Saving Our Energy Sources and Meeting Kyoto Emission Reduction Targets While Minimizing Costs with Application of Vehicle Logistics Optimization

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Paper prepared for presentation
at the Walking the Talk: Sustainable Transportation
Implementation, Performance and Results Session
Of the 2006 Annual Conference of the
Transportation Association of Canada
Charlottetown, Prince Edward Island

Abstract

Transportation operations and logistics is an area that can be used to help ensure a sustainable and environmentally friendly transportation system in Canada. This study focuses on the estimation of emission reduction benefits and the potential energy savings that can be realized with logistics optimization, particularly those resulting from computerized vehicle routing and scheduling (VRS) of pickups and deliveries at a trucking terminal. The objective of this research was to quantify the benefits and potential efficiency gains in terms of emission reduction with computerized VRS optimization (CVRSO) implementation by making a comparative analysis between different CVRSO methods and existing manual VRS methods.

After setting up the CVRSO system, different optimization criteria were used and it was found that, in addition to significant cost savings, a significant benefit in terms of a reduction in energy use and corresponding pollution reduction is achieved by minimizing operational costs (by combining fixed costs and both distance-related and time-related costs, and optimizing the routing and scheduling for the fleet of vehicles). The results showed that it is possible, in some cases, to achieve up to 40% reduction in energy consumption and related emissions by implementing CVRSO within the trucking industry. To help meet the emission reduction targets to which Canada agreed by ratifying the Kyoto protocol, and to save and use our energy sources more efficiently, all levels of government and transportation engineers should take more of a proactive role to promote the implementation of such systems within the trucking industry by making such systems more convenient, practical, and realistic to be used by the transportation companies. These emission reductions and energy savings can be achieved while at the same time providing direct economic gains to the transportation industry and the general economy.

Key Words: Emission reduction, Meeting Kyoto target, Commercial vehicle optimization, Vehicle routing and scheduling, Vehicle logistics optimization.

1. Introduction

Canada ratified the Kyoto Protocol in December 2002 with a commitment to reduce its greenhouse gas (GHG) emissions to 5.2% below 1990 levels by 2008-2012 (Environment Canada, 2003). The Canadian economy is growing, as is the demand for freight transport. Thus the demand for petroleum products and resulting fuel consumption is also increasing. As a result of the decreasing energy supplies and increasing dependence on other countries for energy sources, energy efficiency is becoming increasingly important. Vehicle routing and scheduling optimization (VRSO) is a very promising means to achieve significant reductions in total distance traveled by commercialized fleets, which would significantly increase the freight transportation (trucking) efficiency and, as a consequence, reduce GHG emissions significantly.

VRSO is the efficient organization of goods and services in transportation operations from a central point(s) to a set of destinations. The number and the types of vehicles required for servicing the number of existing depots and stops has to be determined and a route and schedule has to be developed for each vehicle in order to solve a vehicle routing and scheduling problem (VRP). A general VRP at the terminal consists of optimizing the process of assigning particular destinations (customers) to individual trucks and/or tractors, and then determining the visiting order of customers and the routes of vehicles for deliveries and pickups (DPs).

This study analyses a real Atlantic Canada trucking terminal operation in order to understand the potential efficiency gains and improvements and to quantify these efficiency gains in terms of emission reduction that can be made through vehicle routing and scheduling optimization (VRSO). The focus of this study is to perform a comparative analysis between the base case, in which manual vehicle routing and scheduling procedures are used, and the proposed case, in which computerized vehicle routing and scheduling optimization (CVRSO) procedures are used. One of the main objectives of the research was to develop a better understanding of how application of CVRSO can help meet Canada's ratified Kyoto protocol target.

Recent developments in computer technology and operations research allow significant reduction in the operating costs of a trucking company by solving the VRP with software packages as opposed to traditional manual vehicle routing and scheduling (VRS) techniques. Having too many constraints, such as various time windows for each customer during which deliveries or pickups can be made, different vehicle capacities, different types of freight (e.g. frozen freight versus dry goods), working hour limitations, as well as a large fleet and a large customer pool, make it very challenging to solve the VRP manually, even for the most skilled dispatchers and logistics planners. The VRSO software packages can be programmed to find a more efficient solution under the given constraints.

The typical operation at a trucking company's terminal involves goods being delivered from the depot (terminal) and pickups being brought back to the depot for further consolidation and linehaul distribution. In a trucking operation at the terminal, deliveries are typically done first during the morning hours of the day and pickups are done in the afternoon. Logistics managers or dispatchers determine the delivery and pickup sequences and which vehicles are to be used. Customers have their own time windows (TW) and specific demand characteristics, which affect the DP sequences.

This case study was based on a New Brunswick Saint John terminal operation, which includes 17 tractors, 5 straight trucks, and about 21 trailers. The trucks are used for less than truckload (LTL) or full truckload (FTL) DPs. As a clarification FTL is defined in this study as a truck serving three or fewer customers.

All trucks used in the terminal operation are equipped with a Cancom Satellite system which consists of a built in GPS (Global Positioning System) and onboard computer. Thus, dispatchers and managers can see the positions of the trucks in real time and communicate with the drivers through text messages via the Cancom Satellite system. The AS/400 system is also used to integrate the GPS tracking and driver communications. Using this integrated communication system, when the driver enters a delivery in the onboard computer as being completed, the dispatchers and managers can see at the terminal that the order has been delivered.

2. Problem Definition

The main problem that trucking companies face at a terminal is in deciding which vehicle is to be used to service which customers and in what order the deliveries are to be made. The standard solution for this problem is determined by the logistics managers or planners (dispatchers) using their professional judgment and experience, and, although this has been acceptable practice in the past, it yields inefficiencies in the operations as it is not humanly possible to account for all the constraints and variables. The whole fleet of vehicles inherently experiences these inefficiencies and, as a result, the fleet consumes more fuel, thus producing increased GHG emissions and wasting energy resources.

3. Research Objectives

The primary objectives of this applied research are as follows:

1. To increase the efficiency by incorporating better logistics management, and

2. To quantify efficiency gains in terms of emission and fuel consumption reductions.

Increased efficiency is achieved by reducing the overall operating cost of a trucking company while at the same time increasing the quality of the service. The overall operating cost of the company has three main contributors: fixed costs such as equipment costs, time-related costs such as wages paid to the drivers and distance-related costs such as fuel consumption cost. The quality of the service is essentially measured by the ability to deliver goods in a timely manner and to adhere to specific customers' predefined time windows.

The classic approach for CVRSO disregards the actual costs and focuses on minimization of total distance or total time, or total cost (where cost minimization consider either distance-related or time-related costs). Distance-related costs are determined by multiplying distance by cost per kilometer, and time-related costs are determined by multiplying operating time by cost per hour. However, actual costs are some combination of distance-related and time-related costs.

In some cases, time minimization will yield minimum operating costs, and in other cases distance minimization will yield minimum operating costs. However, it is impossible to know which minimization, if any, will yield the minimum total operating costs. In most cases, the minimum cost is achieved by some combination of both distance and time minimization.

In this research operating cost was determined by accounting for both distance-related and the time-related cost variables as well as fixed cost (cost of possessing a vehicle when it is not being used). The operating cost function was determined by using a combination of transportation cost information found in the literature review and using the actual cost data associated with the trucking operations at the Saint John terminal.

After the cost function determination, this cost-based minimization was applied for the entire vehicle routing and scheduling optimization procedure, which yielded a better understanding of the operating costs and provided an estimation of the real minimum operating costs.

4. Literature Review: Nature and Types of VRP

VRS problems can be classified into two main groups:

1. Arc Routing, and

2. Point-to-Point (Node) Routing.

In arc routing problems a single vehicle or a fleet of vehicles must service all (or a subset of) the arcs of a transportation network, whereas in node routing problems the service activity occurs at all (or at a subset of) the nodes [1]. Arc routing problems involve finding efficient ways to travel over a set of links in a transportation network. Some of the arc routing applications include garbage collection, snow removal, sweeping, gritting, meter reading, school bus routing, mail delivery, and other door-to-door operations that require servicing every property along the full length of the street network [2].

Point-to-point routing applications include fuel oil delivery, sales personnel scheduling and routing to the customers, and pickup and delivery operations. This literature review focuses on DP operations at a trucking terminal, which are generally the most common in terms of volumes and expenditures.

VRS solution methods can be grouped into two categories:

1. Exact solutions approach, and
2. Heuristic solutions approach.

Exact solution methods look into almost every possibility to find the solution. This method is practical for relatively small problems. Depending on the size of the operation, to do an exact solution, where almost all possible combinations are examined, might take weeks or months, even for a significantly small sample size, with the fastest processors. Traveling salesman problems (TSP) are the basic problem for VRP [3]. VRP can have a larger set of solution possibilities, depending on the nature of the problem. The TSP can be described as having N destinations, and the cost, $C_{ij,}$ to travel from destination *i* to *j*. A salesman (vehicle) starts from the depot to visit each destination once and return back to the depot. The problem is to find the optimal route and the destination visiting order that would yield the minimum total travel cost. The TSP is one of the best known problems of combinatorial optimization [4]. If the entire set of solutions were enumerated, the number of calculations would be N! [5].

Table 1 shows the rapid growth of computational time for solving TSP when N (the number of destinations (customers)) increases. In this example, a 10 gigahertz (GHz) processor with basic computation time of 10^{-10} seconds was used. As can be seen in Table 1, when N increases from 10 to 50 destinations, the computation time to find an exact solution increases from 0.00036 seconds to $9.64 * 10^{37}$ billion years.

Table 1 Exponential Computation Time Increase with Sample Size

Sample Size	Computation Time	
10	0.00036	seconds
20	7.7	years
30	841111	billion years
40	$2.59 * 10^{21}$	billion years
50	$9.64 * 10^{37}$	billion years

Heuristic and meta-heuristic algorithms do not guarantee an optimum solution. However, when it is impractical to find exact solutions, these heuristic-based algorithms are preferred for VRSO. Optimization is essential for improving the existing conditions in VRP. Optimization is defined in the dictionary as ”an act, process, or methodology of making something (as a design, system, or decision) as fully perfect, functional, or effective as possible; specifically: the mathematical procedures (as finding the maximum of a function) involved in this” [6]. Although heuristic and meta-heuristic algorithms do not always indicate how good the result is in relation to the global optimum, they are the most practical choice for solving problems because of the potential efficiency gains and improvements that they can make.

The Clarke-Wright heuristic algorithm was the earliest heuristic algorithm that was developed to solve the VRP [7]. Many heuristic algorithms, which are now commonly used are the Tabu Search (TS), Simulated Annealing (SA), Genetic Algorithms (GA), and Repeated Descent (RD). Gendreau *et al*. applied several heuristics to the VRP and found that the GA, SA, and TS techniques performed significantly better than other algorithms in VRP [8]. Wright and Marett [9] showed that TS outperformed both SA and RD on the TSP. Reviews on ten of the most common TS heuristics for the VRP with their main features of neighbourhood structures, short term memory, long term memory, and intensification can be found in one of the most recent surveys conducted by Cordeau and Laporte [10].

Christie and Satir [11] reviewed several existing case studies and found that a 10% to 30% reduction in operational costs is possible through VRP optimization for DPs operations. The DP operations were modelled with the commercially available TransCAD Transportation GIS software package, the VRS module of which uses the TS algorithm.

5. Transportation Network

Building an accurate and reliable transportation network is essential for any CVRSO applications. The most accurate way of creating a network is using a GIS (Geographic

Information System) database, as a GIS database contains the actual coordinates of the streets and many attributes that are available for each feature. A transportation network can be defined as a set of nodes and links. Nodes are locations where flows start, end, or branch and links carry the flow from one node to another. In order to ensure accuracy of the research results, several corrections and additions to the existing road and street network had to be made such as: editing for missing streets, extra streets, false intersections (overpasses or underpasses), and discontinuous links; direction of flow editing for one-way or two-way information; toll editing to account for additional cost for the links with tolls; and delay information editing to account for lost times at nodes (both signalized or stop sign) in case of a right turn, left turn, U-turn and through (straight transition). Further editing was done to account for turn restrictions or other delay information such as waiting time for a ferry.

6. Transportation Network Validation

After adjustments and calibration to the node attributes (average delay times at intersections), model estimates of travel times agreed, in general, with measured travel time. The discrepancies arise from the nature of the transportation network, as sometimes delays can fluctuate at intersections. As Figure 1 shows the coefficient of determination, R-squared, indicates that over 96% of the variation in observed times have been explained with the model estimates. The statistical analysis indicates that there is strong agreement between the model estimates and observed travel times.

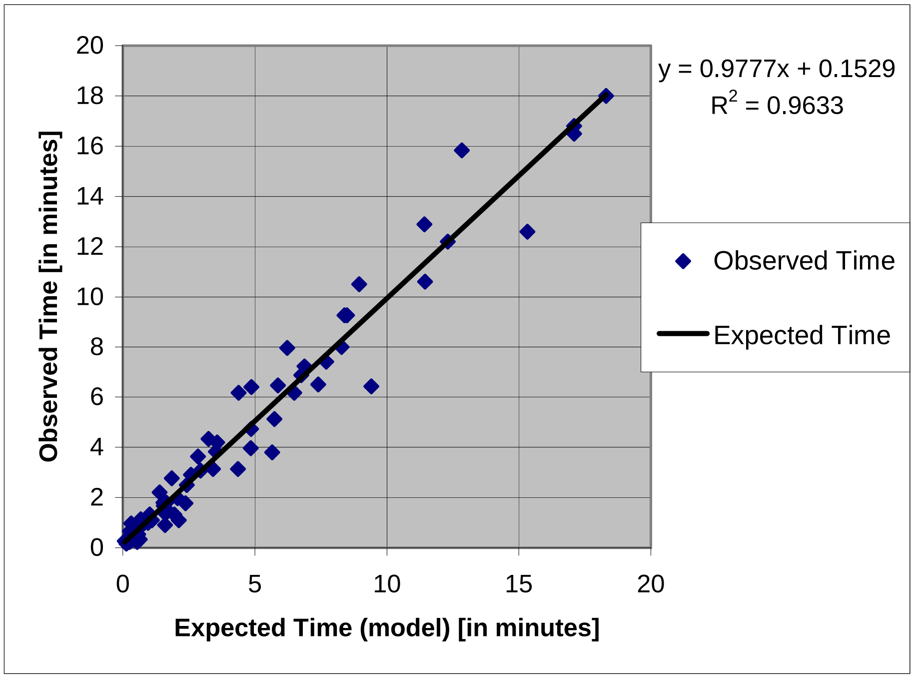

Figure 1 Observed Versus Expected Time Linear Representation

7. Methodology

None of the climate action plans at the provincial and federal levels, which give the general policy outline of reducing greenhouse gas emissions, mentioned the possible reduction in gas emissions and fuel consumption with VRSO techniques. It should also be noted that VRSO could be applied in many transportation areas such as: transit systems, maintenance operations, staff DPs, mail DPs, street sweeping and garbage collection. VRSO is very promising as a very real means to significantly accumulate environmental benefits as well as economic benefits, if it were to be appropriately recognized and acknowledged by the transportation policy makers and accepted as part of the strategy to meet Kyoto targets while helping to ensure the sustainability of our transportation system.

There is an ongoing effort throughout the world to control the increasing levels of carbon dioxide emitted into the atmosphere. The transportation industry makes the largest contribution to greenhouse gas emissions in the world [12]. In Canada in 1990, emissions were 148Mt (million tons) in CO_2 equivalent. The 2010 levels are forecasted to be 193Mt generated by the transportation industry, due to economic growth. Canada's commitment is to reduce emissions by 6% of the 1990 levels by 2010. To meet the Kyoto target, transmission emissions should be reduced by 54Mt. Commercial trucks, excluding light trucks, account for 27% of transportation emissions, which is the largest share of any of the modes.

Two types of operational data were obtained from the Saint John terminal operation. The first was DP data for the greater Saint John LTL (less than truckload) for one week from Monday to Friday. The second data set was DP data for greater Saint John FTL (full truckload) for two consecutive days, Thursday and Friday of the same week.

The TransCAD 3.61 software package [13] was used to build the model and to complete the VRSO. The model was set up so that the three different minimizations (time minimization, distance minimization, and cost minimization) can be individually used in the optimization process.

Rather than using trucking industry average costs, the actual cost information was obtained for the Saint John terminal operation. The cost data was divided into three classes as: fixed cost, distance-related variable cost, and time-related variable cost. Although an industry average could be used for VRSO, using real costing information gave more comprehensive and reliable data with which to perform cost minimization in VRSO.

Transportation cost is very important in order to understand sources of increase in efficiency of the transportation system. Increasing the efficiency of the transportation process will reduce the cost of transportation, which in turn will be reflected in lower price to end product users (consumers). A literature review on transportation costs revealed a better understanding of the transportation cost measurements in general terms. In this research, a simple transportation cost function was developed from the trucking companies' point of view, as a private provider.

The typical approach for VRSO is to minimize the total distance traveled by the fleet. The new trend for VRSO is to minimize the total travel time. As the transportation cost literature review revealed, the transportation cost actually requires that these two major components be considered together, since there are distance-related cost components and time-related cost components.

A transportation costing framework was used to evaluate this proposed cost function. The transportation company operates in a certain region with a certain fleet and employees. Practically, the main characteristics of a transportation company do not change in a short period of time. This assumption was made in order to have a simplified transportation cost function. This means that, if the main characteristics of the company change, the cost function should be adjusted according to those changes.

The proposed function should be very useful to help trucking companies to understand their real costs and evaluate their pricing according to the real cost for the company to transport the goods from point A to point B. The general practice is to use average transportation pricing, which depends on total revenue and total expenditure of the company. This method yields cross subsidization within the company without awareness of the details for the transportation cost of individual types of goods.

Based on the data availability, the fixed costs are grouped as follows:

1. Capital (vehicle) cost,
2. Insurance,
3. Fees for tolls and parking,
4. Registration,
5. Depreciation with respect to time, and
6. Overhead on facilities.

The distance-related variable costs are grouped as follows:

1. Fuel consumption,
2. Tire cost,
3. Maintenance cost with respect to usage (mileage), and
4. Depreciation cost with respect to usage (mileage).

The time related cost variables are grouped as follows:

1. Driver Wages
2. Preventable maintenance cost with respect to idling time (IT), and

3. Fuel consumption cost with respect to idling time.

And the remaining costs are grouped as fixed costs including utilization factors.

The proposed cost function (C) is:

$$C = f(t, d, p) \text{ or } C = a + b_1.t + b_2.d$$

The transportation cost for a trucking company, under any particular operating margin assumption, is represented by "*d*" (distance of transportation), "*t*" (time to transport), and "*a*" (fixed cost). Coefficients b_1 and b_2 represent the cost per hour and cost per kilometer, respectively. The price of the fuel (p) can also be integrated with cost determination when necessary (or fuel price can be captured in coefficients b_1 and b_2).

Implementing the cost minimization (by writing a costing script in TransCAD) in the VRSO process assisted to better understand the efficiency gains in terms of operating cost reduction and environmental benefits. An analysis of operating cost reduction was done between the existing manual VRS system and the computerized VRS method to determine the economic benefits of the computerized system over the manual. The operation cost function utilized fixed and variable costs in a certain operational margin; with an efficiency improvement, the operational margin is likely to change, which would affect the accounting approach to costing.

Furthermore, the environmental and energy benefit analyses reflect only external savings for the public and the country. They do not quantify or describe economic benefits and fluctuations in a company's competitiveness amongst rival companies, nor do they take into account any reflected potential savings that may be passed onto customers. Having an efficient transportation system would cause a spillover efficiency effect on the economic system as a whole.

8. Research Comparison Criteria

To determine how much savings would be generated through this case study, it was necessary to compare it to the existing manual VRS. Since existing (manual) VRS was inherently in the data that was obtained in the form of which vehicle was assigned to which customers, and the sequence in which the customers were visited, it was possible to first determine operating costs with the manual VRS which could be compared to that for CVRSO.

The manual VRS cost was determined by analyzing all truck manifests and for every truck; the time and distance traveled was determined, and the total fleet time and distance traveled was obtained by adding the time and distance costs for each individual truck. Computer calculations for CVRSO and the manual VRS for the total cost (determined by using the transportation cost function), travel time, and travel distance were saved for further comparison.

After determining operation cost for both manual VRS and CVRSO, distance-related and time-related fuel consumption savings, resulting from the difference between manual VRS and CVRSO, were quantified as potential energy consumption savings. By multiplying fuel consumption savings with gas emission factors (Environmental Canada, 2003) emission reduction was quantified.

9. Research Results

The results of the three different optimizations (time minimization, distance minimization, and cost minimization) undertaken for the CVRSO process for the entire fleet are presented in this section.

Table 2 summarizes the total weekly and annual operating costs estimated for both LTL and FTL and for the total operation for each scheduling method. The weekly amounts were based on a 5-day working week, and these values were expanded by 48 working weeks per year to obtain the estimated annual operating cost. Figure 2 shows the total operating cost for different type of VRS.

Table 2 Total Weekly and Annual Operating Costs

Total Operating Cost Weekly	LTL ($)	FTL ($)	**Total ($)**
Manual VRS	30240	17902	48142
Time Min. CVRSO	13861	11185	25046
Distance Min. CVRSO	13146	9941	23087
Cost Min. CVRSO	12686	9877	22563
Annual Total Operating Cost	LTL ($)	FTL ($)	**Total ($)**
Manual VRS	1451510	859301	2310811
Time Min. CVRSO	665347	536861	1202208
Distance Min. CVRSO	630994	477178	1108171
Cost Min. CVRSO	608918	474106	1083024

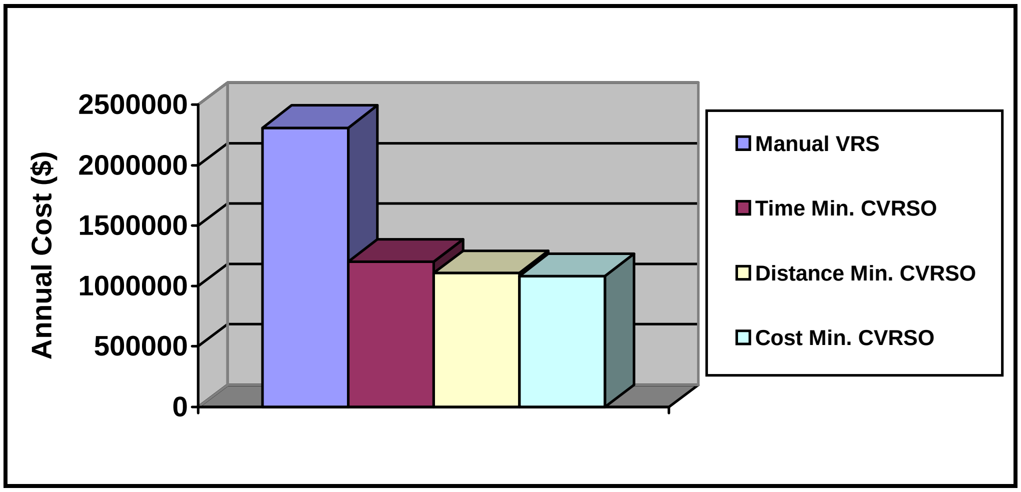

Figure 2 Total Annual Operating Costs

By implementing a computerized VRS system, the benefit at a single terminal ranged from approximately 1.1 to 1.2 million dollars per year. Additional economic savings would result from being more organized and having better schedules when using CVRSO.

Table 3 was calculated based on table 2, by using fuel consumption factors for both time-related and distance-related fuel consumption. Table 3 shows the total annual fuel consumption obtained for different VRS methods.

Table 3 Total Weekly and Annual Fuel Consumptions

Weekly Fuel Consumption	LTL (L)	FTL (L)	**Total (L)**
Manual VRS	2177	2203	4380
Time Min. CVRSO	1896	1577	3473
Distance Min. CVRSO	1611	1003	2614
Cost Min. CVRSO	1538	1056	2594
Annual Fuel Consumption	LTL (L)	FTL (L)	**Total (L)**
Manual VRS	104496	105744	210240
Time Min. CVRSO	91008	75696	166704
Distance Min. CVRSO	77328	48144	125472
Cost Min. CVRSO	73824	50688	124512

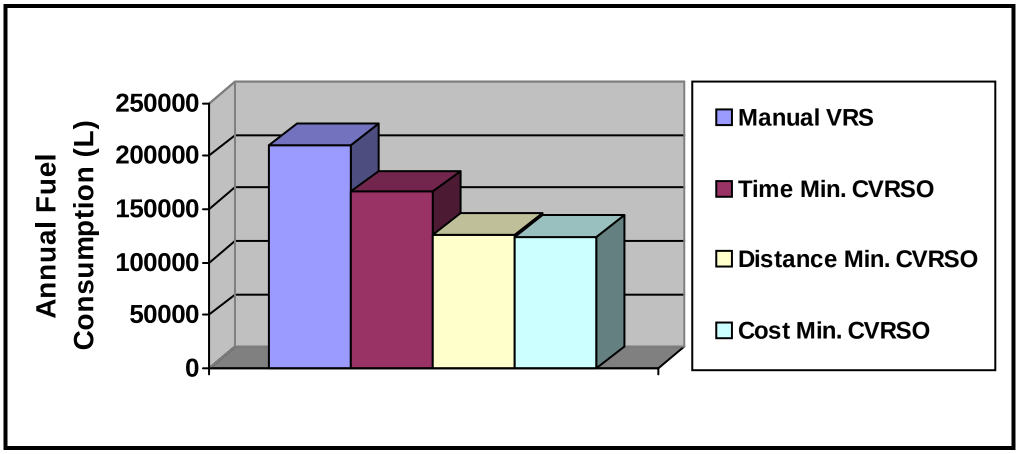

Figure 3 Total Annual Fuel Consumption

In Table 4, by subtracting each optimization values from the manual VRS values, the total savings were obtained in either litres of fuel or dollar values.

Table 4 Total Annual Energy Savings

Annual Energy Savings (L)	LTL	FTL	**Total**
Manual VRS	0	0	0
Time Min. CVRSO	13488	30048	43536
Distance Min. CVRSO	27168	57600	84768
Total Cost Min. CVRSO	30672	55056	85728
Annual Energy Savings ($)	LTL	FTL	**Total**
Manual VRS	0	0	0
Time Min. CVRSO	$ 10,251	$ 22,836	$ 33,087
Distance Min. CVRSO	$ 20,648	$ 43,776	$ 64,424
Cost Min. CVRSO	$ 23,311	$ 41,843	$ 65,153

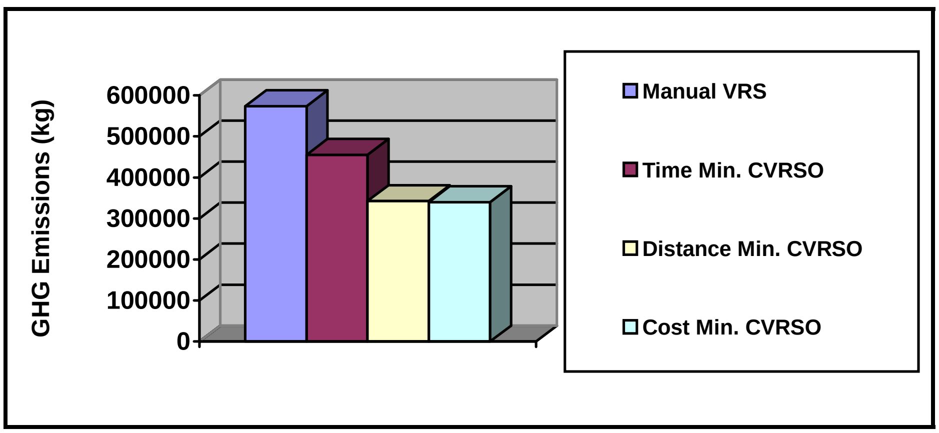

Figure 4 Total Annual GHG Emissions

The estimated annual emissions for each VRS method, as outlined in Table 5 and Figure 4, were determined by multiplying the relevant emission rate [14] with its corresponding fuel consumption from Table 3.

Table 5 Total Annual GHG Emissions

Total Annual Emissions	Units	CO_2	CH_4	N_2O	**Total GHG**
GHG Emissions Rate	(g/L)	2730	0.13	0.08	2764
Manual VRS	(kg)	573955	27.33	16.82	573999
Time Min. CVRSO	(kg)	455102	21.67	13.34	455137
Distance Min. CVRSO	(kg)	342539	16.31	10.04	342565
Cost Min. CVRSO	(kg)	339918	16.19	9.96	339944

Table 5 presents the amount of emission produced for each gas and total GHG (CO_2 equivalent) for each VRS method in kilograms. Table 6 gives a total GHG savings relative to manual VRS in both kilograms and percent for each of the optimization methods. A total savings of approximately 234 tones of GHG, equivalent to a 40.8% reduction, for one year was found for one trucking terminal operation when cost minimization CVRSO was used instead of the manual VRS procedure.

Table 6 Annual Emission Savings

Annual Emission Savings	CO_2 (kg)	CH_4 (kg)	N_2O (kg)	**Total GHG (kg)**
Manual VRS	0	0	0	0
Time Min. CVRSO	118853	5.66	3.48	118862
Distance Min. CVRSO	231417	11.02	6.78	231434
Cost Min. CVRSO	234037	11.14	6.86	234055
Emission Savings Percentage	CO_2 (%)	CH_4 %)	N_2O (%)	**Total GHG (%)**
Manual VRS	0	0	0	0
Time Min. CVRSO	20.7	20.7	20.7	20.7
Distance Min. CVRSO	40.3	40.3	40.3	40.3
Cost Min. CVRSO	40.8	40.8	40.8	40.8

As the emission calculation results revealed in this section, a 40.8% reduction in GHG emissions by implementing a CVRSO is very significant. Even though this is based on a relatively small sample, one week, and is a case study for an individual terminal operation, it is indicative of the potential benefits of CVRSO to help meet the Kyoto targets for emissions reduction in Canada. In order to meet the Kyoto target, transportation emissions in Canada must decrease by 54 million tones or 28% by 2010 [15]. Current federal and provincial policies and action plans related to climate change do not recognize or promote CVRSO although there is a recognition that technology may help to meet the GHG emission reduction target. It should also be noted that CVRSO could be applied to almost any transportation mode or vehicle class including passenger cars. CVRSO alone is more promising than the total of all other federal programs to provide a greener environment while, at the same time, helping to ensure the sustainability of our transportation systems through increased efficiency.

10. Conclusions

The freight industry is an essential part of the broader economic system. Trucking companies have the largest share of the freight industry primarily because of the convenience of their direct door-to-door service. Recent developments in operations research, GIS, communication, and computer technology make it possible for the trucking industry to achieve significant efficiency gains with CVRSO implementation.

Based on a case study with a Saint John trucking terminal operation the GHG emission and energy consumption reductions, relative to manual VRS (with annual GHG emission of about 574000 kg), was estimated to be between 20% and 40% when incorporating CVRSO (cost minimization CVRSO resulted in only about 340000 kg of GHG emissions annually), depending on type of minimization utilized.

Economic benefits and efficiency gains for the trucking company were significant when implementing CVRSO. The benefits of CVRSO go well beyond those listed here. As transportation is one of the most important components of the economic system, a very significant efficiency improvement would affect the rest of the economic system in a positive way. These benefits were not captured in this study; however, some will be outlined here.

In urban areas, traffic related savings include: travel time reduction for the fleet of trucks and a reduction in the number of trucks, both of which will decrease traffic congestion and the corresponding pollution from the general traffic, as well as decreased travel time for other commuters, and a reduction in the number of accidents that occur, thus decreasing loss of life and hospital costs in the process.

Dependence on fuel and fuel-related products, such as tires, will reduce because of the improved efficiency in moving the freight. By reducing the amount of fuel and tires used, there will be significant savings for the country in terms of direct and indirect energy. There would also be less dependence (almost all developed countries are dependent) on importing these petroleum-based products. When the industry realizes the benefits and implements a computerized system, these benefits should be passed, in part, onto the consumers through reduced prices and gained efficiency, which will help the economy as a whole.

Since there are significant savings to be realized by this country and other countries, both economically and environmentally (as a result of decreased green house gas emissions), the governments should take a lead role in making computerized vehicle routing and scheduling optimization a reality, possibly by making reliable GIS databases easily available to the public. The governments, at all levels, should take a lead role by putting in place a policy that encourages the development of a systems approach to the integrated use of transport vehicles and the transportation infrastructure. Presently government policy only encourages efficiency improvements on a segregated, independent basis for each of the system components: the vehicle and the transportation infrastructure. Efficiency gains for each component is a recognized benefit, but when a systems approach is taken the total gain can be much greater than the sum of the efficiency gains of each individual component. If the method by which the goods and people are delivered by vehicles over the transportation network can be improved significantly using computerized vehicle logistics optimization, then governments should be developing the policy to encourage this area of technological development and should be implementing strategies that will ensure the successful adoption of this technology throughout the public and private transportation industry. Also, the governments should be encouraged to implement these procedures in their operations, such as maintenance operations, street cleaning, and street patching, which would result in significant savings for the public that could in turn be spent on producing more accurate and reliable GIS networks and databases, so further research can be conducted and more savings can be generated. Since most developed countries have cleaner air and reduced pollution as a major objective, the vehicle logistics optimization techniques, as demonstrated in this study, can, not only help to address the sustainability issues in transportation through the identified efficiency improvements, but also assist the countries in meeting their air quality targets.

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