NEW ZEALAND INTERMODAL FREIGHT NETWORK AND THE POTENTIAL FOR MODE SHIFTING

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ABSTRACT

Intermodal freight transport is a system of interconnected networks involving various modes and facilities allowing transfer of commodities from one mode to another. The system aims to provide efficient, seamless transport of goods from the origin to its destination offering producers and manufacturers a full range of transportation modes and routing options.

In this paper, we review the different modes of freight transportation in New Zealand as well as the current trends of mode share. A GIS-based optimisation model is created integrating road, rail and shipping network called the New Zealand Intermodal Freight Network (NZIFN).

The resulting model uses deterrence parameters such as operational costs and time-of-delivery as well as energy consumption and emissions, evaluates trade-offs, and finds the most optimal route from a given origin to a destination. The model is applied to hypothetical scenarios of distribution from Auckland to Wellington and Auckland to Christchurch which demonstrates how freight mode choices impact different costs associated with freight movement and the potential savings of moving by rail or shipping.

I. INTRODUCTION

In New Zealand, road freight movements play an essential role in sustaining and supporting economic growth and contribute to the quality of life of its residents. According to the New Zealand Business Council, freight volumes would increase by 70-75% over the next 30 years if the current growth rate continues (NZBC, 2011). An increase in road freight is tied up to gross domestic product (GDP) growth. However, decoupling of GDP and road freight, where GDP grows at a faster rate than road freight, is one of the holy grails in the field of the freight transportation (McKinnon, 2007). Unfortunately for New Zealand, trends have shown that road freight volumes increase faster than GDP growth, in particular between 1992 and 2007, decoupling was only manifested on years 2005 and 2006 (MFE, 2009). Decoupling is particularly important as it offers the prospect of economic prosperity with reduce impact on the environment in the form of emissions. At the same time, in light of peak oil, the sustainability of the over-reliance of New Zealand's economy on road freight is in question. One way to accomplish decoupling and to solve the over-reliance on fossil fuel is a shift to less energy intensive and lower emission modes such as rail or coastal shipping (McKinnon & Woodburn, 1996).

Modal shift requires the establishment of an intermodal freight network with transfer facilities from one mode to another. Modelling an intermodal transport network is much more complex than a unimodal network as each mode has its own specific characteristics with respect to infrastructure and transport units, and operational research strategies are also needed on transfer hubs such as finding their optimum location, allocation of capacities, and other drayage operations (Macharis & Bontekoning 2004, Sirikijpanichkul & Ferreira, 2006).

The goal of this project is to create a visualisation tool that will look at the potential of having an intermodal freight network with the proper infrastructures in place. A functional intermodal network for the country requires investments to build new infrastructure and maintain existing ones, and that the true costs of each transportation mode are factored into the model including capital expenditures, time, maintenance, congestion and also pollution-related costs (Bolland 2010, Black 2010). However constraints on data availability will entail several assumptions concerning infrastructures, as well as simplifying the cost-functions for modes and connectors. Through this, we can look at the economic, environmental and energy impacts of intermodal freight transportation and in particular assess the overall opportunities for mode-shifting of New Zealand freight.

II. REVIEW OF RELATED LITERATURE

A. Intermodal Freight Network

An intermodal network is defined as an integrated transportation system consisting of two or more unimodal networks. Each network is composed of a set of points, called nodes, and a set of point connectors called segments. Just in the case of unimodal systems, network optimisation models are also utilised in intermodal freight transport logistics (Crainic & Laporte, 1997). These models are used to find the optimal routes with cost or deterrence function given usually by distance, actual operational costs of transport and time-of-delivery. GIS is a computer system used to analyse, store, manage and graphically present a database with spatial components. In particular, ArcGIS, a GIS software produced by the Environmental Systems Research Institute's (ESRI) has a built-in Network Analyst tool that uses shortest-path algorithms to solve the most optimal routes.

Several researchers have utilised the capabilities of GIS to construct intermodal freight networks (Boile 2000, Standifer & Walton 2000, Southworth & Peterson 2000). The interdisciplinary team from Rochester Institute of Technology developed the Geospatial Intermodal Freight Network (GIFT) using ArcGIS 9.3 to create an intermodal network model connecting highway, rail, and shipping networks through ports, railyards and other transfer facilities in the United States and Canada (Winebreak et al, 2008). The main distinction of the GIFT model from other GIS-based models is the inclusion of energy and environmental attributes on each segment of the intermodal network. Energy costs are measured as British thermal unit per Twenty-foot-equivalent unit-mile travelled or (BTU/TEU-mi). The emission attribute is measured in terms of different pollutants (grams/TEU-mi) including carbon dioxide [CO_2], carbon monoxide [CO], particulate matter [PM_{10}], nitrogen oxides [NO_x], and sulphur oxides [SO_x] (Winebreak 2008, Comer et al 2010).

The GIFT model uses a hub-and-spoke approach in order to form a connection between the three modal networks. Network segments refer to actual and existing network datasets in the United States and Canada. Network spokes are artificial connections created to connect the 3 modal networks and represent transfer facilities. The hub-and-spoke approach connects modes directly through facilities using a Python-based ArcGIS script that builds an artificial link between appropriate modal networks and transfer facilities. These spokes are artificial because they may not follow a physical connection (such as a road) but instead are used as proxy for transfer paths. To make a realistic scenario, transfer penalties are applied to all of the spokes to represent costs, energy use, time delays, and emissions associated with intermodal transfers. These penalties are integrated into the overall optimisation calculations so that they are incorporated in route determination.

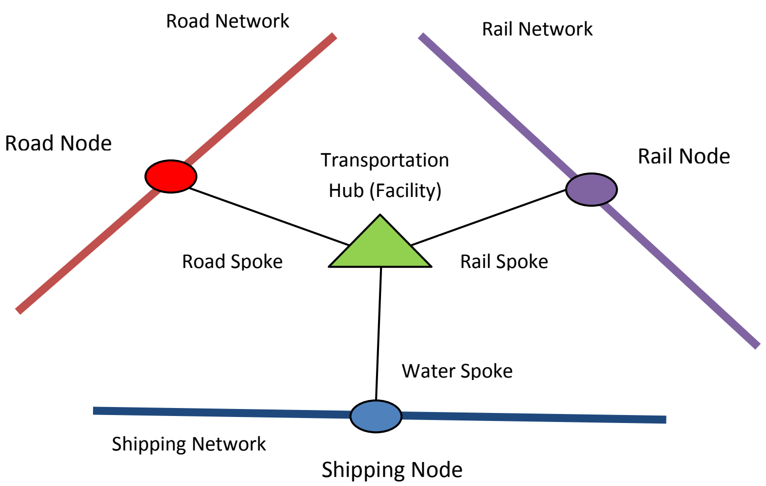

Figure 1: *The Hub-and-Spoke Approach in making intermodal network connections in the GIFT model*

B. Freight Flows in New Zealand:

The trends of increasing dependence and reliance on the road network of the freight movements in New Zealand is evident from the increase of road freight utilisation from years 2005 to 2008 (Bolland 2005, Paling 2008). The percentage share of the different freight modes including road, rail, coastal shipping and air is summarised in Figure 2. Expectedly, road freight has a bigger share for tonnes lifted than tonnes-kms travelled as rail and shipping are utilised more for longer distances, while air has negligible percentage owing to its high costs. Both tonnes lifted and tonne-kms travelled on the road increased from years 2005 and 2008 while rail and coastal shipping have shown a slight decreased. Road will remain the dominant mode for freight transport in the foreseeable future and only up to 7% of road freight may be shifted to rail (NZBC, 2011).

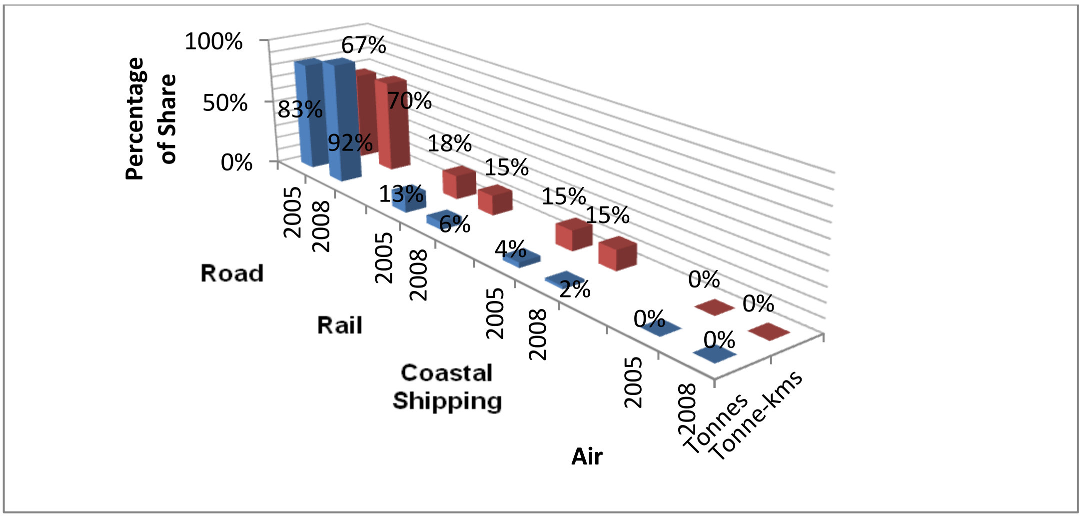

Figure 2: *Summary of Freight Task by Mode for years 2005 and 2008*

The breakdown for selected commodities and shows that modal shares vary significantly by products with rail having a relatively high share of coal, dairy products, and meat is shown in Figure 3. Coastal shipping only has significant share on commodities such as petroleum and cement.

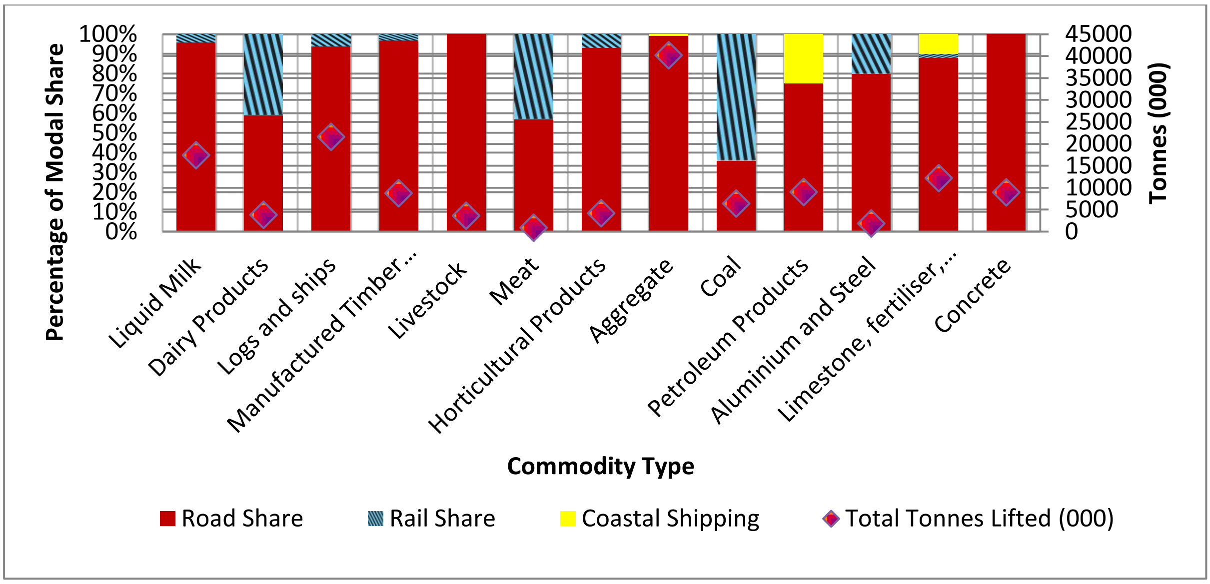

Figure 3: *Mode Share for Selected Commodities (Paling, 2008)*

C. Existing Freight Network Infrastructures in New Zealand

The creation of the New Zealand Intermodal Freight Network (NZIFN) model requires a review of the current key infrastructure systems supporting the competing modes of road, rail and shipping, namely the a) Road Network, b) Rail Network, c) Ports (Rockpoint, 2009).

1) Road Network – The road infrastructure in New Zealand is summarised in Table 1.

Table 1: *Categories of roads in New Zealand.*

Categories	Total Length	Percentage of Total	Percentage of Vehicle-kms travelled
State Highways	11,000 km	12%	50%
Local Roads	83,000 km	88%	50%

Aside from the network itself, other road services such as drayage operations provide the essential intermodal components for rail, international and coastal shipping movements.

2. Rail Network – The utilisation of New Zealand rail network is summarised in Table 2.

Table 2: New Zealand *Rail Network Utilisation*

Freight Route	Freight Services Per Day	Line Capacity Utilised	Gross Tonnage	% North Bound	% South Bound
Auckland-Wellington – Christchurch	8	77%	2,870,231	43%	57%
Auckland - Tauranga	13	80%	3,588,084	61%	39%
Christchurch – Dunedin – Invercargill	9	75%	1,840,299	56%	44%
				% East Bound	% West Bound
West Coast – Christchurch	11	51%	2,468,958	99%	1%
Hawkes Bay Taranaki	13	60%	850,072	16%	84%
Other Lines			3,839,191		

New Zealand rail infrastructure has suffered from significant underinvestment problems. In 2008 only 4,000 km of rail tracks exist to service both freight and passenger operations down from 5,689 km in 1953 (Rockpoint, 2008). Rail operations are impacted by the age, design and condition of the country's rail infrastructure. New Zealand's rail system operates for the most part with an 18 tonne maximum axle load whereas world standards are 25 tonnes per axle load. Bridges, tunnel clearances and steep gradients in the network restrict the weight, height and speed of rail freight. While recent investment has targeted key areas of restriction, bridges remain a major network issue and until addressed, track upgrades elsewhere are unable to be fully utilised (Rockpoint, 2008).

3. Coastal shipping – New Zealand is currently serviced by 16 key ports and summarised in Table 3.

Table 3: *New Zealand key ports (Rockpoint, 2008)*

Port	Location/City, Region	Container Terminal	Port Type
North Port	Marsden Point, Whangarei, Northland	No	Bulk
Ports of Auckland	Waitemata Harbour, Auckland	Yes	International
Ports of Auckland	Onehunga (Manukau Harbour), Auckland	No	Coastal
Ports of Tauranga	Sulphur Point, Mt Maunganui, Bay of Plenty	Yes	International
Eastland Port	Gisborne, Poverty Bay	No	Bulk
Port Taranaki	New Plymouth, Taranaki	Yes	Bulk

Port of Napier	Napier, Hawkes Bay	Yes	Regional
CentrePort	Wellington	Yes	Regional
Port Marlborough	Picton, Marlborough	No	Bulk
Port Nelson	Nelson, Tasman	Yes	Regional
Port of Westport	Westport, West Coast	No	Coastal
Port of Greymouth	Greymouth, West Coast	No	
Lyttelton Port	Lyttelton, Canterbury	Yes	International
PrimePort Timaru	Timaru, South Canterbury	Yes	Regional
Port Otago	Port Chalmers, Dunedin, Otago	Yes	International
SouthPort	Bluff, Invercargill, Southland	Yes	Bulk

New Zealand only 16 commercial freight ships, the rest of the commercial fleets are for tourism and fishing purposes (Rockpoint, 2008). Historically, the country is heavily reliant on maritime trade owing to its topography that no part of the 270,000 square-km landmass is more than 100 km away from the coast. However with improved land transport infrastructure, coastal shipping became less attractive as a means of transport.

III. METHODOLOGY

The modelling framework for the NZIFN uses the hub-and-spoke approach of GIFT (See Figure 1). In particular this study is divided into 3 major steps namely, a) Creation of geospatial intermodal freight network, b) Assigning costs variables on each network, c) Determining freight flows and scenario analysis. A Step-by-step outline is given on Figure 4.

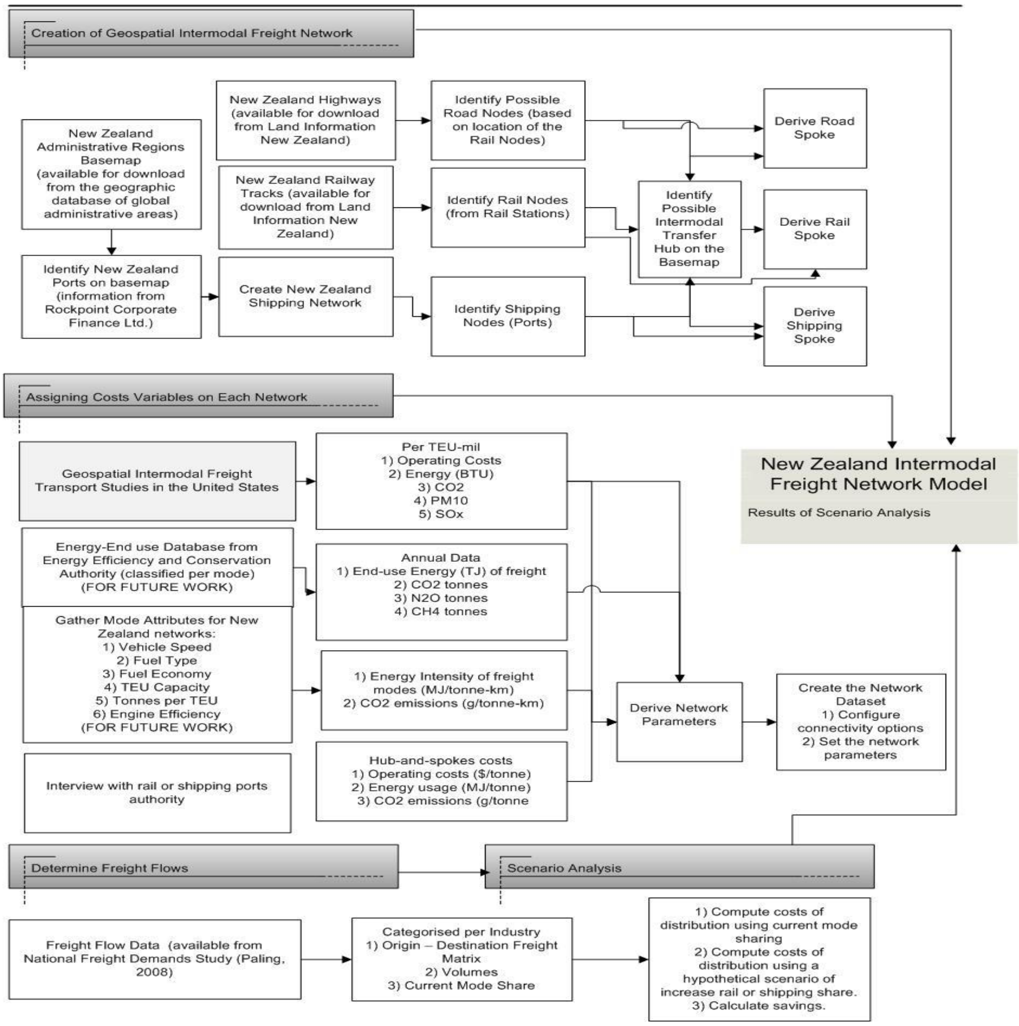

Figure 4: *Summary of the Modelling Framework for NZIFN*

IV. THE NZIFN MODEL AND CASE STUDIES

A. Creation of geospatial intermodal freight network for New Zealand

Existing geospatial datasets to be used in the creation of the Intermodal Freight Network are the Improved New Zealand Road Centrelines, New Zealand Railway Tracks and New Zealand Railway Stations, all created by Land Information New Zealand (LINZ). The road network is built from the State Highways category of New Zealand Road Centrelines including connectivity segments such as roundabouts and on-off ramps. It was tested for its self-connectivity using ArcGIS 10 Network Analyst. The rail network is built from the Zealand Railway Tracks. The shipping nodes are created using the 16 port locations given in the previous section. The rail nodes will be a subset of the New Zealand railway stations and are chosen according to the descriptions in Table 4.

The New Zealand shipping network is made from the port geographical location given on the Section II ensuring connectivity between each port but does not use the actual shipping routes. The construction of the intermodal transport facility is illustrated in Figure 2. The intermodal freight network will consists of 10 datasets and is summarised in Table 4.

Table 4: *Summary of 10 geospatial datasets used for the NZIFN*

Description	Geomtery Type	Source	Content
Road Network	Polyline	Improved New Zealand Road Centrelines by LINZ Pre-processed by the authors	State highways including roundabouts, on-off ramps, and ensuring overall connectivity
Rail Network	Polyline	New Zealand Railway Stations by LINZ	Entire railway tracks shapefile
Shipping Network	Polyline	Created by authors	Artificial network created using 16 key ports of the country
Intermodal Transfer Hub	Points	Created by authors	Artificial points/nodes selected near port locations and/or railways stations which can serve as a transfer facility
Road Nodes	Points	Created by authors	Artificial points/nodes on the road network selected near the created Intermodal Transfer Hubs
Rail Nodes	Points	New Zealand Railway Stations by LINZ Pre-processed by the authors	A subset of the railway stations which are near the created Intermodal Transfer Hubs
Shipping Nodes	Points	Created by authors	16 New Zealand key ports described in the previous section
Road Spokes	Polyline	Created by authors	Artificial connection from road nodes to intermodal transfer hub
Rail Spokes	Polyline	Created by authors	Artificial connection from rail nodes to intermodal transfer hub
Shipping Spokes	Polyline	Created by authors	Artificial connection from shipping nodes to intermodal transfer hub

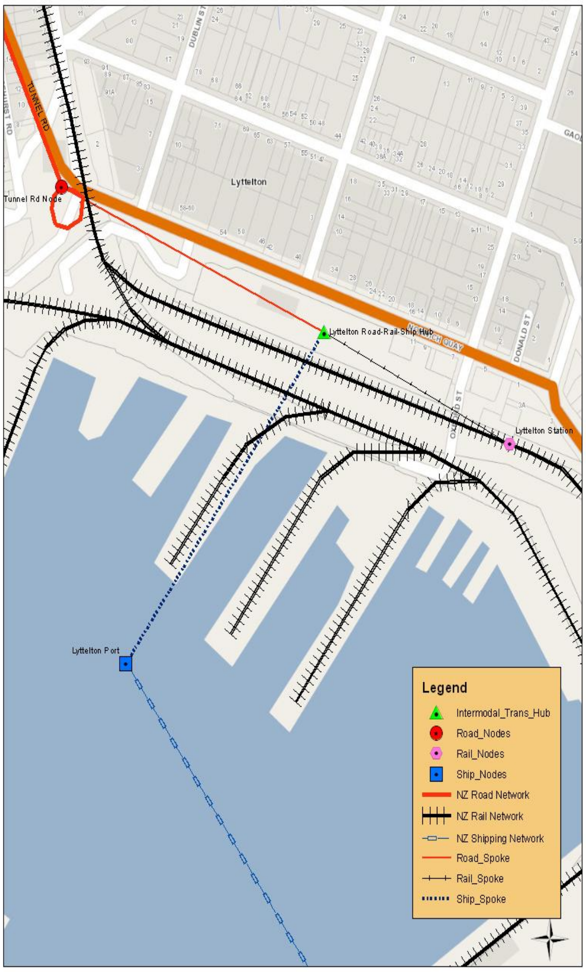

Figure 5: *Construction of the Intermodal Network*

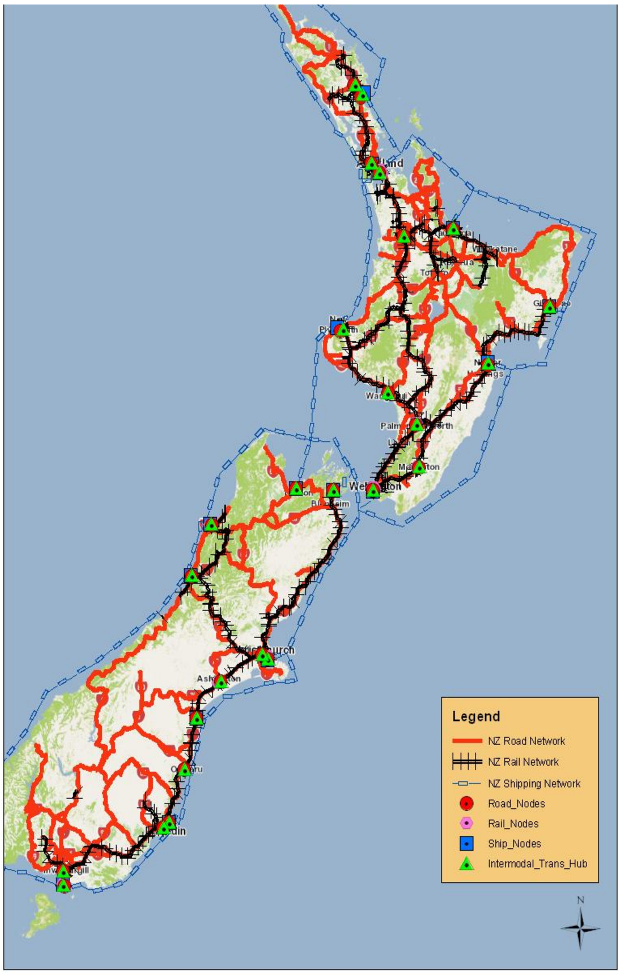

Figure 6: *The New Zealand Intermodal Freight Network*

B. Assigning Cost Variables on Each Network

Cost variables (deterrence functions) were assigned to each of network and spoke dataset. In this model, the point dataset do not have any costs associated on them, but instead transfer penalties are assigned to the usage of the corresponding spokes. The first deterrence function is the geographical distance or shape length of each segment of the network and spokes which can easily be calculated in ArcGIS 10. The next attribute is time and this is calculated by dividing the distance with the speed allowed on the network (eg. Speed for New Zealand roads are provided in the original dataset). Other attributes such as energy and greenhouse gas emissions such as (CO_2, PM_{10} and SO_x) parameters will use existing values from studies in the United States (Winebreak et al 2008, Comer et al 2010, Corbett Hawker & Winebreak 20011). The values are converted to SI-units using Table 5 except for the TEU which is retained in the study.

Table 5: *Conversion of Units*

1BTU = 0.0010549 MJ	1 US $ = 1.33 NZD (exchange rate as of Dec 2011)
1mile = 1.61 km	1 TEU = 12-14 tonnes

Table 6: *Data for transport modes from case studies of the GIFT team (Winebreak et al 2008, Comer et al 2010, Corbett, Hawker & Winebreak 2011)*

Mode of Transport	Speed (kph)	Operating Cost ($/TEU-km)	Energy (MJ/TEU-km)	CO2 (g/TEU-km)	PM10 (g/TEU-km)	SOx (g/TEU-km)
Road	By road class*	0.71	7.01	661.74	0.07	0.14
Rail	45	0.45	1.70	124.84	0.06	0.02
Ship	25	0.41	8.55	679.5	0.61	2.07

*Road class speed ranged from 20-110kph

Table 7: *Data for intermodal transfer penalties from case studies of the GIFT team (Winebreak et al 2008, Comer et al 2010, Corbett, Hawker & Winebreak 2011)*

Transfer Facility	Time (hr/TEU)	Operating Cost ($/TEU)	Energy (MJ/TEU)	CO2 (g/TEU)	PM10 (g/TEU)	SOx (g/TEU)
Road Spoke	1	46.7	26.73	9200	10.5	5
Rail Spoke	1	46.7	26.73	4100	10.5	5
Ship Spoke	1	46.7	26.73	2500	10.5	5

C. Sample Case Analysis

Using Network Analyst toolset in ArcGIS 10, the NZIFN model was tested on two case studies to investigate intermodal route optimisations based on time, operating costs, energy, and environmental objectives. The first case analysed is distribution from Auckland to Wellington and the second is from Auckland to Christchurch. The routes were solved minimum time, operating costs, energy, and CO2 (the accumulated costs PM_{10} and SO_x are computed inherently in the analysis but they are not used as objective functions because their corresponding values are much lower in comparison to CO_2). The results of the optimisation on both case studies are displayed in Figures 7 and 8 and on Tables 8 and 9.

For the first case study, rail is an attractive mode to minimise energy and CO_2 emissions but little saving on the operational costs and doubling the time it takes road (truck) to do the deliveries. Table 8 also shows that for intra-island distribution such as Auckland to Wellington, the usage of ship performs poorly on all accounts.

The second case study shows that there are more incentives for using rail and shipping, probably due to the longer distances and the inter-island transfer. Shipping provides low-cost transport of goods while rail is once again the best mode for energy and emissions-savings. On both studies, it is apparent that the only benefit of using road (trucks) is that it has lower total than other modes.

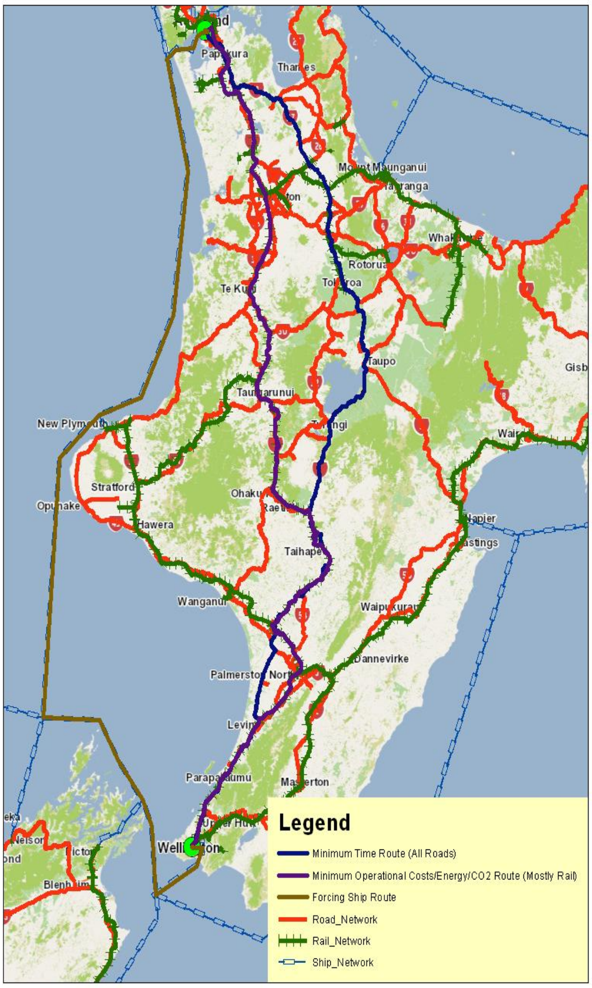

Figure 7: *Scenario Analysis of Distribution from Auckland to Wellington*

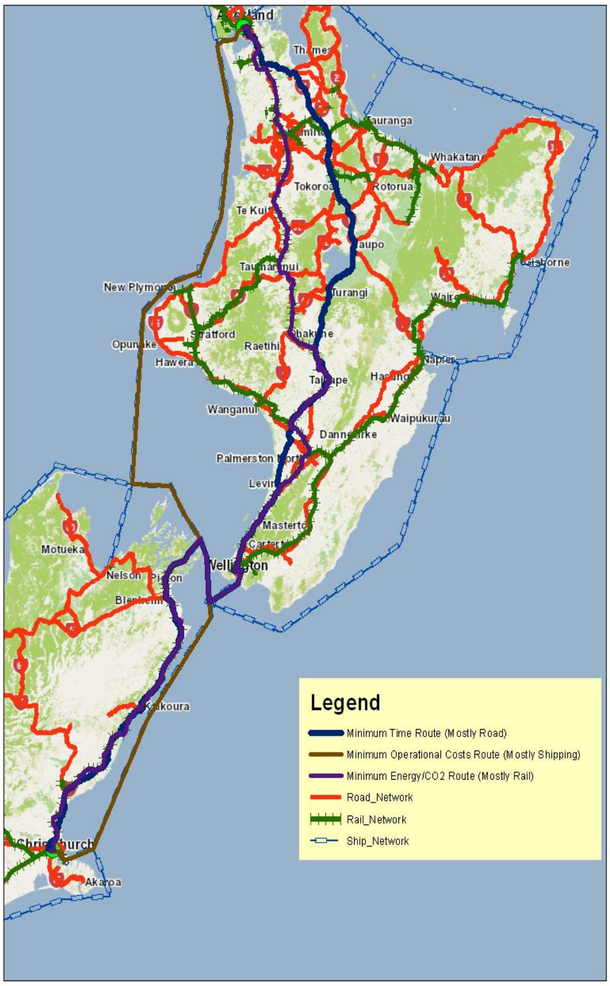

Figure 8: *Scenario Analysis of Distribution from Auckland to Christchurch*

Table 8: *Results for optimisation model runs from Auckland to Wellington*

Route	Primary Mode	Total Time (hr)	Total Operational Costs ($)	Total Energy (MJ)	Total CO_2 (g)	Total PM_{10} (g)	Total SO_x(g)
Min Time	Road	7	462	4496	425,463	46	90
Min Operational Costs, Energy, CO2	Rail	17	419	1215	100,703	66	26
Forcing Ship Route	Ship	34	423	5812	470,972	441	1400

Table 9: *Results for optimisation model runs from Auckland to Christchurch*

Route	Primary Mode	Total Time (hr)	Total Operational Costs ($)	Total Energy (MJ)	Total CO_2 (g)	Total PM_{10} (g)	Total SO_x(g)
Min Time	Road	21	917	8302	772,955	197	470
Min Operational	Ship	45	570	7945	648,342	593	1887

Costs							
Min Energy, CO2	Rail	37	867	3268	271,436	231	373

Current freight flows and the potential of modal shift were then explored. The mode share of different commodities was discussed in Section II.B, here we will investigate mode-shifting for some commodities which are already utilising either rail or shipping (which means the some form of existing infrastructure is already in place). Using the freight matrices of inter-regional distribution in the country (Paling, 2008), we selected commodities that are currently being distributed from Auckland to Wellington region by rail, and Auckland to Christchurch by shipping, and calculate the current costs of distribution using the current mode share and also with the road share arbitrarily decreased to some percentage.

For the Auckland to Wellington scenario analysis, the commodity chosen is Aluminium and Steel with 60,000 tonnes being moved annually from Northland/Auckland to Taranaki/Manawatu-Wanganui/Wellington region with road and rail having shares of 80% and 20%, respectively. Meanwhile for the Auckland to Christchurch analysis, the commodity chosen is Petroleum with 300,000 tonnes being moved annually from Northland/Auckland to Canterbury region with road and shipping shares of 75% and 25%, respectively (Paling, 2008). Note that both commodities selected are non-perishable items, which means that the timeliness of their deliveries is not crucial and benefits of other attributes of savings on operating costs, energy and emissions could be given a greater weight.

Table 11 shows that significant savings are achieved on Energy and greenhouse gas emissions (except on particulate matter of PM_{10}) with rail share increasing from 20% to 30%. Table 13 shows that significant savings are achieved not only on Energy and CO_2 emissions but also on operating costs by doubling the share coastal shipping.

Table 10: *Mode Share of the Auckland to Wellington distribution of Aluminium and Steel*

Commodity	Aluminum and Steel	Current Road Share 80%	Current Rail Share 20%	Hypothetical Road Share 70%	Hypothetical Rail Share 30%
Total Tonnes	60,000	4,8000	12,000	42,000	18,000
Number of TEUs	4,286	3,429	857	3,000	1,286

Table 11: *Costs of Distribution from Auckland to Wellington of Aluminium and Steel for the Current Scheme and for a Hypothetical Scenario*

	Total Operational Costs ($)	Total Energy (MJ)	Total CO_2 (g)	Total PM_{10} (g)	Total SO_x(g)
Current Road Costs	1,584,720	15,414,857	1,458,730,286	157,714	308,571
Current Rail Costs	358,989	1,041,429	86,316,857	56,571	22,286
Current Total	**1,943,709**	**16,456,286**	**1,545,047,143**	**214,286**	**330,857**

Costs					
Hypothetical Road Costs	1,386,630	13,488,000	1,276,389,000	138,000	270,000
Hypothetical Rail Costs	538,483	1,562,143	129,475,286	84,857	33,429
Hypothetical Total Costs	**1,925,113**	**15,050,143**	**1,405,864,286**	**222,857**	**303,429**
Savings	**18,596**	**1,406,143**	**139,182,857**	**-8,571**	**27,429**

Table 11: *Mode Share of the Auckland to Canterbury distribution of Petroleum*

Commodity	Petroleum	Current Road Share 75%	Current Shipping Share 25%	Hypothetical Road Share 50%	Hypothetical Shipping Share 50%
Total Tonnes	230000	172,500	57,500	115,000	115,00
Number of TEUs	16429	12,321	4,107	8,214	8,214

Table 12: *Costs of Distribution from Auckland to Canterbury of Petroleum for the Current Scheme and for a Hypothetical Scenario*

	Total Operational Costs ($)	Total Energy (MJ)	Total CO_2 (g)	Total PM_{10} (g)	Total SO_x(g)
Current Road Costs	11,299,859	102,292,500	9,523,909,821	2,427,321	5,791,071
Current Shipping Costs	2,340,825	32,631,250	2,662,833,214	2,435,536	7,750,179
Current Total Costs	**13,640,684**	**134,923,750**	**12,186,743,036**	**4,862,857**	**13,541,250**
Hypothetical Road Costs	7,533,239	68,195,000	6,349,273,214	1,618,214	3,860,714
Hypothetical Shipping Costs	4,681,650	65,262,500	5,325,666,429	4,871,071	15,500,357
Hypothetical Total Costs	**12,214,889**	**133,457,500**	**11,674,939,643**	**6,489,286**	**19,361,071**
Savings	**1,425,795**	**1,466,250**	**511,803,393**	**-1,626,429**	**-5,819,821**

V. CONCLUSIONS

Freight transportation is one of the pillars of economic growth for New Zealand. This paper provides a tool to look at the intermodal freight transport in an objective manner and investigate the benefits of shifting from road to less energy and emissions-intensive modes such as rail and shipping. The NZIFN model allows a trade-off analysis using different objectives functions such as minimising time, operating costs, energy and emissions.

Two hypothetical case studies were analysed in this paper namely a) Auckland to Wellington distribution of Aluminium and Steel and b) Auckland to Canterbury distribution of Petroleum and the computations for both studies showed the potential savings of shifting a fraction of the total commodities moved from road to rail or shipping. The calculations showed significant Energy and CO_2 emissions-savings and even reduced operating costs. Both of the commodities chosen were non-perishable and hence timeliness of deliveries may be traded for energy and emissions benefits particularly as fuel supply decreases and emission reduction schemes raise the relative costs of trucking.

The results of the hypothetical analysis could be useful for policy-makers in decision-making process concerning proper investments for a sustainable freight system for New Zealand. By investing on infrastructures that would aid in the creation of an intermodal freight system for New Zealand, it is possible to build a system more resilient to rising fuel prices and reduce environment impact.

VI. RECOMMENDATIONS

The NZIFN model used in the scenario analysis is based uponcosts parameters from the United States study (Winebreak et al 2008, Comer et al 2010, Corbett, Hawker & Winebreak 2011). As a future work, it will be possible to utilise New Zealand-based data such as that provided by the Energy Efficiency and Conservation Authority for the deterrence parameters on the road, rail and shipping networks. Also, it is recommended to interview and survey port and transfer facilities to look at the transfer penalties for existing hubs-and-spokes in New Zealand.

The next step is to investigate the risk exposure of the current distribution scheme to constraints on the oil-supply and cap on emissions.

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