRUCE	44.280604	-81.304321
LEEDS & GRENVILLE	44.65297	-75.9327	CHATHAM-KENT	42.4	-82.183333
LENNOX & ADDINGTON	44.66667	-77.166667	ELGIN	42.773121	-81.180794
OTTAWA	45.41157	-75.698194	HALDIMAND-NORFOLK	42.835767	-80.306847
PETERBOROUGH	44.5	-78.166667	HURON	43.617305	-81.539327
PRESCOTT & RUSSELL	45.46101	-75.107065	LAMBTON	43.01712	-82.08429
PRINCE EDWARD	44	-77.25	MANITOULIN	45.783708	-82.106162
RENFREW	45.63831	-77.167403	MIDDLESEX	42.981981	-81.25412
STORMONT, DUNDAS & GLENGARRY	45.12276	-74.87333	OXFORD	43.130556	-80.746667
BRANT	43.15267	-80.171591	PERTH	43.5	-81.083333
DUFFERIN	44.05275	-80.187506	WATERLOO	43.480926	-80.537664
DURHAM	43.93684	-78.928824	WELLINGTON	43.780332	-80.543845
GREY	44.466	-80.632692	ESSEX	42.163944	-82.734714
HALIBURTON	45.1762	-78.549065	ALGOMA	46.4953	-84.345317
HALTON	43.53254	-79.874484	COCHRANE	48.484728	-81.301351
HAMILTON	43.2436	-79.889075	KENORA	49.793003	-94.466165
KAWARTHA LAKES	44.53375	-78.900648	NIPISSING	46.319107	-79.434225
MUSKOKA	44.9	-79.366667	PARRY SOUND	45.347783	-80.034459
NIAGARA	43.05817	-79.290213	RAINY RIVER	48.615278	-93.401667
NORTHUMBERLAND	43.99677	-78.127556	SUDBURY	46.247399	-81.763661
PEEL	43.70263	-79.779968	THUNDERBAY	48.415802	-89.2673
SIMCOE	44.47165	-79.829674	TIMISKAMING	47.513081	-79.677437

APPENDIX III: The Geographical Positions of the Consolidation Centres and Recycling Plants for the WEEE Program in Ontario

Geographical positions for the WEEE consolidation centres in Ontario

Consolidation Centres			Geographic Pos. (Degrees)	
			Latitude	Longitude
East	1	Kingston	44.263565	-76.50336
	2	Brockville	44.602214	-75.690712
	3	Belleville	44.204279	-77.378742
	4	Ottawa	45.411572	-75.698194
Central	5	Ajax	43.838599	-79.028484
	6	Richmond Hill	43.874023	-79.384919
	7	Mississauga	43.630627	-79.6667
	8	Hamilton	43.243603	-79.889075
	9	Barrie	44.3812	-79.686998
West	10	Cambridge	43.387342	-80.321323
	11	London	42.979398	-81.246138
	12	Chatham	42.404804	-82.191038
North	13	North Bay	46.319107	-79.434225
	14	Sudbury	46.49	-81.01
	15	Thunder Bay	48.415802	-89.2673

Geographical positions for processing and recycling centres in Ontario

Processing & Recycling Centres		Geographic Pos. (Degrees)	
		Latitude	Longitude
1	ADL Process Inc.	43.667995	-79.465635
2	Artex Environmental	43.695104	-79.586681
3	e-Cycle Solutions	43.669529	-79.645825
4	FCM Recycling Inc.	45.912738	-73.337043
5	GEEP – Global Electric Electronic Processing	44.376003	-79.708436
6	Greentec	43.411772	-80.315043
7	La Relance Outaouais	45.49627	-75.703853
8	Mida International	43.224264	-79.720532
9	Sims Recycling Solutions	43.68892	-79.705058
10	Target Recycling Services Inc.	43.84693	-79.036784
11	Toronto Recycling Inc.	43.857812	-79.388293

APPENDIX IV: The Computer Modeling Process of WEEE Network

GENERATION & COLLECTION

- Creation of truckloads from different collection nodes given the different distributions
- Assigning attributes to each truckload: Creation origin, creation time, destination based on the minimum distance from the 15 consolidation centres, the distance to be travelled, number of pallets given the truck capacity distribution.
- Recording outputs: The collection cost based on the load tonnage, total distance covered, and the number of passing loads
- Sorting the loads based on their destination

TRANSPORTATION

- Sending each load towards the destination using an unlimited pool of available trucks given the calculated travelling time distribution
- Recodrding the collection to consolidation transportation cost based on the distance to be travelled by each truck

CONSOLIDATION

- Receiving each truck at the given destination station
- Generating pallet entities based on the payload of each truck (unloading) at each station
- Assigning attributes to each pallet: The WEEE material group based on the given compositions, entry time to the consolidation centre, entry time to the waiting queue for filling up a 24 pallet truckload
- Holding each material for a given time distribution (processing distribution)
- Batching the first 24 processed pallets at each station as a single truckload
- Assigning the destination processing plant, distance to be travelled, and the transportation entry time to each truck entity

TRANSPORTATION

- Sending each load towards the destination using an unlimited pool of available trucks given the calculated travelling time distribution

PROCESSING & RECYCLING

- Receiving each truck at the given destination station
- Recording the number of received trucks at each recycler
- Holding each truckload for a given time distribution (processing time)
- Assigning the arrival time to each truckload
- Recording the total consolidation to recycling distance covered and transportation cost as well as the total number of trucks received.
- Unloading the truckloads
- Sorting the pallets based on their consolidation region and recording the average sitting time for each pallet at each region
- Recording average collection to consolidation and consolidation to recycling distance travelled, the consolidation inventory cost, and the system time for each pallet.
- Sorting the material based on the given recycling rate and recording the landfill quantity and cost as well as the recovery quantities.
- Disposing the entities