Integrated planning as a 'smart' solution for improved sustainability of construction logistics: A transport perspective

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Abstract: The trans-disciplinary nature and extent of the construction supply chain make it prone to inefficiencies at its component domain/segment boundaries. Project-centric delivery accentuates these. Logistics, a significant element of the construction supply chain, forms part of complex systems with multiple stakeholders and a wide range of concurrent on-/off-site in-action activities, processes, and systems. Transport is the largest logistics component, with most other processes (except warehousing) being business processes and not 'real' ones. The low-value/high-volume nature of construction materials leads to substantial transport requirement, even for small projects, with costs up to half the logistics costs or a fifth of construction costs. Transport is naturally fragmented, with a component intrinsic to every business, and asset ownership and deployment typically external to it. Incremental inefficiencies, driven by siloed planning between involved stakeholders, aggregate into visibility at the macro level. Adverse sustainability impacts are the obvious consequence. Transport optimisation results from re-configuring activities, re-combining resources, and re-positioning actors, which demand integrated strategic and/or operational planning. This paper undertakes data-driven analysis of an integrated business model as a 'smart' solution for improved transport efficiency in a specific New Zealand construction supply chain segment. Quantification and validation of sustainability benefits is undertaken using domestic/international parameters.

Keywords: Construction transport; Integrated Planning; Sustainable logistics; Vertical integration

1. Introduction

The construction industry typically contributes approximately 13% to the global Gross Domestic Product (GDP) (Barbosa et al., 2017). This sector plays a significant role in generating employment, enhancing infrastructure, and supporting businesses. Its activities are crucial for socio-economic progress but also lead to significant consumption of resources. As of 2019, the construction domain accounted for 35% of the world's energy usage and contributed 38% to global emissions (UNEP, 2020). These figures are the result of various factors, including upstream issues leading to embodiment of resources, and downstream (operation and maintenance related) factors. The construction sector is highly fragmented (Guerlain et al., 2019; Jones et al., 2022; Riazi et al., 2020; Shakantu & Emuze, 2012). This manifests at two levels *viz* from an industry perspective due to the presence of numerous small firms, and from a construction project perspective due to disaggregation of the construction process and entities (Alashwal & Hamzah, 2014; Alashwal & Fong, 2015). Logistics, which encompasses aspects

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like transportation, warehousing, and inventory management, is a critical interdisciplinary aspect of the complex Construction Supply Chain (CSC). It significantly impacts project management and costs (Ying and Tookey, 2014). Fragmentation leads to challenges in coordination and integration, resulting in inefficiencies and wasteful resource dissipation (Alashwal & Fong, 2015), typically at the boundaries of the comprising organisational or process elements. These ultimately lead to concerns about the sector's sustainability. The diverse elements within logistics offer substantial opportunities for optimisation within the construction sector, both in terms of strategic planning and operational execution.

Transportation constitutes the largest component within the realm of logistics, as highlighted by various sources (Bowersox et al., 2002; Madadi et al., 2010), mainly due to the fact that most logistics processes, excluding warehousing, are conceptual rather than physical operations (Szymonik, 2012). Given that construction materials possess a high volume but relatively low value when compared to other industries (Balm & Ploos van Amstel, 2018; Lovell et al., 2005), transportation assumes a significant role within the domain of construction logistics. Consequently, transportation needs, even for relatively small projects, can be considerable. Apart from considerations related to energy consumption, emissions, and financial costs (Smith et al., 2002; Szymonik, 2012; Ying et al., 2014), there are additional externalities associated with transportation that affect various dimensions of sustainability. These externalities can be immediate and direct, such as pollution, noise, and traffic congestion, or more indirect, including the disruption of ecosystems, health consequences, and a diminished quality of life (Chatziioannou et al., 2020). Therefore, optimisation of the transportation function of construction logistics has the potential to result in improved sustainability.

This paper studies the impact of vertical integration of business processes and integration of the planning function between the service provider and the consumer as ‘smart’ solutions to optimise transportation operations and, therefore, improve sustainability. It studies a narrow New Zealand CSC segment of plasterboard distribution in Auckland, providing indicators for the manufactured construction products market.

2. Establishing the baseline

The baseline for this paper will be established along four dimensions *viz* the construction logistics problem, the construction supply chain for material delivery, parameters for assessing efficiency of freight transport, and a description of the problem whose analysis was undertaken. The idea of smart solutions is embedded in the problem description.

2.1. Construction logistics

Construction logistics are concerned with preparing, coordinating, controlling, and managing the flow of products from processing of raw materials processing to final application of the finished product in a project, and the reverse logistics of removing waste and finally disposing it off (Agapiou et al., 1998; Ying & Tookey, 2014). Complex systems with diverse stakeholders comprise construction logistics. These are concurrently engaged on- and off-site in wide-ranging activities, processes, and systems. These can be conveniently grouped into the three domains of organising and planning, transportation, and activities taking place on-site (Janné, 2020; Janné et al., 2018).

The logistics process provides a framework for integrated decision-making regarding inventory, warehousing, transport, materials handling, and industrial packaging. Efficient construction logistics require planning, management of loading and unloading zones, warehousing (internal and external to the construction site), on- and off-site handling of materials, and transportation for linking actors and channels of a logistics system (Ekeskär & Rudberg, 2016; Janné & Fredriksson, 2019; Janné et al., 2018).

Construction logistics costs are invariably embodied in the material cost without distinction (Ying & Tookey, 2014). Transport in construction logistics does not get the attention it merits, even though a substantial proportion of urban goods-vehicle movements related to construction. Hence, construction deliveries are referred to as ‘hidden’ logistics in literature (Balm & Ploos van Amstel, 2018; Verlinde, 2015; Ying & Tookey, 2014), their costs being referred to as ‘hidden’ costs.

The construction logistics problem is typically viewed from the contractor’s perspective, who needs to manage all suppliers and deliveries at the project level (site). The issue has its genesis primarily in the limited storage space on any construction site. On-site logistics coordination addresses a project's horizontal (disaggregation of skill sets/expertise) and vertical (straitjacketing of a construction project into well-defined phases) fragmentation issues. It is, however, incapable of addressing longitudinal fragmentation (between projects); the supplier, the construction site, and the transporter are independent entities with minimal co-ordination, coming together only for site-centric deliveries.

The perspective, however, reverses when viewed from the supplier’s end. When managed by the supplier, deliveries effectively get consolidated, therefore demonstrating higher efficiencies as compared to business-as-usual (Dhawan, 2023).

2.2. The materials delivery supply chain

Between the manufacturers (or major or bulk suppliers) at one end of the construction supply chain (CSC), and the consumer (the site) at the other, sit the Builders’ Merchants (BMs). BMs represent a storage and consolidation point as the primary intermediary between the manufacturer (major or bulk supplier) and the contractor. Manufacturers of construction materials and components sell goods through three typical models, i.e., direct to the customer, sale of a limited range of goods through a specialist stockist, and a BM.

The first model (direct to the customer) is invariably applied for large consignments such as steel framing etc. that need not go through intermediaries. The second model (sale through specialist stockists) is typically employed when manufacturers market their inventories through their own subsidiaries. The third model (supplies by the BM, referred to as the Freight-into-Store model) is what works for most situations, where the retail quantities are usually too small to be managed by bulk suppliers or manufacturers.

The proliferation of the Freight-into-Store model is also due to the unstated but critical economic function of the BM providing the working capital for construction by extending a line of credit to contractors. A fluctuating market demand compels the retention of high safety stocks, whose carrying costs are borne by BMs, anywhere upto 20% of the inventory cost itself annually, including invested capital (Agapiou et al., 1998; Bowersox et al., 2002; Dhawan, 2023; Vidalakis & Tookey, 2005; Vidalakis et al., 2011). BMs supply a variety of essential construction materials to the sector, with significant over-the-counter deliveries to the buyer. These deliveries are for both ‘heavy’ (sand, bricks, blocks, and aggregate) and ‘light’ (fixtures, fittings, tools, plumbing, and heating supplies) materials.

Typically, BMs may operate at the national, regional, and local merchant level. Those operating at a national scale may have national and/or regional distribution centres (RDCs), with local depots/warehouses (WHs) serving specific geographical areas for interfacing with customers. The transport function of these depots is not an entity in itself; rather, it is a derived demand existing to serve the purpose of materials delivery to the customer. The fleet of depot is typically small and serves a local customer network which may include the residents, construction sites, and bigger construction businesses or organisations. Planning of delivery trips is based on the staff's knowledge about the local routes and locations. While regional and national merchants maintain centralised control over their fleet, which is managed professionally by a nominated manager, at the BM’s depot level the depot manager, who is not a transport professional, manages the transport fleet and its operations. The focus of depots is customer service and not efficiency of transport utilisation. Orders are typically accepted a day in advance for the ensuing day's work (Dhawan, 2023).

2.3. Transport efficiency assessment

The important factors impacting the efficiency of physical goods handling are Filling rate, Vehicle/Resource Efficiency, Freight Transport Efficiency, and System Efficiency/Effectiveness (Pahlén & Börjesson, 2012). The first and second are operational/tactical, while the third and fourth are strategic. To understand vehicle utilisation, 'Filling Rate' is introduced here as, *"the ratio of the actual goods moved to the maximum achievable if the vehicles, whenever loaded, are loaded to their maximum loading capacity"* (McKinnon, 1999). In the case of a truck, vehicle utilisation (the ratio of the vehicle capacity utilised to the available vehicle capacity) narrows down to five measures (McKinnon, 2010; Pahlén & Börjesson, 2012): -

- **Level of empty running:** The proportion of the distance travelled empty.
- **Weight-based loading factor:** Ratio of the actual weight carried by the truck to the maximum weight it can carry (the rated payload capacity).
- **Tonne-km loading factor:** Ratio of the actual tonne-km transported to the maximum tonne-km (based on the rated payload capacity) possible. Unlike the weight-based loading factor, which assumes a constant loading factor on a trip, tonne-km is dynamic as they vary with delivery or collection of consignments.
- **Volumetric loading factor:** A three-dimensional perspective of vehicle fill that considers proportion of the total cubic capacity of the vehicle occupied by the load.
- **Deck-area coverage (or 'load area length')** A two-dimensional view of vehicle loading that considers proportion of the vehicle floor (or deck) area covered by a load. In case of loading height limitations or constraints, deck area limits loading and not the cubic capacity.

The efficiency of the construction industry's transport function depends upon the utilisation of vehicle capacities across onward and return trip segments. A major logistical challenge is finding backloads for returning vehicles. Empty running of vehicles, earlier considered only a wasted resource, is now viewed through the lens of environmental liabilities. Consequently, from a policy and business model perspective, reduction of empty running is a key focus of most sustainable distribution strategies (McKinnon & Ge, 2006).

2.4. Problem description and research questions

Fragmentation is an identified challenge in the construction sector, with transport being a major contributor. Evidence-based decision-making in the construction freight/logistics domain is constrained by a general dearth of pertinent data. Data relates to individual freight journeys with a general lack of an SC perspective, amongst others (McKinnon, 2015). These present barriers to quantifying optimisation as a result of implemented SC models and assessing further improvement potential of implemented SC and/or logistics models. The problem under investigation pertains to the supply of plasterboard by New Zealand's largest supplier in Auckland.

In the business-as-usual scenario, distribution is through a disaggregated SC in the form of the Freight-into-Store model, with three nodes of interest, i.e., the manufacturer (warehouse), the BM network, and the consumers or construction sites. The model has two links (Manufacturer – BM and BM – Construction Site) linking three nodes for both information and material movement. Each one of the nodes has storage as one of its primary functions. This model has substantial time and space associated with the intermediate node (the BM), where material arrives in bulk from the manufacturer and departs in bulk or retail to consumers (construction sites). The Freight-into-Store model represents the ‘Distributor storage with carrier delivery’ logistics model (Chopra et al., 2013). A transformation to a more efficient logistics model involved (forward) vertical integration of plasterboard distribution as an extension of manufacture, followed by outsourcing of the transport function on a Second Party Logistics (2PL) basis.

The modified model presents three nodes with three links, as opposed to the Freight-into-Store model. Two of these links handle the exchange of information for invoicing and delivery (Contractor – BM, BM – Manufacturer). The third link is the physical transportation of material between the Manufacturer and the Construction site. In the context of this research, this model is referred to as the 'Direct-to-Site' model and can be viewed as an instance of the 'Manufacturer storage with direct shipping' approach to logistics. (Chopra et al., 2013).

The dataset indicated employment of approximately 26 trucks of different payload capacities and 42 truck trips daily. The pricing of transportation was uniform on a ‘per-tonne’ basis across Auckland irrespective of the destination. The trucks employed are all flat-bed trucks which consume diesel fuel.

Ostensibly, the Direct-to-Site solution is ‘smart’ as it uses hardware (transport), intelligent elements (internal organisational intelligence and analysis), data elements (truck movement data, consumer demand, BM invoicing), and intangible service elements (consumer satisfaction and personnel competencies) (Huikkola et al., 2022) to deliver a service with a higher efficiency. The improvement in transport efficiency was, however, not quantified. This presented the following research questions: -

- **RQ1.** What is the quantum of efficiency improvement achieved by implementation of the Direct-to-Site model over the Freight-into-Store model?
- **RQ2.** What is the potential for further improvement in transport efficiency and the means to achieve it?

3. Transport efficiency analysis

3.1. Transport efficiency measures

The two measures (from section 2.3) selected for analysing the transport efficiency in this paper are the weight-based loading factor (termed ‘loading efficiency’ - at dispatch) and tonne-km-based loading factor (termed ‘capacity utilisation’). The former is static, as it is a measure at a point in time and does not consider distances, while the latter is dynamic as it includes loads and distances across the complete trip.

The dataset for analysis included the dispatch load, delivery destinations, and loads consigned to each destination. It did not, however, include the sequence of delivery and distances between various nodes along the route. Sampling of the dataset needed to be undertaken for introducing distances into the analysis (due to the dataset size). A sample size of about 370 was found to be statistically significant for the available dataset (Krejcie & Morgan, 1970). Simple random sampling (probability sampling) was undertaken. Data reflecting more than three drops was deleted as this formed less than 1% of the dataset, hence, not considered significant.

3.2. Quantification of efficiency improvement from the Direct-to-Site over Freight-into-Store model

As a result of VI, and therefore, the distribution function's inclusion into the manufacturer's operations, the Direct-to-Site model modifies the transportation network by eliminating one node and one linkage in the transportation network. Figure 1 illustrates the transportation network in the Freight-into-Store and Direct-to-Site configurations. Considering that the three linkages joining the three nodes form a triangle, the length of any one link will always be less than the sum of the other two unless all three nodes lie on the same line, in which case they will be equal. However, actual manifestations of road and destination networks are rarely composed of straight lines. Therefore, an evaluation of the reduction in distances travelled in the Direct-to-Site model compared to those that would have been travelled under the Freight-into-Store model for each set of BM-destination combination facilitated quantification of benefits vertical integration creates for transportation operations in the CSC.

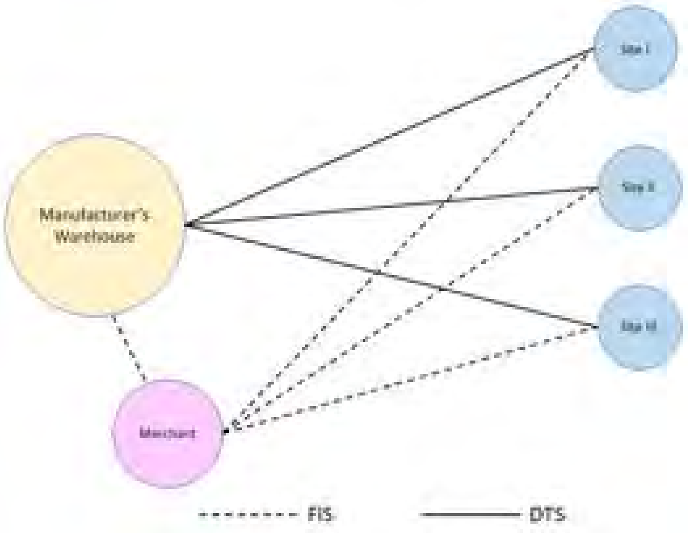

Figure 1: Transport network configurations for the Freight-into-Store and Direct-to-Site distribution models.

Even though these would be indicative for this segment of the CSC (plasterboard distribution) and contextual to Auckland, they provide a benchmark for improved efficiencies. A comparison of the distances involved in the Direct-to-Site and Freight-into-Store models for every trip provided a straightforward assessment of the improved transport efficiency in terms of reduction in travel distances. The aggregated results are presented in Table 1.

Table 1: Quantification of reduction in distances travelled by trucks in the Direct-to-Site model on the Freight-into-Store baseline.

Parameter	Direct-to-Site (km)	Ratio of Direct-to-Site to Freight-into-Store
Average	27.04	0.7086
Maximum	119.1	2.19
Minimum	3.8	0.1047

Individual BM-destination distances were considered for the analysis since circa 75% of the truck trips in the dataset involved a single drop. Instead of presenting the distances travelled individually in the Direct-to-Site and Freight-into-Store models, a ratio of the distances presents a stronger indication of improved efficiency through reduction of distances travelled. On an average, the distances travelled in the Direct-to-Site model are 70% of the Freight-into-Store model. A 30% reduction in distances travelled translates to approximately 11.11 km per trip.

3.3. Potential for further transport efficiency improvement

To investigate further potential for efficiency enhancement within the Direct-to-Site model, the problem was formulated as, *"Assessing the potential for improved efficiency of 'Direct-to-Site' transport operations for plasterboard supply in Auckland, New Zealand, proposed to be addressed through operational data analysis."* The sequence of drops was introduced in the sampled dataset from the 'Eroad' (a private IT services company in New Zealand providing GPS enabled tracking for transport) database. Based on distances between nodes, and the sequence of drops, the loading efficiency at dispatch (static) and the capacity utilisation (tonne-km based - dynamic) were calculated. Table 2 presents these analyses.

Table 2: Loading efficiency and capacity utilisation of trucks (Direct-to-Site model).

Drops	Trips	Loading Efficiency			Capacity Utilisation		
		Maximum	Minimum	Average	Maximum	Minimum	Average
1	261	99.21	4.31	55.89	49.61	2.16	27.99
2	81	99.77	6.45	57.08	55.79	3.33	27.84
3	28	90.33	14.99	60.53	42.11	4.93	24.82
Weighted (fleetwide)		Average		56.36			27.61

The following were inferred from the above analysis: -

- Underutilised truck (payload) capacity (nearly 252 tonnes daily on average), resulting in 72% of tonne-km going unutilised.
- The potential for optimisation of daily truck operations through reduction in the number of trips by better loading, indicating the requirement of better planning.

3.4. Operations Research as a further 'smart' solution

Application of Linear Programming (LP) (the Transportation Model) from operations research was explored as an optimisation tool. The basic design of a transportation problem is represented by a network with nodes representing sources and destinations and arcs linking the nodes representing routes, quantities of material moving, and the per unit shipping cost on that route (Taha, 2008). It aims to minimise the cost of satisfying the requirements of the destinations within the existing production capacity (Uzorh & Innocent, 2014). The problem under consideration presented certain peculiarities that differentiated it from a standard transportation problem. Hence, it was reformulated as follows: -

- The sampled dataset was disaggregated into one day's operations at a time.
- Instead of the warehouse, each truck trip was considered a source with a capacity equal to the truck payload capacity (supply).
- Each delivery undertaken during the day was taken to be a consumer (demand).
- The channel cost (per unit transportation cost) was assumed to be unity (being fixed), in the absence of specific figures (being commercially sensitive). Any other positive number would do equally well.

The ‘Solver’ add-in to MS Excel was used for solving the transportation problem using LP, with a restriction of not more than 200 objective co-efficients in the problem matrix. Since the exercise was a proof-of-concept, the dataset was truncated in a manner to include as many truck trips as possible from a day, while maintaining trip integrity (i.e., no trips were split). The specific parameters applied were: -

- Total load to be delivered equal to the summation of the node demands (‘equal to’).
- Total load to be delivered less than or equal to the trip capacities (‘less than equal to’).
- The objective co-efficients (per unit channel transportation costs) taken as unity.
- The objective function is taken to be minimisation of the cost (in this case it transforms to minimisation of transportation resources - trucks, since channel costs were constant - unity).

The matrix was then solved for decision variables (allocation of loads to trucks). The resulting optimisation of transport across the sampled dataset is shown in Table 3.

Table 3: Transport optimisation (improved efficiency) using LP.

Parameter	Manual allocation	LP-based allocation	Improvement (over manual baseline)
Average loading efficiency	56.36%	89.85%	59.42%
Daily truck trips	11	7	36.36%
Capacity utilisation (tonne-km)	27.61%	49.38%	78.84%

The figures in Table 3 pertain to truncated (sampled) dataset presented to the transportation model. The number of trips for the complete sample works out to about 26 (pro-rata), which is a reduction of 16 truck trips daily. This quantification will be used for evaluating sustainability benefits. Application of LP presents a manifestation of the need for integrated planning. In the status quo, the manufacturer’s aim was transportation of certain quantities of plasterboard daily. The employment of resources was left entirely to the discretion of the 2PL service provider, as a consequence of the payments model which considered the daily tonnages transported, rather than the distances covered. There is no imperative for resource-use analysis, as long as the daily tonnages are delivered. Maximising transport utilisation becomes an imperative under two conditions. Either the payments model is per-km, or the sustainability perspective is introduced, which brings in the requirement for minimising distances travelled by trucks for the required deliveries. Integration of the manufacturer in the planning process, even if to the extent of monitoring transport utilisation, is an outcome. This integration is considered a ‘smart’ solution as it meets the criteria of hardware (transport), intelligent elements (internal organisational intelligence and analysis), data elements (truck movement data, consumer demand), and intangible service elements (consumer satisfaction and personnel competencies) to optimise the distribution process. In this case the involvement of the manufacturer is as a consumer of 2PL services.

4. Sustainability benefits

From the analysis so far, sustainability benefits accrue from the following individual contributors: -

- Adoption of the Direct-to-Site model over the Freight-into-Store model for plasterboard distribution (status quo).

- Improved loading of trucks as a result of optimisation through LP (analysis), and therefore, improved capacity utilisation.
- Reduction in the number of trucks as a consequence of improved loading (analysis).

4.1. Reduction in fuel consumption from adopting Direct-to-Site over the Freight-into-Store model

As a result of adopting the Direct-to-Site model, there is a reduction of 11.1 km in distance travelled per truck trip. An analysis of the sampled dataset showed the average payload capacity of trucks as being 21,170 kg. This was benchmarked against a longitudinal study (2015-2018) in New Zealand (Wang et al., 2019), where truck fleet in New Zealand has been categorised based on Gross Vehicle Mass (GVM), and the fuel consumption of each GVM category assessed, irrespective of the payload. The average payload of 21,170 kg fits neatly into the GVM category of 20,000 kg to 24,999 kg, with an average fuel consumption of 46.7 litres of diesel per 100 km. A reduction of 11.1 km translates to 5.18 litres of diesel per trip. Considering 42 trips a day, the overall daily diesel consumption reduction is 217.56 litres. @ 247 working days annually, ***reduction in diesel consumption works out to nearly 53,700 litres per annum***. ***In terms of distance, the reduction is 126,100 km annually.***

4.2. Reduction in fuel consumption from improved capacity utilisation of trucks

The reduction in diesel consumption due to improved capacity utilisation is reckoned from the work of Henningsen (2000), which presents a plot of the approximate fuel consumption in tonnes per kilo-tonne of load (y-axis) for various capacity utilisation factors (x-axis) when transported over a distance of 3,218 km by various transportation modes (experimental results). The improvement in fuel efficiency is converted to actual reduction in fuel consumption by superimposing capacity utilisation data from Table 3 on the plot (Figure 2).

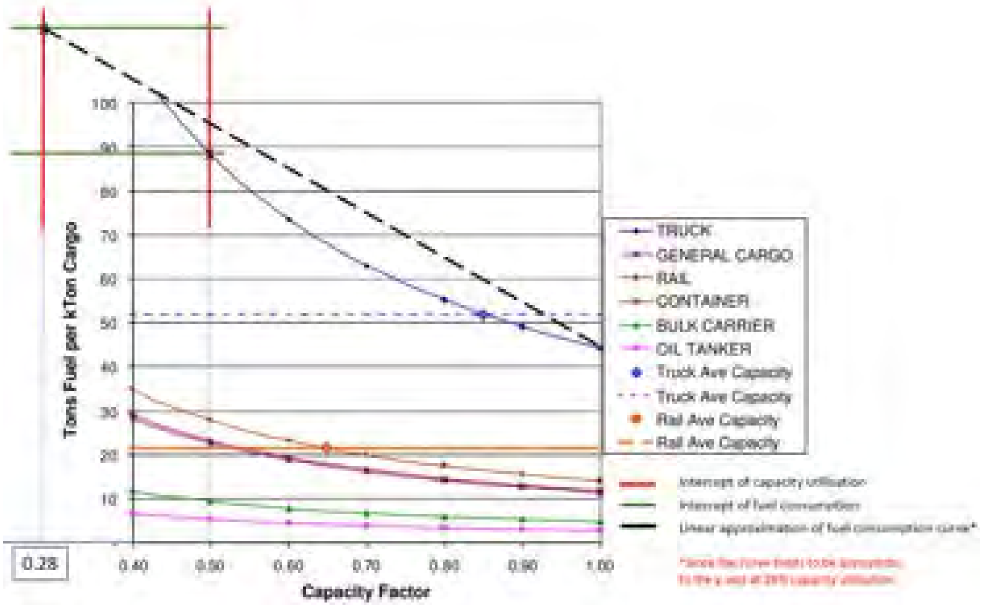

Figure 2. Estimation of reduction in fuel consumption due to improved capacity utilisation of trucks based on Henningson, 2000

The intercept between the green lines is converts to a figure of about 0.0074 kg/tonne-km (0.0082 litres/tonne-km) of reduction in diesel consumption [(113,000 – 88,000)/(3218 x 1000) kg/tonne-km]. In the scenario of improved capacity utilisation, 330 tonnes of plasterboard are transported across 26 trips, each trip transporting approximately 12.69 tons. For a vehicle carrying 12,690 kg of load, it converts to 0.1057 litres of diesel reduction per km. The trip length is found from the average distances between destinations in a three-drop trip obtained from the sampled dataset. These are presented at Table 4. The generalised trip length works out to approximately 52.3 km.

Table 4. Distance parameters for a generalised trip.

Drops	Trips	Distances			
		WH – Drop 1	Drop 1 –Drop 2	Drop 2 – Drop 3	Drop 3 – WH
1	261	22.76	0	0	22.76
2	81	24.92	10.55	0	28.22
3	28	23.67	11.84	16.16	32.6
Weighted Average		23.29	3.21	1.22	24.62

The reduction in diesel consumption per trip, therefore, is 52.3 x 0.1057 = 5.53 litres of diesel. 26 trips daily, over 247 working days annually translate to approximately ***35,500 litres of diesel annually***.

4.3. Reduction in fuel consumption due to reduction in the number of truck trips

The number of truck trips reduce by 16 (from 42 down to 26) on application of the transportation model. Considering the generalised trip length of 52.3 km, 16 trips convert into approximately 836 km per day, and 206,700.00 km annually. Considering the average GVM of trucks as being employed (status quo) of the 20,000 – 24,999 kg category, 206,700.00 km annually translate to a reduction of 46.7 x 206,700.00 / 100 = ***96,524 litres of diesel per year. This is in addition to 16 trucks effectively going off the road, and the associated reduction in distances travelled.***

4.4. Aggregating sustainability benefits

4.4.1. Emissions reduction

From the emissions guide issued by the Ministry for the Environment (MfE, 2022a), the CO2-e per litre of diesel is approximately 2.69 kg. An annual reduction of approximately 185,700 litres of diesel from adoption of the Direct-to-Site model, improved loading of trucks, and reduction in the number of trips converts to ***513,585.00 kg CO2-e, or 513.58 tonnes CO2-e annually.***

4.4.2. Monetised benefits

Monetisation of benefits is quantified per km based on statistics obtained from various documents in the public domain on a per km basis in Table 5.

Table 5: Monetisation of benefits on a per km basis (Briggs et al., 2016; Climate Change Commission, 2021; Ernst & Young, 2021; Ministry for the Environment, 2021; New Zealand Transport Agency, 2021; Stroombergen, 2023).

On account of	Impact or value	Based on	Per km impact
Emissions contribution	21% 24.8%	Emissions contribution from the transport sector Contribution of freight transport to transport emissions	Multiplication factors
Social cost of damage by freight transport	NZ$520mn per annum	Transport sector share is NZ$2.1bn annually Freight transport share is 24.8% 3bn annual freight km	NZ$0.173
Cost of deaths due to freight transport	NZ$693mn per annum	51.5 deaths per bn freight km 3bn annual freight km NZ$4.47mn monetised cost of death	NZ$0.231
Annual Air Quality and GHG costs from HGVs	NZ$673.9mn per annum	NZ$465mn and NZ$208.9 air quality and GHG costs per annum, respectively, from HGVs	NZ$0.225
Shadow carbon price		NZ$108.9 average central estimate of shadow per tonne carbon price (2022-2035) 3bn annual freight km 82681 kilotonnes GHG emissions in 2021 24.8% of transport sector (21%) contribution by freight transport	NZ$0.157
Congestion costs per vehicle km removed from the road		Simple average of congestion costs per vehicle-km in various regions of NZ	NZ$0.95
Total impact			NZ$1.736

Based on the above table, a total reduction of 332,800 km annually (from a summation of reduced km due to adoption of the Direct-to-Site model and those due to reduction in vehicle trips due to improved loading) translates to nearly ***NZ$577,700.00 annually*** in monetised benefits.

5. Conclusion

The analysis undertaken in the paper pertains to application of ‘smart’ solutions based on hardware (transport), intelligent elements (internal organizational intelligence and analysis), data elements (truck movement data, consumer demand), and intangible service elements (consumer satisfaction and personnel competencies) (Huikkola et al., 2022) to deliver a service with a higher efficiency. The specific transportation function addressed is the distribution of plasterboard from the manufacturer’s warehouse. In the first stage, the ‘smart’ solution of vertically integrating the distribution function as an extension of manufacturing was undertaken. The business model was integrated; however, the planning was still disaggregated, with no participation of the manufacturer in transport planning. In the second stage, further integration in the form of manufacturer participation in transport planning, along with the use of ICT tools (computer-based algorithm for applying LP to transport planning) was undertaken. The first stage though has been implemented, and the second stage of integration is still a recommendation. The aggregated impact of both the ‘smart’ solutions is an annual reduction of nearly 513 tonnes of CO2-e in emissions, and a monetised benefit of almost NZ$577,700.00 annually due to the reduced movement of trucks. Integrated reverse logistics can potentially provide further opportunities for achieving even higher levels of emissions reduction, and therefore, sustainability in transport operations.

Though the analysis pertains to a very narrow segment of the New Zealand CSC (plasterboard delivery), it provides benchmarks and pointers towards the potential for transport optimisation, and therefore, improved sustainability existing in the manufactured construction products sector.

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