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Using Transport to Quantify the Impact of Vertical Integration on the Construction Supply Chain: A New Zealand Assessment

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Abstract: New Zealand (NZ) construction is highly fragmented, comprises primarily micro small and medium enterprises (MSMEs); 32.5% of approximately 67,000 operating businesses are 'small' (up to 19 employees), while 65% are sole traders. The construction supply chain (CSC) is extensive, prone to inefficiencies at segmental boundaries accentuated by project-centric delivery. Conversely, it presents significant opportunity for consolidation and improved efficiency. Vertical integration and CSC management from the supplier-end rather than the project-end enable component elements to be individually independent in terms of ownership, while integrating their management above the tactical CSC level. This leads to improved operational philosophy and employment. Quantifying impacts, however, is a challenge due to lack of tangibility. This can be effectively overcome using quantifiable parameters associated with the CSC's transport component. The paper investigates transport operations in a narrow NZ CSC segment over a three-month period to quantify improved performance using operational data and further potential for resource optimisation using operations research-based planning. Research outcomes point towards: (i) Fleet management strategy; (ii) Integrated planning and operational delivery; (iii) Non-price attributes in tendering/contracting; (iv) Change in the delivery model of manufactured construction products; (v) Information and communication technology-based solutions; and (vi) Integration of reverse logistics.

Keywords: construction supply chain; construction logistics; construction transport; transport sustainability; vertical integration

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1. Introduction

The construction sector creates/improves infrastructure, provides employment opportunities, and supports involved businesses, while contributing circa 13% to the global GDP [1]. The sector's operations demonstrate significant resource consumption while significantly contributing to socioeconomic development. As of 2019, 35% of global energy consumption and 38% emissions were attributable to the construction sector (UNEP, 2020). From the perspective of the construction process, both upstream embodiment of resources and downstream consumption (operation and maintenance) are the primary components.

The sector is rife with deep-rooted fragmentation [2–5]. Fragmentation manifests from a large number of small firms segregating the sector at the industry level, while at the project level, it is through disintegration of processes and entities [6].

Logistics is interdisciplinary in nature [7] and is a substantial component of the complex construction supply chain (CSC) from the viewpoint of management as well as costs [8]. Fragmentation precludes integration and continuity, creating barriers for coordination and integrated operations from a lack of clarity in division of responsibility, building inefficiency into processes [6]. Substantial sustainability concerns are a result of the consequent resource overheads. Logistics has widely diverse components from stock/inventory management and warehousing to transportation [9] (p. 12) and, as such, presents a substantial opportunity for optimisation of the construction sector through operational as well as strategic means.

Most processes pertaining to logistics (other than warehousing) are business processes with no physical manifestation [9]. This results in transportation being the single largest logistics element [10] (pp. 32–34). The volume/cost nature of construction materials (high volume–low cost) compared to other industrial sectors [11–14] makes transport a significant component of construction logistics.

Transport has multiple externalities across the three domains of sustainability, apart from costs, energy consumption, and emissions [9,15,16], which may be direct (noise, congestion, pollution), or indirect (health impacts, loss of ecosystems, reduced quality of life). [17]. Construction logistics, therefore, present a potent opportunity for improved sustainability through optimisation of the transportation function.

Based on a series of climate change assessments, transport is likely to contribute to circa 60% of global emissions by 2050 [18]. Analysis also evidences that freight transport is one of the most difficult sectors to decarbonise, more for challenges in deployment of decarbonisation measures at the required scales than for availability of options [19,20].

NZ has peculiar physical attributes [21], viz., its geographical isolation [22], a deregulated market [23], thin population density, low-density urbanisation, and an elongated sprawl as an agglomeration of 'urban villages' [24] in a longitudinal configuration along its land mass. Consumption nodes are remote from distribution centres, have small populations, small volumes, and low demand profiles.

As a result of the peculiar physical, market, and economic attributes typified in New Zealand, circa 93% of freight movement is road-bound (a third of it pertaining to construction), 5.6% by rail, and 1.6% by coastal shipping in terms of tonnage. In terms of tonne-km, road takes 75.1%, rail 11.5%, and coastal shipping 13.4% of the total share. Road freight is 99% diesel powered. NZ construction transport is part of a fragmented, undercapitalised road freight industry, with an ageing fleet and sub-optimal operations. Market dynamics compound the issue [25–27].

In keeping with the nature of the NZ market, its construction sector exhibits certain peculiarities. Primarily comprises MSMEs [28], 32.5% of the sector (approximately 67,000 operating businesses) are considered 'small' (1 to 19 employees), while 65% are sole trading operators. Circa 150 industry organisations and subsector groups, in addition to governmental, consenting, and regulatory bodies, add to the milieu [29,30]. Isolated geographically from the rest of the world [22], it adopts improved philosophy slowly, with a consequent delay in introduction of new ideas, typically eight years behind UK initiatives.

A deeply fragmented industry, construction tends to build inefficiencies at the boundaries between the elements comprising its supply chain, leading to overall sub-optimal performance of the sector. In turn, upgradation initiatives are challenged by deficits in understanding, knowledge, and skills, especially in logistics [8]. The sector has demonstrated sub-optimal productivity over the last about 40 years (Figure 1) [31].

This study aims at investigating the transport operations of a narrow, vertically integrated segment of the NZ construction supply chain, to demonstrate the efficiency building potential of vertical integration (as a supply chain strategy) and finding the means to quantify improved efficiency through assessment of transport operations (at the operational level). It also examines potential application of operations research in planning as an efficiency enhancement tool in construction logistics.

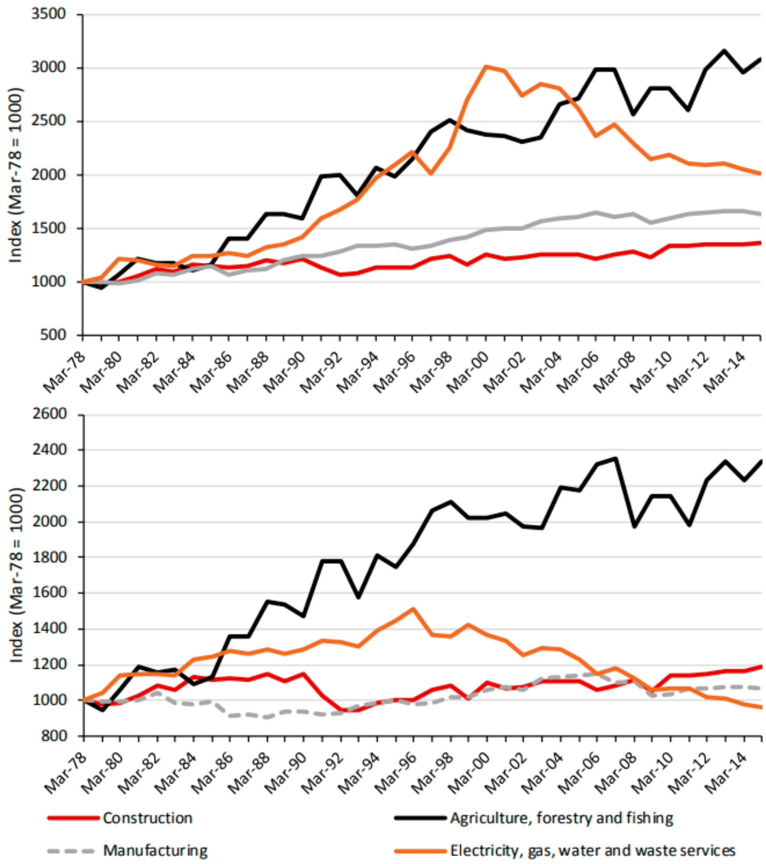

Figure 1. New Zealand construction sector productivity: A historical perspective (Adapted with permission from Ref. [31]. Copyright 2018 by BRANZ). Note. Top—Labour productivity = GDP generated/paid hours of work. Bottom—Multi-factor productivity = GDP generated/(capital units + labour units generated).

2. The Construction Industry and Fragmentation

2.1. The Construction Industry

> *"Construction is the broad process/mechanism for the realization of human settlements and the creation of infrastructure that supports development. This includes the extraction and beneficiation of raw materials, the manufacturing of construction materials and components, the construction project cycle from feasibility to deconstruction, and the management and operation of the built environment"*. [32] (p. 4)

The construction industry contributes significantly to economies, typically 13% to the global GDP [1]. The sector exhibits certain typical characteristics: heterogeneity and fragmentation (dependence on a wide range of very different professions); criticality of transport and logistical aspects; non-transportability of the final product; adaptability of the final product to a variety of uses; built assets being amongst the most durable of human artefacts; construction projects typically being prototypes; shorter depreciation period for investments compared to other industrial sectors; low entry-level due to relatively small operational capital requirements; close links to the economic cycle; labour intensive; high workforce mobility and growing need for skills; site construction phase driven contract duration; high accident rates; and typically high waste generation. Increasing inhabitants, visitors, urban complexity, and quality of life expectations require ever greater construction sector performance. The built environment, therefore, continually sees increased demand for construction, repair, and renovation [13].

Project-centric by nature, construction generates employment, creates and improves infrastructure, and supports businesses [33]. Individual uniqueness of construction projects is exemplified by singularity of design, convergence of the supply chain (SC) on site, project bespoke operations, SCs with minimal standardisation, and repetitive reconfiguration of SCs through lifecycle stages [22,34,35]. No projects are the same even if they are of the same type since factors such as locality, economy, and policies have a high impact on the associated variables [4].

The low cost and high-volume characteristics of construction materials implies involvement of substantial transportation components even for small projects [12,36,37], underscoring the significance of logistics in construction. The transport component of logistics is a specialised function and involves ownership of assets. Being a non-core area of operations for most construction firms, contractors, and sub-contractors, yet being specialist in nature, it is typically outsourced by the construction sector. Disaggregation of the planning and implementation functions invariably results.

2.2. Fragmentation in Construction

Fragmentation in the construction industry is an acknowledged phenomenon. It manifests at two levels: The construction industry's structure (a relatively large number of small firms causing industry segregation) and the activities and entities involved at the project level (delineation of design and construction and limited coordination and integration). The sequential nature of construction process, diverse specialisations of contractual partners, poor communication and coordination between various functional disciplines, lack of trust, and temporary collaboration of stakeholders are primary drivers of fragmentation [6].

The deeper fragmentation boundaries centre around the project envelope in most project environments manifesting as project organisation boundaries (expertise, hierarchical, and cultural-related boundaries) and project management boundaries (social, knowledge, and action boundaries). Typical project characteristics responsible for fragmentation are project complexity, delivery requirements, high degree of specificity, location-based activities, regulation, complexity of services, and market segmentation [6,38]. Intimate involvement of an external domain, i.e., transportation, along the project timelines, and across actors tends to exacerbate the already existent fragmentation.

Institutionalisation of project-based delivery presents fragmentation along three dimensions, i.e., *vertical*, a separation of firms and workers into different stages of project delivery (e.g., planning, design, product and process definition, construction, operation, and maintenance); *horizontal*, delivery of complementary products and services by different specialists at approximately the same stage of a process (i.e., separation of firms and individuals into crafts, trades, and disciplines); and *longitudinal*, disruption in the continuity of a team by reassignment at the end of a project, taking any tacit, accumulated knowledge with them (i.e., separation of firms and individuals into distinct projects) [2,5,12,37].

Fragmentation precludes integration and continuity in work, hence, directly influencing business models and philosophies for management [13,39]. It is accentuated by the disaggregated professions, delineated design and construction, uniqueness/singularity of projects, the essence of relationships, and the project organisation [40]. Fragmentation challenges coordination and division of responsibility and results in process inefficiencies and increased resource overheads [41]. Owing to a highly fragmented SC, short term and transactional relationships, poor communication and information flow, and highly interdependent tasks and activities compared to other industries (e.g., manufacturing), the operating environment of the construction industry is extremely complex and uncertain [16,34,42]. A constantly evolving SC makes the challenges even more acute [16].

3. Supply Chains and Their Management, Logistics, and the Construction Context

3.1. Supply Chains

A supply chain (SC) may be described as "*a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer*" [43] (p. 4). The SC may be viewed from two perspectives, i.e., the comprising elements, defining a beginning and an end, with the intermediate space occupied by the flow of goods (raw materials, value-addition, and transfer to a consumer), and an extended view of the SC by integrating extra activities [44].

Based on these, SCs may be direct, extended, or ultimate. The direct SC comprises suppliers and customers of a central business unit. The extended SC includes upstream and downstream actors associated with an immediate supplier and an immediate customer, i.e., their immediate suppliers and customers respectively, while, the ultimate SC includes all business units involved in product, service, finance, and information flow between ultimate suppliers and ultimate customers, including functional intermediaries, e.g., financial service providers, logistics organizations, and market research firms [43,45].

3.2. Supply Chain Management

A comprehensive definition of SCM is "*The objective of managing the supply chain is to synchronize the requirements of the customer with the flow of materials from suppliers in order to effect a balance between what are often seen as conflicting goals of high customer service, low inventory management, and low unit cost*" [46]

SCM does not look at only the neighbouring entity; rather, its view extends across the entire SC, aiming to increase transparency, alignment, configuration, and coordination of the SC, regardless of corporate or functional boundaries [47]. From its definitions, SCM may be summarised into three dimensions: the objective—efficiency and cost-effectiveness through collaborative efforts across the system; the role—to produce products conforming to customer requirements; and the scope—encompassing business activities from strategic through tactical and operational levels, through efficient integration of suppliers, manufacturers, wholesalers, logistics service providers, retailers, and end users [48].

SC optimisation, excellence, and integration are the focus areas of structural as well as operational management of business units (BUs), viz., arrangement of suppliers of goods and services, products and services demand and flow network management, business philosophy, and competitive advantage through coordination and synchronisation. Integration efforts focus on organisational structure, coordination, relationships, intra- and inter-enterprise communication, operational orientation, sourcing, and resource (including cost) management [47,49]. Table 1 illustrates the broad criteria comprising supply chain management (SCM) along with the applied concepts they pertain to, providing the means to assess an SC [45]).

Table 1. Criteria comprising supply chain management.

Criteria	Concepts
Management of the supply chain	*Applied concepts*: planning, organising, implementing, motivating, controlling *Pertain to*: goods, services, efficiency
Logistics	*Applied concepts*: processing, storage, and transportation *Pertain to:* raw materials, in-process inventory, finished goods
Aims and objectives	*Applied concepts*: value, customer requirements, trust, relationships, competitive advantage *Pertain to*: long-term, sustainability
Comprising entities	*Applied concepts*: suppliers, manufacturers, warehouses, stores *Pertain to*: products, services

Of specific interest to this paper are the first two criteria, i.e., management activities manifesting as vertical integration and logistics activities manifesting as transport operations.

3.3. Logistics

> One of the initial definitions of logistics, formulated by the then Council of Logistics Management (CLM) (now Council for Supply Chain Management Professionals—CSCMP) during 1986 was "*The process of planning, implementing and controlling the efficient, cost-effective flow and storage of materials, in-process inventory, finished goods and related information flow from point-of-origin to point-of-consumption for the purpose of conforming to customer requirements*" [50]. Logistics integrate inventory, storage/warehousing, transportation, materials handling and packaging in a decision-making framework. Physical flow of materials and management of goods, services, and information in an interdisciplinary environment represents logistics manifestation.

Logistics functions are performed through logistics processes, which are defined temporal sequences of successive conditions and changes and a set of logically associated tasks and activities. Logistics processes achieve a change or a business result by transforming input data into output and adding value to product/service, risk, and information. These may be classified based on value creation (through direct, indirect, and conditional relationships, or do not create value) and value added (adding high value, essential but non-value adding, and developmental processes for increasing process efficiency) [51].

The most commonly accepted perspective of the relationship between logistics and SCM propounds four approaches, viz., traditionalist defines SCM as a special way of logistics; relabelling refers to all logistics activities as SCM; unionist considers logistics a sub-set of SCM, with SCM involving a larger range of variables and management attributes and is, therefore, more complicated than logistics; and intersectionist approach considers both having their own elements, with certain common areas/activities. The most widely accepted view is the unionist view [52,53].

The important elements comprising logistics processes, relevant to this study, are material flow, information flow, stocking, infrastructure, orders, warehousing and inventory management, transport, and waste management [9].

3.4. The Construction Context

3.4.1. The Construction Supply Chain

The CSC takes after the nature of the construction industry in terms of its characteristics or attributes, viz., a converging SC directing all materials for assembly of the product (the built asset) on the nominated construction site; establishing the 'manufacturing plant' around the manufactured product (the built asset), as opposed to manufacturing, where more than one product passes through the plant; a temporary SC with repetitively reconfiguring project organisations (leading to fragmented processes, instability, and delineation of the design function from actual construction) [22,34,35]; and effectively a make-to-order (MTO) SC for a unique, one-off product (built asset) [3,4,54]. Information, material, and capital flows connect the primary actors in the CSC (owner, consultant, contractor/subcontractors, suppliers, and user) into a network [55,56].

Certain outcomes of the CSC characteristics that impact CSCs and their functioning are: substantial customer influence on the project and logistics; fragmented SC in terms of actors, business purposes, and methods; multiple stakeholders leading to multiple organisations and relationships including material, information, service, product, and fund flows between stakeholders; transactional buyer–supplier relationship leading to conflict, mistrust, and a singular focus on margins; temporary multiple organisations (project-based nature leading to fragmentation, adversarial relationships, and opportunistic environment); inertia in construction organisations to change due to conservative perspectives driven by risks; a make-to-order (MTO) SC with the client commencing and terminating the process; collaborative opportunities are possible and need to be explored; and non-transportability and durability of the construction product leading to cyclical demand [57].

The CSC may be viewed from two perspectives, that of the main contractor and that of the supplier (Figure 2).

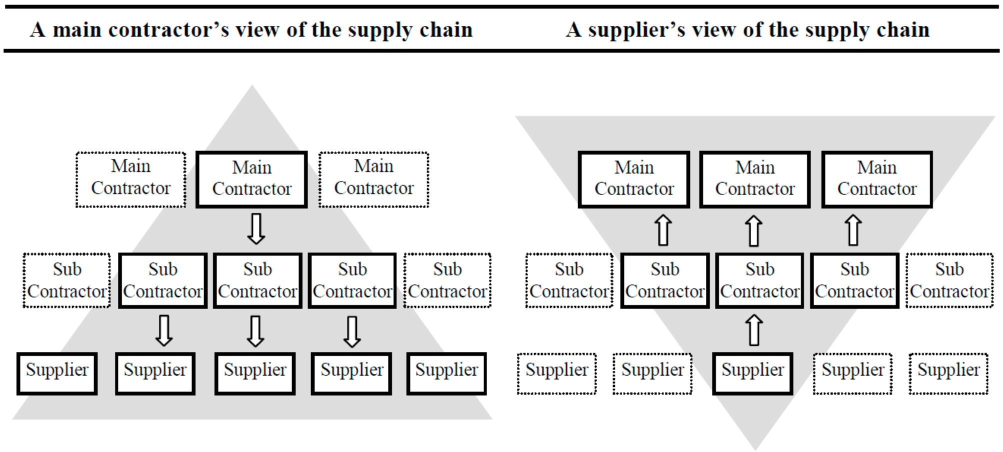

Figure 2. The two perspectives of the construction supply chain (Adapted with permission from Ref. [58]. Copyright 2005 with the authors).

A construction contract sees various work packages being sub-contracted. Each sub-contractor trading with more than one supplier (invariably builders' merchants) implies a complex management situation on the site. This is in part for managing the deliveries and in part for lack of storage space on the construction site. When the CSC is viewed from the BM's perspective, forecasting demand is very difficult, leading to a series of logistics problems from the supplier's viewpoint.

3.4.2. Construction Logistics

The elements comprising construction logistics are forward and reverse logistics. Forward logistics includes preparation, coordination, control, and management of flows of products from processing of raw materials to their final application in a construction project. Reverse logistics integrates waste removal and disposal into the domain [8,59]. In a construction setting, logistics may be considered as all activities pertaining to supply of the right materials and resources to fulfill customer requirements, e.g., planning [60], supplying material and maintaining (un) loading zones [61], on- or off-site storage [62], and handling of materials both on- and off-site [63,64].

Construction logistics typically comprise whole-project logistics (member of many logistics chains, performing complex logistics processes within the triad of time, space, and budget); supply logistics (material delivery from sources external to the construction site); and on-site logistics (coordination of material flow on the construction site) [65].

Construction logistics are part of complex systems, have multiple stakeholders, and exhibit a wide range of concurrent systems, processes, and activities, both on- or off-site. Construction logistics integrate planning and organisation, transport, and site activities [59,66–68]. This aligns with the two fundamental approaches to construction logistics, i.e., improving interactions between suppliers and procurers through focus on various echelons of the CSC and improving performance through higher efficiency of materials handling and delivery scheduling within the project environment [58].

The typical roles performed by construction logistics are: establishing clear interfaces between the SC and the construction site, integrating the construction site with the SC for improved efficiencies both in the SC as well as on-site, coordination with local stakeholders, and value addition. These point to the typical challenges, i.e., division of responsibility, inefficient SC, as well as on-site logistics and coordination voids. Optimised performance demands a high degree of awareness and coordination/integration. [41].

Construction logistics are heavily impacted by the nature of the construction industry, viz., each construction site, being unique and temporary, requires customised logistics [22,34,35]; the material intensive nature of construction sites demands material supplies on an irregular basis [67]; the sequential nature of construction activities tends to transmit delays, errors, and inefficiencies across the complete range of activities; a wide variety of operational and management philosophies are applied; and typical inefficient utilisation of resources as a result of industry fragmentation manifesting in a number of actors working in different temporary construction consortia [41].

3.4.3. Builders' Merchants in the Construction Supply Chain

Builders' merchants (BMs) represent the first-tier suppliers connecting manufacturers and contractors. Located at the focal point of building materials flow from the point of production (manufacturer) to the point of consumption (construction site), they are uniquely positioned to manage upstream (finances and information) and downstream (materials), in effect regulating these. As 'stock-holders', they function as a stock buffer, bearing the cost and risk of inventories, and make available credit for contractors' operations, effectively functioning as builders' bankers [59,69].

Three major issues governing dependency between BMs and the construction market merit mention: (i) the competitive nature, low profit margins, and high risks underscore the line of credit established by BMs; (ii) as the principal in establishing this line of credit, BMs exert control over prices through the indirect costs associated with inventory and movement of stocks; and (iii) as the provider of storage and consolidation facilities for building contractors, by bearing the inventory carrying cost [58].

4. The Transport Component of Construction Logistics

Transport is the largest component of logistics [10] since most other logistics processes (except warehousing) are business processes, not physical ones [9]. The low-cost/high-volume nature of construction materials, sustained delivery requirements, planning and coordination voids on a construction site, typically small deliveries, and transport externalities present significant logistics challenges [11–14].

A discussion of construction transport demands prior insight into freight transport with specific reference to urban goods distribution. The generic urban freight transport (UFT) framework comprises three elements, viz., demand (for goods produced at places other than at the demand location, requiring transportation), supply (for meeting the demand through facilities and transport), and context (demand–supply interaction-based logistics operations translating into actual vehicle movements). The physical environment surrounding demand–supply defines the contexts and operating domains of various associated SCs. Each component can be mapped onto stakeholders associated with UFT, viz., receivers (generate demand and, therefore, the need for transport), shippers (senders of goods for fulfilling receivers' demand), and logistics service providers (LSPs) (link between receivers and shippers through actual deliveries resulting from logistics operations). Local authorities regulate contextual movements, while citizens inhabit the physical environment [70–72].

Fundamental differences differentiate construction site deliveries and distribution of consumer goods. Construction sites typically have high material requirements and need deliveries to be aligned to a potentially irregular demand profile [67]. Construction materials' delivery and waste removal activities are typically disaggregated and uncoordinated, the businesses being different with distinct SCs having no integration [33,73]. Transport associated with construction sites (delivery as well as waste removal) is managed for its own best efficiency, ignoring impacts on the wider transportation system and the area of operations [74].

The project delivery mechanism precludes synchronisation between activities of adjacent construction sites. Employment of waste collection vehicles over and above the delivery fleet increases the number of vehicles operating within the same infrastructure, creating competition between road users, leading to congestion [70,75]. Increased traffic also leads to indirect impacts, e.g., decreased asset utilisation, reduced labour productivity, high inventory levels, increased costs and time for distribution and transportation, and sub-optimal transport capacity utilisation, amongst others [76]. The resultant inefficiencies are accentuated by unidirectional loading of vehicles (onward trip for delivery and return trip for waste removal vehicles) in addition to non-utilisation of full vehicle capacity (part loading) [74,75,77].

A paradox exists, where fully loaded delivery vehicles may potentially lead to overstocking of materials on-site (leading to congested workspaces, avoidable material damage, and waste) vis-à-vis an overloaded transportation system due to less-than-full loads on vehicles travelling to site and empty travel from site [62]. Typically, less than 50% load factors are achieved [78].

The proportion of freight transport associated with construction may be estimated from EU data (50%) [13] and from another study by Muerza and Guerlain (2021), which places it at 30% [3,79]—benchmarks for understanding the contribution of transportation to construction logistics. Transport efficiency is a function of capacity utilisation across onward and return trips. One of the major logistical challenges in the construction industry is finding backhauls [73]. Non-optimal capacity utilisation leads to increased externalities vis-à-vis tonnages handled [62].

A total of 60–80% of work in construction projects pertains to procurement of materials and services from suppliers and/or sub-contractors, because of construction materials being low cost/high volume compared to other industries [12,13,64,80]. Considering that materials usually account for circa 30–50% of the cost of a project [16,59], logistics costs may be about 30% of the gross work performed. A substantial cost component, this presents high optimisation potential, especially considering that up to two-thirds of logistics costs (translating to 20% of the built asset cost on average) may be attributable to transportation, which is inherently inefficient in the construction sector [9,51,78,81]. Three aspects of construction transport support its optimisation, viz., manner of employment, SC characteristics, and technology [82].

Considering BMs an essential component of the CSC, transportation of material for construction sites typically gets routed through the BM in an 'echeloned' CSC. The important parameters for assessing logistics efficiency (with parameters for transport efficiency as a subset) typically may be: order frequency, materials/products, number of vehicles associated with transport operations of the warehouse (WH), vehicle weight and volumetric capacities, waiting periods at WH, travel distances and durations, loads carried, and turnaround times [58]. These point to the parameters that may be effectively utilised for assessing the efficiency of transport operations such as distances travelled, loading efficiency, capacity utilisation, etc.

5. The New Zealand Construction Supply Chain

5.1. Composition

Construction supplies pass through a series of SC levels before being used in construction. Different types of projects are serviced by different SCs, e.g., certain products may be sold through BMs or retailers, while certain builders or types of projects may directly source from manufacturers or importers. The overall CSC picture in New Zealand, from the wholesale end to the consumer end, appears approximately as follows:

- There are a number of domestic manufacturers, typically specialising in one type of building material at the wholesale supply end, e.g., timber or cement, in addition to international building supply companies importing material into New Zealand.
- At the distribution level, there are five major building supplies merchants, some of whom specialise in supplying to builders and trade customers, while others have trade as well as retail stores. Other than these, several smaller merchants and retailers have varying presence with a varying range of products across New Zealand.
- There is a wide range of business models at the physical construction level, from large residential builders through small-to-medium enterprises, subcontractors, and do-it-yourself builders.
- Consumer (end-user) preferences shape the types of construction as well as material selection. Public and Iwi/Hapū (Māori community) developers/end-users are major drivers of demand for urban construction, stand-alone, or in partnership with others.

- The other significant actors in the NZ construction materials supply chain are: (i) specifiers such as architects or consultants (e.g., designers and quantity surveyors), who can significantly influence types of structures as well as selection of products and materials; (ii) building consent authorities (BCAs), who are responsible for issuing building consents and inspection of newly constructed buildings for building code compliance; (iii) industry bodies performing the regulation, representation, and research functions, e.g., NZ Building Industry Federation, NZ Construction Industry Council, NZ Green Building Council, and multiple trade-related associations and organisations; and (iv) research and certification bodies, e.g., BRANZ, who can substantially influence which new products make it to the market. Figure 3 is representative of the NZ CSC [83].

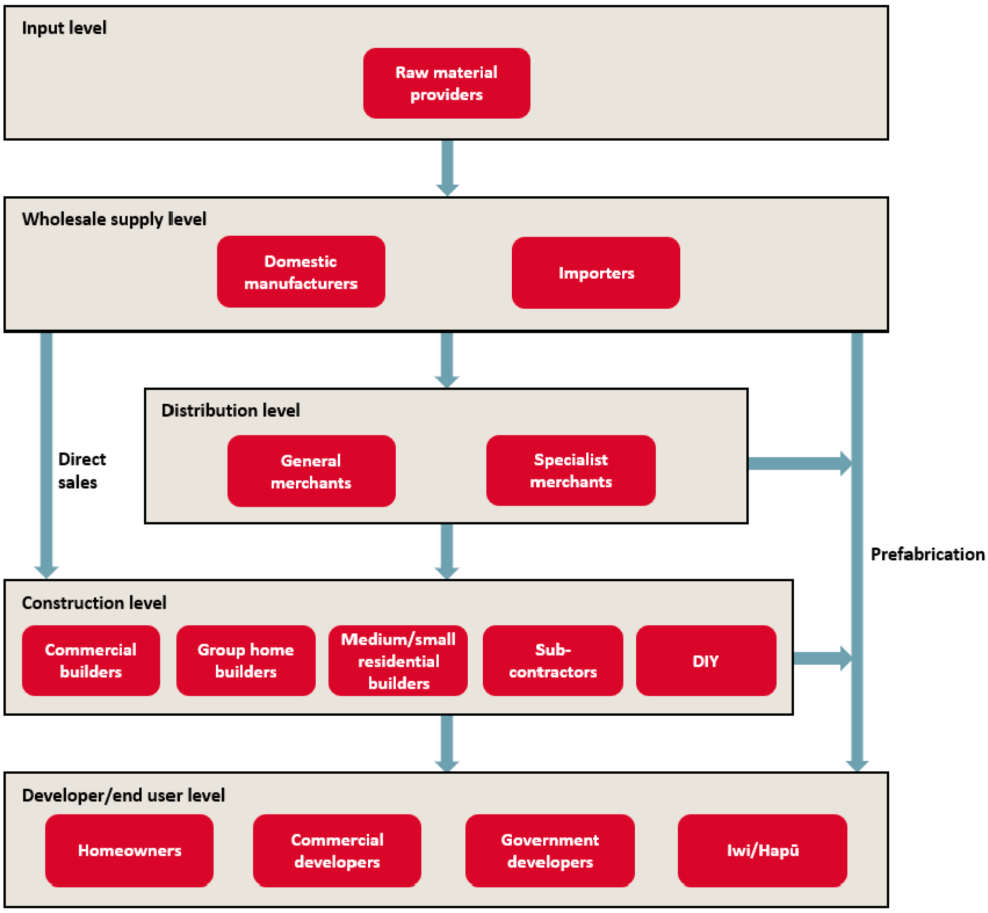

Figure 3. The New Zealand construction supply chain [83].

5.2. Concentration and Vertical Integration

Concentration in a market implies control of a large proportion of the supply by relatively few suppliers, with the most extreme manifestation being a monopoly (a single supplier controlling all the supply). High concentration can be a result of suppliers gaining market share through price and quality and maintaining their position against new entrants, through a weak competitive process over a long time or through prevention of the entry of other suppliers through high entry or expansion barriers. This can accord higher market power to some suppliers, resulting in the ability to set higher prices or lower quality. Market power may be constrained by other factors, e.g., determination of prices through buyer–seller negotiations, where buyer power could countervail against the suppliers' market power.

The supply of certain building materials in New Zealand appears to be highly concentrated, especially in the supply of plasterboard and concrete, while only five major

BMs operate at the retail and distribution end. Concentration in New Zealand also manifests in the form of vertical integration. Manufacturers also operate BMs. Whilst it can generate significant efficiencies in managing the SC, and therefore positively impact competition, it can make entry of independent (non-vertically integrated) firms at different levels of the SC difficult, due to lack of supply of key inputs or access to competitive distribution services [83].

Vertical integration is classified as backward (upstream—supplier network) and forward (downstream—distribution network) and encompasses both materials and services [84]. The relevance of this discussion to the paper is that the operational analysis undertaken in the next section pertains to one such vertically integrated firm, who, in addition to forward vertical integration of the distribution network, has also taken transportation into its fold by implementing transporting manufactured goods directly from the manufacturer's WH to construction sites (invoiced by the BM) (direct-to-site (DTS) delivery) rather than routing deliveries to BMs, who further take responsibility for site delivery (BM delivery). The two logistics models are discussed in Section 6.1. The discussion of 'vertically integrated' delivery operations presents an interesting means of making transportation operations more efficient vis-à-vis those pertaining to distribution through the already integrated distributor network.

6. Research Methodology

The objective of the research reported in this paper was three-fold: (i) to examine the transportation model adopted by the sole NZ manufacturer/supplier of plasterboard, considering the substantial presence of BMs in the NZ CSC; (ii) to analyse the adopted model for drawing a comparison with the conventional echeloned model (manufacturer-BM-customer), in terms of transportation parameters; and (iii) to investigate the potential for further improving the transport component associated with the distribution model. The case study strategy with quantitative methods was adopted, since the aim was to quantify the efficiencies generated by adoption of specific distribution models and application of operations research algorithms on transport operations 'as-executed' to investigate further potential for optimisation.

At a first glance, trucks are not 'fully' loaded at the time of despatch. Further, all deliveries except a few are within the urban agglomeration of the Auckland region, which manifests as a linear sprawl [24]. The deliveries may, therefore, be considered as typically being less than truckload (LTL) and pertaining to urban delivery, though not necessarily last mile. Potential generalisability of the results is likely to be at two levels:

- At the tactical level: management of transport operations to transform LTL deliveries to full truck load (FTL) despatch, therefore improving loading efficiency and reduction in truck movements by reduction in the number of trucks for the same deliveries through optimisation.
- At the strategic level: considering different ways of doing business in terms of long-term fleet management (fleet composition and fleet replacement), reducing or eliminating the gap between operations and planning of transport, and integrating non-price attributes (NPA) in tendering/contracting.

6.1. Distribution Models, Data Collection, and Data Filtering

Based on a conversation with the logistics manager of the manufacturer of plasterboard, it was quickly established that there were two simultaneous distribution models being practiced. The first was the conventional echeloned or distributor storage with carrier/last-mile delivery (manufacturer–BM–customer) and the second, manufacturer storage with direct shipping [85] with consignments with invoicing by the BM (Figure 4). The WHs undertaking these deliveries were separate. It was also established that the transport operations were outsourced to a third-party logistics service provider (LSP) based on unform 'per-tonne' rates, rather than 'per km', across the complete Auckland region.

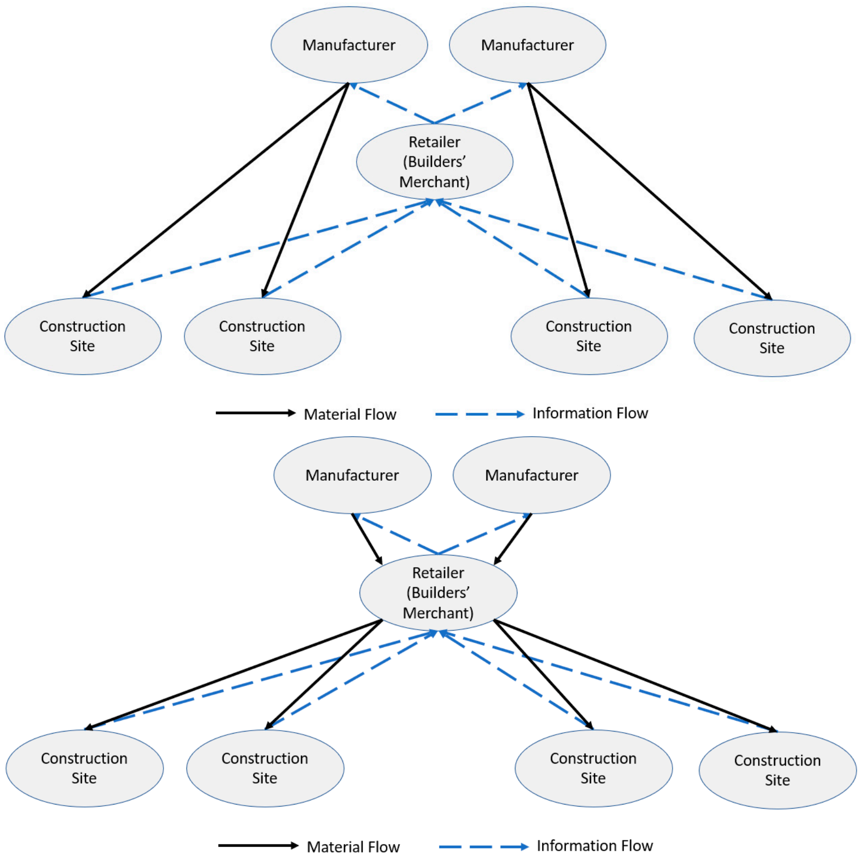

Figure 4. Manufacturer storage with direct shipping (**top**) and distributor storage with carrier delivery (**bottom**) (based on [85]).

For the purposes of the research reported here, operational (truck movement) data over approximately three months were obtained from the manufacturer's WH undertaking DTS deliveries. The data components of interest were the vehicles (trucks) being used for delivery and the details of the trips (departure details as indicators of individual trips, load, destinations (therefore drops) and the loads delivered). However, out of these, the following were not available in the database being maintained by the manufacturer's WH:

- The distances travelled by the trucks for each delivery: It is understood that the need for maintaining a record of distances travelled by trucks was not considered relevant due to the payments model adopted (per tonne as opposed to per km with different rates for different distances/areas). Distances, therefore, were of no consequence so long as the daily tonnages could be delivered by the LSP within the day.
- The delivery sequence where the number of drops was more than one: The reason for this is, again, understood as the payments model. This needed to be obtained from the 'Eroads' database (an IT services company in NZ with solutions for vehicle tracking; the data is considered robust and is employed widely in research related to transport).

Data for 3672 trips were available. However, data pertaining to only 2716 trips were considered for data analysis. Data were removed from the dataset for the following reasons:

- Certain truck trips were found having zero loads: The loads were found to be packing material such as stretch polythene wrapping, etc. It was interpreted that these were included for purposes of charging and did not have any relationship with actual truck trips.
- Trucks whose specifications were made available by the WH, however, whose details could not be verified against the NZ Vehicles Register: Trips pertaining to these were excluded from the dataset considered for analysis.

- Trucks loaded beyond their rated capacity (obtained from the NZ vehicles register): Certain trucks showed overloads. On confirming from the firm, it emerged that data may have been aggregated over more than one trip by the same truck on one day as a documentation error, especially due to the payments model in force. Trips showing truck overload at despatch from the WH were removed from the dataset being analysed.
- Trips pertaining to delivery outside Auckland or invoicing by BMs located outside Auckland: Since the study was undertaken for the Auckland conurbation, and there were different payments models implemented for different regions, data pertaining to destinations outside of Auckland, as well as the invoicing of BMs outside the Auckland region, were removed from the dataset. The complete trip was removed even if only one segment pertained to locations outside Auckland, as a means to maintain trip data integrity.
- Single Data Points: Two trucks in the dataset represented only one trip. Considered insignificant, these were removed from consideration.
- Trucks without details in Eroad database: Truck trips involving more than one drop whose data was not available on the Eroad database were removed since the sequence of delivery could not be ascertained.
- Trips with more than three drops: A total of 32 trips were found having four drops, six trips had five drops, and three trips had six drops. Considered statistically insignificant, these were removed.

Based on filtration of data, a total of 59 days of data out of the original 92 days remained for analysis.

6.2. Sampling and Modelling

One of the analyses to be undertaken was the optimisation being accrued from DTS deliveries, as opposed to manufacturer–BM–site delivery. This required determining point-to-point distances. Due to the large dataset, sampling was considered. Out of 2716 trips, a figure of 338 trips was considered statistically significant [86]. Point-to-point distances were obtained from Google Maps.

However, before sampling was undertaken, the 'normality' of transport operations was validated. Each transport operation is considered a function of the underlying random variables, e.g., delivery day and time, delivery quantity, delivery area, availability of trucks, truck capacity (therefore loading and number of potential drops), truck allocation, etc. A validation of the truck loading efficiencies (the ratio of the load on a truck at the starting point to its carrying or payload capacity) being normally distributed would imply that the despatch process (and therefore the transportation process) did not have any undue variation [87] and, therefore, none of the underlying variables exerting undue influence. Figure 5 presents the quantile–quantile (QQ) plot [88] of the loading efficiencies of the trucks for all 2716 trips before sampling.

The co-efficient of determination (R-squared) was found to be 0.9882, validating normal distribution [89], hence, no undue influence of underlying variables. However, the plot shows deviation from the normal distribution at the tail ends of the data. To verify that it does not follow any other distribution as closely as it follows the normal distribution, a histogram was generated to understand skewness in the data (Figure 6), which shows that the data are left skewed.

Since the data were found to be skewed, an assessment of it following some distribution other than normal was undertaken in SPSS. The closest the data followed (in order of graphical closeness of fit) was beta, normal, and logistic distributions. The QQ plots for these distributions are in Figure 7, while the detrended QQ plots are in Figure 8.

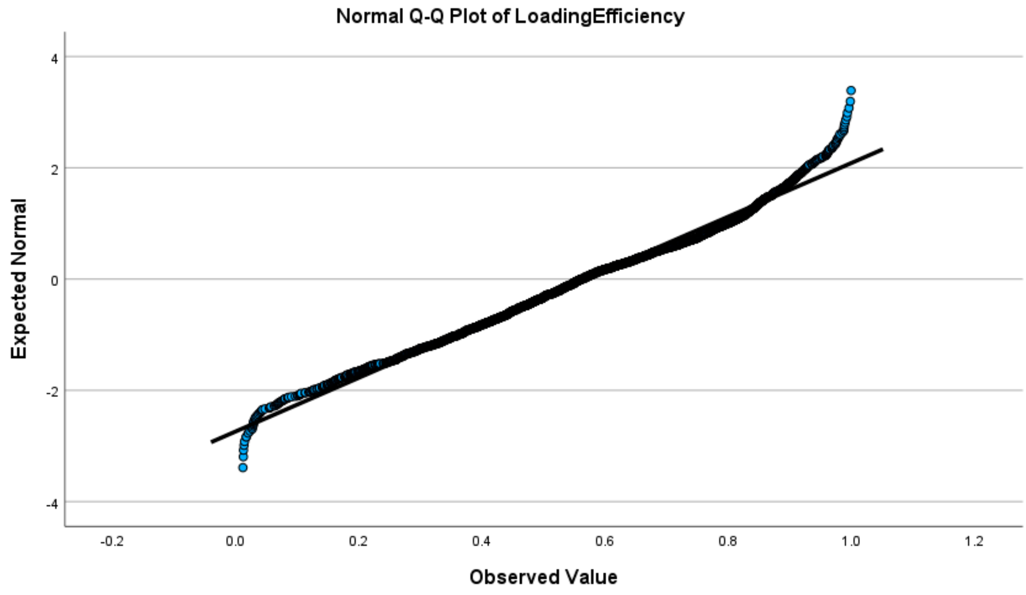

Figure 5. Normal QQ plot for truck loading efficiency.

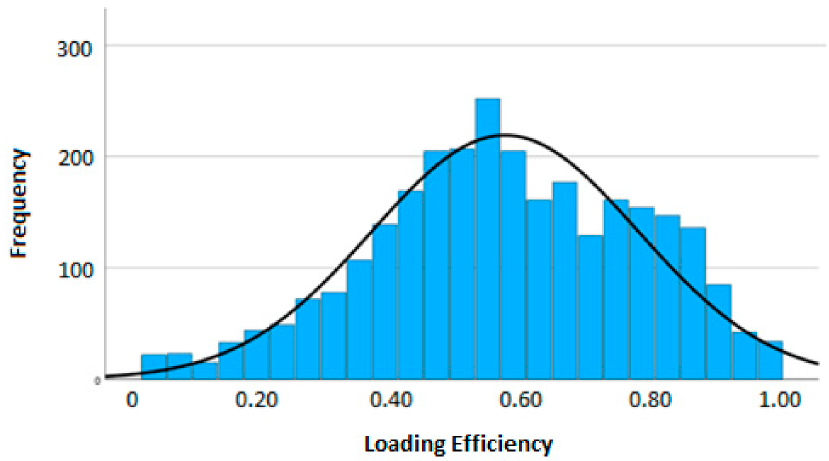

Figure 6. Histogram of loading efficiencies with 25 class intervals (4% each).

In increasing order of deviation from standard distributions, the dataset tends to follow beta, normal, and logistic distributions. The beta distribution is a two-parameter distribution, which tends to replicate the normal distribution in case both the parameters are equal. In the instant case, the skewness of the dataset prevents the best fit from having both the parameters equal, hence, the deviation. However, since the parameters are adjusted by SPSS during evaluation, we consider the underlying closest distribution as the normal distribution. The logistic distribution shows higher deviations as compared to the normal distribution.

Similar QQ plots were plotted for each truck type, and each demonstrated an R-squared value validating normal distribution (a minimum value of 0.88 in the case of one truck type was found), hence, evidencing that no underlying variable has an undue influence on transportation operations. Next, a statistically significant sample was extracted from the dataset. As a first step, each trip was allocated a sequence number by sorting the trips by date, time, and truck ID. A random number sequence of 338 numbers between 1 and 2716 was generated using an online tool and mapped onto the trip sequence numbers to extract the sampled dataset for analysis. This extracted random dataset is considered fully representative of the complete (filtered) dataset (2716 trips), being statistically significant [86].

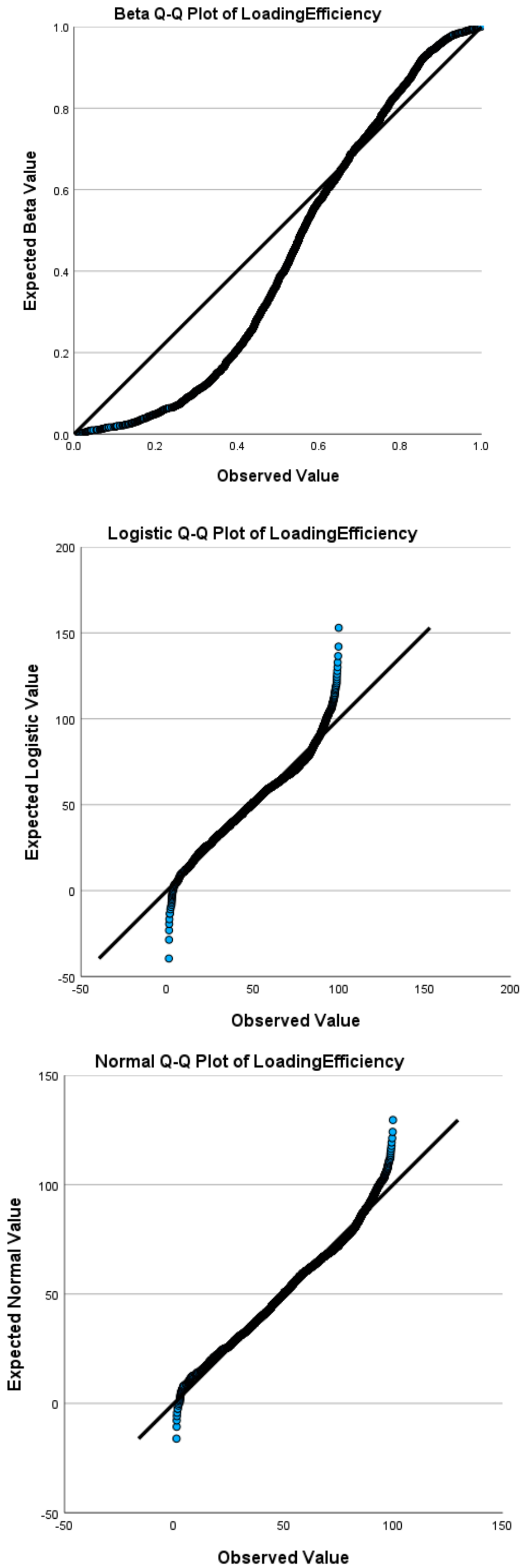

Figure 7. QQ plots of the loading efficiency dataset vs beta (**top**), logistic (**middle**), and normal (**bottom**) distributions generated from SPSS.

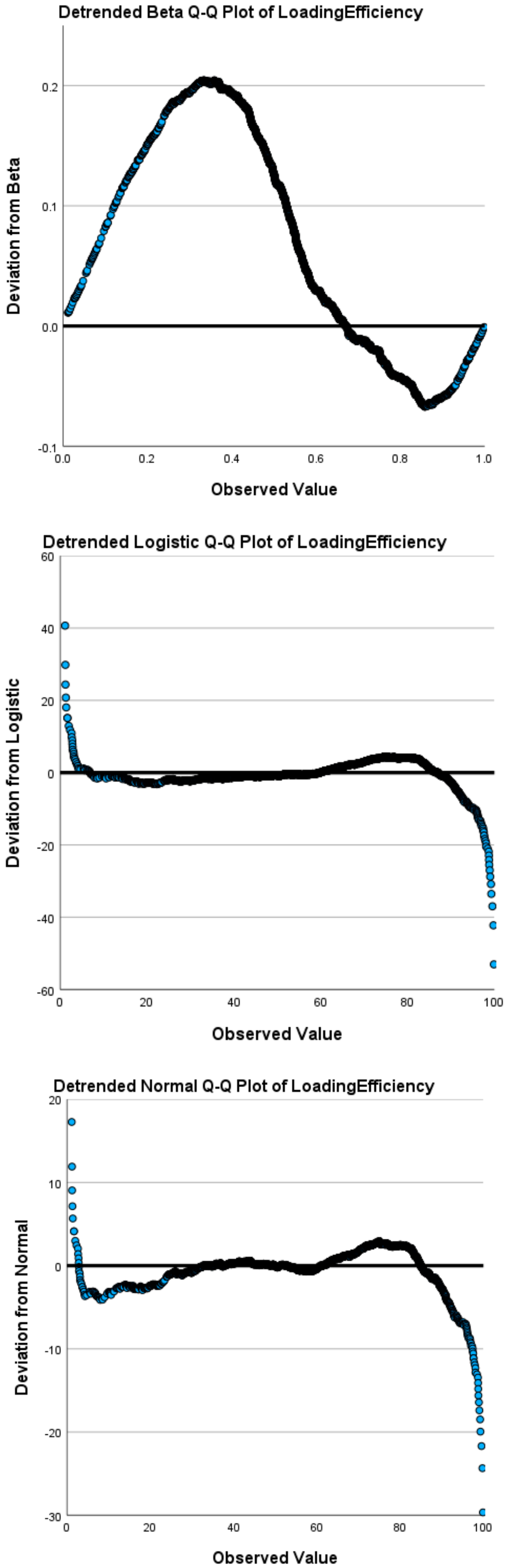

Figure 8. Detrended QQ plots of the loading efficiency dataset vs beta (**top**), logistic (**middle**), and normal (**bottom**) distributions generated from SPSS.

7. Data Analysis and Interpretations

Data Analysis was undertaken in three parts: (i) quantifying the optimisation in terms of distances travelled by trucks in the implemented distribution model (manufacturer storage with carrier/last-mile delivery) vs a standard echeloned delivery model; (ii) assessing loading efficiency (dispatch load vs payload capacity) and capacity utilisation (ton-km delivered vs ton-km available in each trip); and (iii) applying operations research to assess further optimisation potential. Data analysis has been carried out using both the complete dataset and the sampled dataset at different places. The sampled dataset has been used where point-to-point distances are involved.

7.1. Reduction in Distances Travelled Due to DTS Model

Each delivery was associated with a BM (who invoices and bills the product). The implemented distribution model (DTS), in most cases, decreased the distance travelled by trucks for delivery, compared to what they would have had if the delivery by the manufacturer would be at the BM's premises and further under the arrangements of the BM to the site (merchant delivery—MD). Based on measurement of distances between the manufacturer's WH and delivery sites, and the corresponding distances between the manufacturer's WH, the BM's location, and the delivery site from the sampled dataset, the ratio between the distances with the implemented model vs distances calculated for the echeloned distribution model, a reduction in distances travelled by trucks of 11.11 km per trip has been numerically arrived at (Table 2).

Table 2. Reduction in distances travelled by trucks based on DTS model.

Parameter	DTS km	Ratio of DTS km to MD km
Max	119.1	2.19
Min	3.8	0.1047
Avg	27.04	0.7086

Note. Reduction = 27.04[(1/0.7086) − 1] = 11.11 km (Based on each delivery being considered a separate trip from the BM's premises. Most trips being single drops support this optimisation figure).

The reduction in distances travelled is being achieved as a result of: (i) the consolidation function being performed by the manufacturer's warehouse; and (ii) the DTS model encouraging contractors/developers from seeking work and moving out of their usual operating area, which would have led to very high overheads in terms of transportation in the case of the MD model.

7.2. Loading Efficiencies

Loading efficiencies for trucks are available for the complete dataset (without sampling and without filtering). Each area (zone) of distribution and each truck type used exhibit different patterns. These are illustrated at Figures 9 and 10.

Figure 9 illustrates that there are certain delivery districts for which loading efficiencies are higher than the others. On seeking a clarification from the logistics manager, it emerged that round-trip time and number of deliveries are the governing criteria for areas comparatively closer to the warehouse, whereas loading efficiency becomes the governing criterion for areas located far from the warehouse. Bunching of efficiencies of various truck models across delivery districts at Figure 10 illustrates that different types of trucks exhibit peculiar loading characteristics, which are consistent across delivery districts. A high spread in the efficiencies across delivery districts is seen where the number of trips is low, there is a low number of trucks undertaking runs, and there are trucks that may be utilised at a site through the day for their crane capacity rather than undertaking delivery runs. However, overall, there appears to be subjectivity in allocating trucks, their number of trips, and the loading efficiency. This will be substantiated further in the section discussing application of operations research.

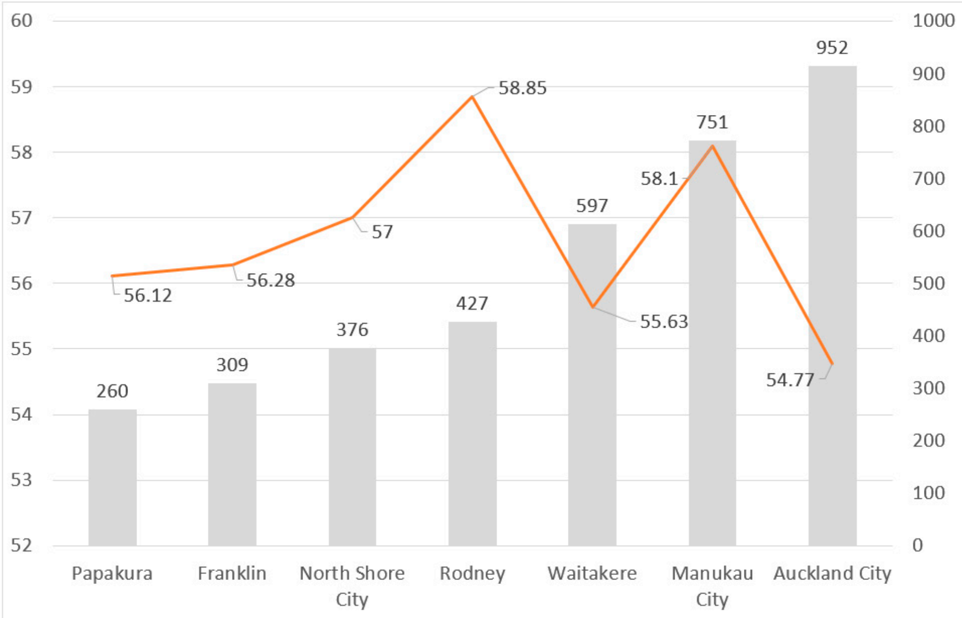

Figure 9. Loading efficiency and trips by delivery district. Note: X-axis—Delivery districts; Y-axis (**Left**)—Loading efficiency in % (pertains to line plot); Y-axis (**right**)—Number of trips (pertains to bar graph).

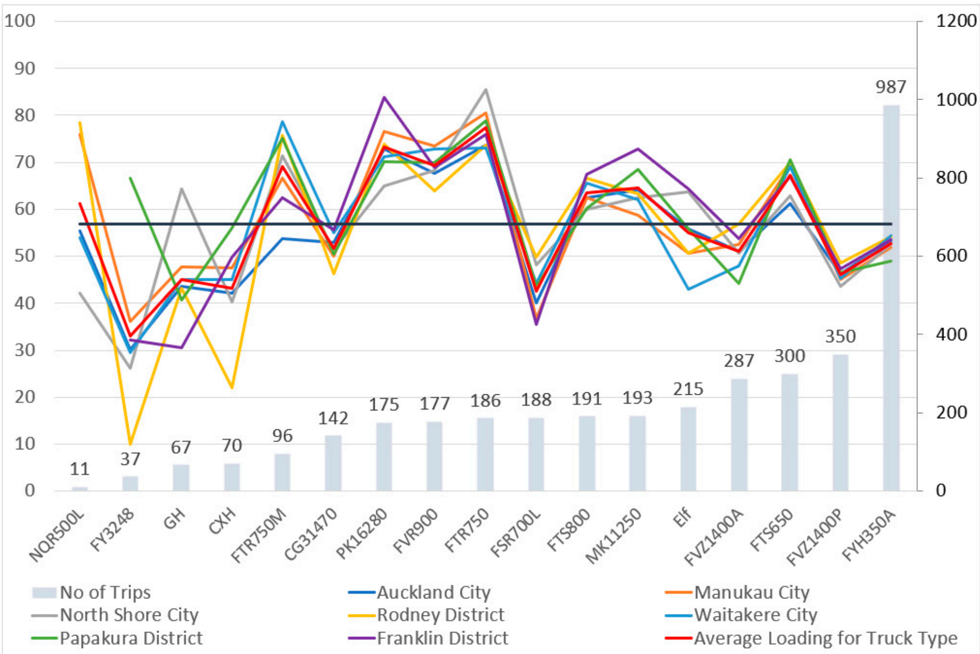

Figure 10. Loading efficiency by truck model and delivery district. Note: X-axis—Truck models; Y-axis (**Left**)—Loading efficiency in % (pertains to line plots); Y-axis (**right**)—Number of trips (pertains to bar graph).

7.3. Capacity Utilisation

Capacity utilisation, measured in tonne-km, is a function of the loading efficiency (initial conditions), number of destinations or drops, distance between various vertices of the route, and drop loads. As such, a comparison of loading efficiencies and capacity utilisation across the number of drops is an efficiency benchmark. However, it needs to be understood that the capacity utilisation can be artificially enhanced if the heaviest load is dropped last. Ideally, loads must keep getting dropped in order of their increasing distance from the warehouse. Sequencing of drops assumes a high significance when assessing capacity utilisation. Table 3 illustrates loading efficiency and capacity utilisation vs number of drops per trip.

Table 3. Loading efficiency and capacity utilisation vs number of drops per trip.

Drops	Loading Efficiency			Capacity Utilisation		
	Max	Min	Avg	Max	Min	Avg
1	99.21	1.13	56.62	49.62	0.56	28.31
2	99.89	1.2	56.38	61.94	1.36	26.8
3	98.15	2.82	58.85	61.01	2.92	27.1

Seen stand-alone, capacity utilisation exhibits an increase from one to two drops and then shows a decline. The data appear to suggest two drops as ideal. Drop in capacity utilisation appears due to the km parameter becoming overbearing with increases in the number of drops, with loads splitting up between drop points, and, therefore, losing strength. Capacity utilisation also appears to suggest major optimisation potential in the employment of trucks in spite of the advantage accrued by the DTS model over the MD model.

7.4. Further Potential for Optimisation—Applying the Linear Programming Model

The low values of capacity utilisation, when seen in conjunction with the low values of loading efficiency, point in the direction of potential optimisation in the number of trucks for performing the same delivery throughout the day. Linear programming (LP) is a powerful technique for optimising transportation of loads between sources and consumers, achieving minimisation of the parameter of interest through problem formulation. In the instant case, an LP (transportation) problem may be formulated as follows:

- Rows: the number of trips of a truck are considered independent sources, each having the capacity of the truck, e.g., if a truck with payload capacity X tonnes does Y trips in a day, we have Y sources with supply capacity X for the transportation model matrix. These present a 'less than equal to' constraint for the LP model, since capacities available are more than the demand (from the determined loading efficiencies).
- Columns: each of the destination loads serviced during the day represent the consumers or the demand. These present an 'equal to' constraint for the LP model since these need to be fulfilled.
- Matrix cells: each one of the cells of the matrix formed by the above rows and columns will be populated with a standard (uniform) figure, since the DTS model works on a 'per-tonne' basis, uniform for transportation across the complete region. For operating the model, we may consider this as unity, although using any other non-zero number will give the same results.
- The problem is a cost minimisation problem, which will translate to resource optimisation in the instant case since costs are uniform across the complete spectrum of operations being examined.

Once the problem is formulated, the 'Solver' add-in to MS Excel can be used effectively for solving this problem. MS Excel, however, presents a restriction on the number of variables (matrix cells) as being up to 200. To overcome this limitation, data pertaining to a given day were truncated in a manner to include as many trucks as possible with all their trips, such that the product of the number of truck trips and the destination loads serviced by them (numbers, not quantities) does not exceed 200.

In MS Excel, the problem appears as follows:

- Column heading: demands (destination loads), representing an 'equal to' constraint for the LP problem.
- Row headings: suppliers (truck capacities repeated for the number of trips), representing a 'less than equal to' constraint for the LP problem.

- Matrix cells: cost of transporting from a supply node to a demand node (in this case uniform or unity).

An illustration of optimisation using LP in MS Excel is in Figure 11, with the top matrix illustrating the truck trips (as sources) in the rows and destinations (as demands) in the columns, while the bottom matrix illustrates the solution achieved by the application of LP.

		1	2	3	4	5	6	7	8	9	10	11	12	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	19.8			
2		1	1	1	1	1	1	1	1	1	1	1	1	19.8			
3		1	1	1	1	1	1	1	1	1	1	1	1	12.32			
4		1	1	1	1	1	1	1	1	1	1	1	1	12.32			
5		1	1	1	1	1	1	1	1	1	1	1	1	12.32			
6		1	1	1	1	1	1	1	1	1	1	1	1	8.63			
7		1	1	1	1	1	1	1	1	1	1	1	1	8.63			
8		1	1	1	1	1	1	1	1	1	1	1	1	8.63			
9		1	1	1	1	1	1	1	1	1	1	1	1	8.63			
10		1	1	1	1	1	1	1	1	1	1	1	1	15.7			
11		1	1	1	1	1	1	1	1	1	1	1	1	15.7			
12		1	1	1	1	1	1	1	1	1	1	1	1	15.7			
														158.18			
Demand		8.79	9.49	0.45	4.17	4.92	4.56	5.71	5.84	8.37	2.61	4.47	6.53	65.91			
		1	2	3	4	5	6	7	8	9	10	11	12	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0.02	4.56	4.22	0	0	0	4.47	6.53	19.8	<=	19.8	1
2		1.24	9.49	0	4.17	4.9	0	0	0	0	0	0	0	19.8	<=	19.8	1
3		7.55	0	0	0	0	0	0	0	0	0	0	0	7.55	<=	12.32	0.612825
4		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
5		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
7		0	0	0	0	0	0	0	0	0	2.61	0	0	2.61	<=	8.63	0.302433
8		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0.45	0	0	0	0	0	0	0	0	0	0.45	<=	8.63	0.052144
10		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
12		0	0	0	0	0	0	1.49	5.84	8.37	0	0	0	15.7	<=	15.7	1
LHS		8.79	9.49	0.45	4.17	4.92	4.56	5.71	5.84	8.37	2.61	4.47	6.53				
Relation		=	=	=	=	=	=	=	=	=	=	=	=		Min	65.91	
Demand		8.79	9.49	0.45	4.17	4.92	4.56	5.71	5.84	8.37	2.61	4.47	6.53				

Figure 11. Optimisation of transport operations (as-executed) using LP by minimising costs.

Minimisation of cost (in this case translating to resources) is achieved through allocation of loads to trucks in a manner that they are fully loaded at the time of departure. Since the capacity (supply) available is more than the demand (from the low loading efficiency available from the dataset), a certain number of trucks become redundant. Hence, the delivery can be completed by a lesser number of trucks. In the above illustration, four truck trips (of various capacities) out of 11 ('as actually executed') become redundant. Similar redundancies of transport were obtained across all 59 days to which the data pertained, when simulated (approximately 30% in terms of the number of trucks required to fulfill delivery requirements). The reduced number of trucks imply lower tonne-km, therefore, a lower unit transportation cost, while resulting in reduced congestion, emissions, and associated sustainability benefits. This analysis, therefore, leads to a 'win-win' situation with improved cost dynamics as well as improved sustainability through reduced externalities of freight transport.

Each truck now has a set of loads it needs to deliver during the day. Hence, in addition to optimisation of the amount of transport being employed for delivery, application of LP has reduced the problem from a vehicle routing problem (VRP) involving multiple vehicles and multiple routes, to a 'Travelling Salesman Problem' (TSP) [90], where the route to be followed by each truck can be independently optimised based on the next vertex it needs to visit within the deliveries specified by the LP solution. This can be readily solved using a 'Hamiltonian Path' approach [91], especially since the number of drops in most cases are within three; therefore, the processing resources are minimal.

8. Discussion

The reported research centres around investigating the advantage accrued from the implemented 'Direct-to-Site' delivery by the manufacturer, as opposed to 'Merchant Delivery' model, which is typically part of an echeloned construction supply chain. DTS represents forward vertical integration of logistics along with an already existing distributor network represented by builders' merchants in NZ.

The operations pertain to Auckland, and the average distance travelled by trucks for DTS delivery (one-way) is approximately 27 odd km. The Auckland conurbation represents an extensive and linear urban sprawl [24], within which a distance of 27 km on an average for DTS delivery evidences the fact that these can safely be considered urban distribution, in this case undertaken by third party LSPs. In any case, these are not 'long-haul' between regions.

Further, the truck fleet consists of specialised (with high-capacity cranes) as well as non-specialised trucks, with most deliveries being performed by non-specialised trucks. The specialised trucks tend to be used more for their crane capabilities rather than the load carrying capabilities, at times staying back on site to handle material delivered by other trucks throughout the day. Invariably, the overall loading efficiencies as well as capacity utilisation of specialised trucks are below that of the balance fleet. On the other end of the spectrum, there are certain trucks with very low payload capacities, which are being used for 'spur of the moment' or 'nearby small' deliveries, also presenting overall low-capacity utilisation.

Considering point-to-point distances, the DTS model appears to provide an optimisation of approximately 11 km vis-à-vis the MD model for every trip considering transport operations 'as executed' from the dataset made available for analysis. Application of the LP algorithm enables further optimisation in terms of the number of trucks required for daily deliveries. It also reduces a complex VRP to a TSP, easily solvable using a Hamiltonian path approach from graph theory.

The above aspects point to both tactical/operational, as well as strategic considerations for conducting business 'differently' to achieve improved sustainability:

1. NPAs should form part of tender evaluation.
2. Demonstrated performance-based award of contracts for transport.
3. Increase in DTS deliveries as compared to BM deliveries.
4. Examination of fleet composition for achieving best loading efficiencies.
5. Standardisation of truck configuration for uniform fleet capabilities.
6. Inclusion of sustainability objectives in fleet planning (discard, rejuvenation, and new technology).
7. Making IT intrinsic to the planning process.
8. Integrating planning and operational delivery.
9. Integrating reverse logistics for transporting plasterboard waste.
10. Utilisation of 'clean' waste in manufacturing.
11. A variety of payment models to optimise costs.

9. Conclusions

The paper presents the general construction supply chain, the relation of logistics and transportation to it, and their New Zealand context. It then focusses on investigating the transport operations of a vertically integrated narrow segment of the New Zealand construction supply chain, bringing out the advantages accrued as a result of integrated logistics. Further potential for optimisation is simulated using simple linear programming routines, and implications for fleet management both in the long- and short-term are emphasized. In doing so, this paper overcomes acknowledged issues in freight transport analysis, i.e., the lack of available freight data to make evidence-based decisions and data analysis from the individual journey rather than the supply chain perspective [92].

Clearly, transport operations form a major component of logistics, and the analysis and interpretations discussed in this paper validate transport optimisation as a powerful tool for sustainable logistics from the reduction/optimisation of resources achieved through business models (vertical integration) and the planning process. Research outcomes point to: (i) fleet management strategy; (ii) integrated planning and operational delivery; (iii) non-price attributes in tendering/contracting; (iv) adoption of innovative delivery models for manufactured construction products; (v) information and communication technology-based solutions; and vi) integration of reverse logistics.

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Data Availability Statement: Restrictions apply to the availability of these data. Raw data from which analysis has been undertaken and its sources cannot be disclosed due to ethical restrictions.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations/Nomenclature

BM—Builders' Merchant; BRANZ—Building Research Association New Zealand; BU—Business Unit; CLM—Council of Logistics Management; DTS—Direct to Site; FTL—Full Truck Load; GDP—Gross Domestic Product; Iwi/Hapū—Māori Community; LSP—Logistics Service Provider; LTL—Less than Truck Load; MD—Merchant Delivery; MSME—Micro Small and Medium Enterprise; NPA—Non-price Attributes; NZ—New Zealand; QQ—Quantile-Quantile; (C)SC—(Construction) Supply Chain; (C)SCM—(Construction) Supply Chain Management; TSP—Travelling Salesman Problem; UNEP—United Nations Environmental Programme; UFT—Urban Freight Transport; VRP—Vehicle Routing Problem; vs–Versus; WH—Warehouse.

References

1. McKinsey & Company. *Reinventing Construction: A Route to Higher Productivity*; McKinsey Global Institute: Shanghai, China, 2017; Available online: https://www.mckinsey.com/~{}/media/mckinsey/business%20functions/operations/our%20insights/reinventing%20construction%20through%20a%20productivity%20revolution/mgi-reinventing-construction-a-route-to-higher-productivity-full-report.pdf (accessed on 12 October 2022).
2. Sheffer, D.; Levitt, R. Fragmentation Inhibits Innovation: Overcoming Professional and Trade Lock-in. Building Research & Information, 2012 Special Issue on New Professionalism. 2012. Available online: https://gpc.stanford.edu/sites/g/files/sbiybj8226/f/wp069_0.pdf (accessed on 15 October 2022).
3. Guerlain, C.; Renault, S.; Ferrero, F. Understanding Construction Logistics in Urban Areas and Lowering Its Environmental Impact: A Focus on Construction Consolidation Centres. *Sustainability* **2019**, *11*, 6118. [CrossRef]
4. Riazi, S.; Zainuddin, M.; Nawi, M.; Musa, S.; Lee, A. A Critical Review of Fragmentation Issues in the Construction Industry. *Talent Dev. Excell.* **2020**, *12*, 1510–1521. Available online: https://usir.salford.ac.uk/id/eprint/57063/1/545-Article+Text-947-1-10-20200514.pdf (accessed on 2 November 2022).
5. Jones, K.; Mosca, L.; Whyte, J.; Davies, A.; Glass, J. Addressing specialization and fragmentation: Product platform development in construction consultancy firms. *Constr. Manag. Econ.* **2021**, *40*, 918–933. [CrossRef]
6. Alashwal, A.M.; Fong, P.S.-W. Empirical Study to Determine Fragmentation of Construction Projects. *J. Constr. Eng. Manag.* **2015**, *141*, 04015076. [CrossRef]
7. Tepić, J.; Tanackov, I.; Stojić, G. Ancient Logistics—Historical Timeline and Etymology. *Tech. J.* **2011**, *18*, 379–384. Available online: https://hrcak.srce.hr/file/107004 (accessed on 22 November 2022).

8. Ying, F.; Tookey, J. Managing Logistics Cost—A Missing Piece in Total Cost Management. In Proceedings of the International Cost Engineering Council IX World Congress, Milano, Italy, 20–22 October 2014; Available online: https://openrepository.aut.ac.nz/handle/10292/11850 (accessed on 11 October 2022).
9. Szymonik, A. *Logistics and Supply Chain Management*; Technical University of Lodz Press: Lodz, Poland, 2012. Available online: https://www.mdpi.gov.gh/wp-content/uploads/2021/01/LogisticsandSupplyChainManagement.pdf (accessed on 15 August 2022).
10. Bowersox, D.; Closs, D. *Logistical Management: The Integrated Supply Chain Process*; The McGraw-Hill Companies: New York, NY, USA, 1996.
11. Lovell, A.; Saw, R.; Stimson, J. Product value-density: Managing diversity through supply chain segmentation. *Int. J. Logist. Manag.* **2005**, *16*, 142–158. [CrossRef]
12. Ying, F.; Roberti, H. Improving Construction Logistics. *BUILD* **2013**, *134*. Available online: https://www.buildmagazine.org.nz/assets/PDF/Build-134-80-Research-Improving-Construction-Logistics.pdf? (accessed on 1 November 2022).
13. Balm, S.; Ploos van Amstel, W. Exploring Criteria for Tendering for Sustainable Urban Construction Logistics. In *City Logistics 1: New Opportunities and Challenges*; Taniguchi, E., Thompson, R., Eds.; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2017; pp. 251–263. [CrossRef]
14. The Bellona Foundation. *Efficient Transportation to and from Construction Sites can Reduce CO_2 Emissions by 50%*; The Bellona Foundation: Oslo, Norway, 2020; Available online: https://network.bellona.org/content/uploads/sites/2/2021/02/Bellona-How-to-optimise-transport-in-construction-1.pdf (accessed on 22 November 2022).
15. Smith, R.; Kersey, J.; Griffiths, P. *The Construction Industry Mass Balance: Resource Use, Wastes and Emissions*; Vridis report VR4 (Revised); Vridis: London, UK, 2003.
16. Ying, F.; Tookey, J.; Roberti, J. Development of SCM Competencies in Construction: Lessons Learned from New Zealand. 2014. Available online: http://openrepository.aut.ac.nz (accessed on 22 November 2022).
17. Chatziioannou, I.; Alvarez-Icaza, L.; Bakogiannis, E.; Kyriakidis, C.; Chias-Becerril, L. A Structural Analysis for the Categorization of the Negative Externalities of Transport and the Hierarchical Organization of Sustainable Mobility's Strategies. *Sustainability* **2020**, *12*, 6011. [CrossRef]
18. Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2014: Mitigation of Climate Change. (AR5)*; Cambridge Press: New York, NY, USA, 2014; Available online: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_full.pdf (accessed on 22 November 2022).
19. Guerin, E.; Waisman, H.; Mas, C. Pathways to Deep Decarbonisation. United Nations; Sustainable Development Solutions Network (SDSN) and Institute for Sustainable Development and International Relations (IDDRI) 2014. Available online: https://www.globalccsinstitute.com/archive/hub/publications/184548/pathways-deep-decarbonization-2014-report.pdf (accessed on 1 October 2022).
20. McKinnon, A. *Decarbonising Logistics: Distributing Goods in a Low-Carbon World*; Kogan Page Limited: London, UK; New York, NY, USA, 2018.
21. Dani, A.; Roy, K.; Masood, R.; Fang, Z.; Lim, J. A Comparative Study on the Life Cycle Assessment of New Zealand Residential Buildings. *Buildings* **2022**, *12*, 50. [CrossRef]
22. Naismith, N.; Monaghan, B.; Zhang, T.; Doan, D.; GhaffarianHoseini, A.; Tookey, J. Examining the Productivity in the NZ Construction Industry. In The 2nd NZAAR International Event Series on Natural and Built Environment, Cities, Sustainability and Advanced Engineering, Kuala Lumpur. 2016. Available online: https://www.researchgate.net/publication/323358720_EXAMINING_THE_PRODUCTIVITY_IN_THE_NZ_CONSTRUCTION_INDUSTRY (accessed on 31 October 2022).
23. Khan, M.; Lockhart, J. Embedding Corporate Social Responsibility into Business Practice: Lessons Learned from New Zealand. In *Clean, Green and Responsible? CSR, Sustainability, Ethics and Governance*; Eweje, G., Bathurst, R., Eds.; Springer: Cham, Switzerland, 2019; pp. 87–105. [CrossRef]
24. Silva, C. Auckland's Urban Sprawl, Policy Ambiguities and the Peri-Urbanisation to Pukekohe. *Urban Sci.* **2018**, *3*, 1. [CrossRef]
25. Ministry of Transport, New Zealand Government (MoT). *National Freight Demand Study March 2014*; Ministry of Transport: Wellington, New Zealand, 2017. Available online: https://pdf4pro.com/view/national-freight-demand-study-transport-govt-nz-ce17a.html (accessed on 12 October 2022).
26. Westpac. Road Freight: Between a Rock and a Hard Place on Decarbonisation (Westpac Economic Bulletin 28 May 2021). 2021. Available online: https://www.westpac.co.nz/assets/Business/toolsrates-fees/documents/economic-updates/2021/Bulletins/Freight-bulletin-May-2021-Westpac-NZ.pdf (accessed on 27 October 2022).
27. Ministry of Transport, New Zealand Government (MoT). *2020 Green Freight Strategic Working Paper*; Ministry of Transport: Wellington, New Zealand, 2020.
28. Seadon, J.; Tookey, J. Drivers for Construction Productivity. *Eng. Constr. Archit. Manag.* **2018**, *26*, 945–961. [CrossRef]
29. Statistics New Zealand. Business Operations Survey: 2018. 2019. Available online: https://www.stats.govt.nz/information-releases/business-operations-survey-2018 (accessed on 1 February 2022).
30. Ministry of Business, Innovation and Employment, New Zealand Government (MBIE). *National Construction Pipeline Report 2021*; MBIE: Wellington, New Zealand, 2021. Available online: https://d39d3mj7qio96p.cloudfront.net/media/documents/national-construction-pipeline-report-2021.pdf (accessed on 2 November 2022).

31. Curtis, M. *Productivity in the Construction Industry 2017 (Study Report SR 388-2018)*; Building Research Association New Zealand Ltd. (BRANZ): Porirua, New Zealand, 2018; Available online: https://www.branz.co.nz/pubs/research-reports/sr388/ (accessed on 4 November 2022).
32. Du-Plessis, C. Agenda 21 for Sustainable Construction in Developing Countries—A Discussion Document. Pretoria, South Africa: International Council for Research and Innovation in Building and Construction Technology, United Nations Environmental Programme International Environment Technology Centre. 2002. Available online: https://www.academia.edu/19056415/Agenda_21_for_Sustainable_Construction_in_Developing_Countries (accessed on 5 October 2022).
33. Shakantu, W.; Muya, M.; Tookey, J.; Bowen, P. Flow modelling of construction site materials and waste logistics: A Case Study from Cape Town, South Africa. *Eng. Constr. Arch. Manag.* **2008**, *15*, 423–439. [CrossRef]
34. Wegelius-Lehtonen, T. Performance measurement in construction logistics. *Int. J. Prod. Econ.* **2001**, *69*, 107–116. [CrossRef]
35. Dubois, A.; Gadde, L.-E. The construction industry as a loosely coupled system: Implications for productivity and innovation. *Constr. Manag. Econ.* **2002**, *20*, 621–631. [CrossRef]
36. Shakantu, W.; Tookey, J.E.; Bowen, P. The hidden cost of transportation of construction materials: An overview. *J. Eng. Des. Technol.* **2003**, *1*, 103–118. [CrossRef]
37. Shakantu, W.; Emuze, F. Improving H&S by Limiting Transport Externalities in South Africa. In Proceedings of the 20th Annual Conference of the International Group for Lean Construction (IGLC), San Diego, CA, USA, 18–20 July 2012; IGLC: San Diego, CA, USA, 2012. Available online: https://iglcstorage.blob.core.windows.net/papers/attachment-83f0dbc8-8f9a-40b1-a05f-2cefb2561598.pdf (accessed on 22 November 2022).
38. Alashwal, A.; Abdul-Rahman, H. (n.d.) Developing a Conceptual Framework of Fragmentation in Construction. Available online: https://www.library.auckland.ac.nz/external/finalproceeding/Files/Papers/46530final00176.pdf (accessed on 22 October 2022).
39. Kesidou, S.; Sovacool, B.K. Supply chain integration for low-carbon buildings: A critical interdisciplinary review. *Renew. Sustain. Energy Rev.* **2019**, *113*, 109274. [CrossRef]
40. Smith, J.; O'Keeffe, N.; Georgiou, J.; Love, P. Procurement of construction facilities: A case study of design management within a design and construct organisation. *Facilities* **2004**, *22*, 26–34. [CrossRef]
41. Construction in the Vicinities Innovative Co-creation (CIVIC). *Smart Construction Logistics*; CIVIC: Stockholm, Sweden, 2018; Available online: https://www.civic-project.eu/sites/default/files/content/bilder/civic-handbook_digital-2.pdf (accessed on 24 October 2022).
42. Briscoe, G.; Dainty, A. Construction supply chain integration: An elusive goal? *Supply Chain Manag. Int. J.* **2005**, *10*, 319–326. [CrossRef]
43. Mentzer, J.T.; DeWitt, W.; Keebler, J.S.; Min, S.; Nix, N.W.; Smith, C.D.; Zacharia, Z.G. Defining Supply Chain Management. *J. Bus. Logist.* **2001**, *22*, 1–25. [CrossRef]
44. Janvier-James, A.M. A New Introduction to Supply Chains and Supply Chain Management: Definitions and Theories Perspective. *Int. Bus. Res.* **2011**, *5*, 194. [CrossRef]
45. Felea, M.; Albăstroiu, I. Defining the Concept of Supply Chain Management and its Relevance to Romanian Academics and Practitioners. *Amfiteatru Econ. J.* **2013**, *15*, 74–88.
46. Stevens, G.C. Integrating the Supply Chain. *Int. J. Phys. Distrib. Mater. Manag.* **1989**, *19*, 3–8. [CrossRef]
47. Cooper, M.C.; Ellram, L.M. Characteristics of Supply Chain Management and the Implications for Purchasing and Logistics Strategy. *Int. J. Logist. Manag.* **1993**, *4*, 13–24. [CrossRef]
48. Anca, V. Logistics and Supply Chain Management: An Overview. *Stud. Bus. Econ.* **2019**, *14*, 209–215. [CrossRef]
49. Chandra, C.; Kumar, S. Supply chain management in theory and practice: A passing fad or a fundamental change? *Ind. Manag. Data Syst.* **2000**, *100*, 100–114. [CrossRef]
50. Cooper, M.C.; Lambert, D.M.; Pagh, J.D. Supply Chain Management: More Than a New Name for Logistics. *Int. J. Logist. Manag.* **1997**, *8*, 1–14. [CrossRef]
51. Ghiani, G.; Laporte, G.; Musmanno, R. *Introduction to Logistics Systems*; J. Wiley: Hoboken, NJ, USA, 2004; Available online: https://pc-freak.net/international_university_college_files/Introduction%20to%20Logistic%20Systems%20Planning%20&%20control.pdf (accessed on 1 November 2022).
52. Larson, P.D.; Halldorsson, A. Logistics versus supply chain management: An international survey. *Int. J. Logist. Res. Appl.* **2004**, *7*, 17–31. [CrossRef]
53. Calis, G.; Kivrak, S.; Coffey, M. The Benefits of Construction Logistics Centres in Construction Supply Chain Management. In Proceedings of the 5th International Project and Construction Management Conference (IPCMC 2018); Cyprus International University, Faculty of Engineering, Civil Engineering Department: North Nicosia, North Cyprus, 2018. Available online: https://www.researchgate.net/publication/331745360_The_Benefits_of_Construction_Logistics_Centres_in_Construction_Supply_Chain_Management_A_Case_Study_Analysis (accessed on 11 October 2022).
54. Seth, D.; Nemani, K.; Pokharel, S.; Al Sayed, A.Y. Impact of competitive conditions on supplier evaluation: A construction supply chain case study. *Prod. Plan. Control* **2017**, *29*, 217–235. [CrossRef]
55. Vrijhoef, R.; Koskela, L. The Four Roles of Supply Chain Management in Construction. *Eur. J. Purch. Supply Manag.* **2000**, *6*, 169–178. [CrossRef]
56. Liao, L. Perspective on Supply Chain Management for Construction Engineering Management Risk Prevention. *Adv. Econ. Bus. Manag. Res.* **2019**, *80*, 547–551. [CrossRef]

57. Behera, P.; Mohanty, R.; Prakash, A. Understanding Construction Supply Chain Management. *Prod. Plan. Control* **2015**, *26*, 1332–1350. [CrossRef]
58. Vidalakis, C.; Tookey, J. The Involvement of Builders' Merchants in the Development of Improved Construction Logistics. In *Proceedings of the 2nd Scottish Conference for Postgraduate Researchers of the Built and Natural Environment (PRoBE)*; Glasgow Caledonian University: Glasgow, UK, 2005; pp. 337–350. Available online: http://www.irbnet.de/daten/iconda/CIB10642.pdf (accessed on 22 November 2022).
59. Agapiou, A.; Flanagan, R.; Norman, G.; Notman, D. The changing role of builders merchants in the construction supply chain. *Constr. Manag. Econ.* **1998**, *16*, 351–361. [CrossRef]
60. Thunberg, M.; Persson, F. Using the SCOR model's performance measurements to improve construction logistics. *Prod. Plan. Control* **2013**, *25*, 1065–1078. [CrossRef]
61. Transport for London. Construction Logistics Plan Guidance for Developers. 2013. Available online: https://content.tfl.gov.uk/construction-logistics-plan-guidance.pdf (accessed on 22 November 2022).
62. Lundesjo, G. *Using Construction Consolidation Centres to Reduce Construction Waste and Carbon Emissions*; Waste and Resources Action Programme (WRAP): London, UK, 2011; Available online: http://www.wrap.org.uk/sites/files/wrap/CCC%20combined.pdf (accessed on 22 November 2022).
63. Lindén, S.; Josephson, P. In-housing or out-sourcing on-site materials handling in housing? *J. Eng. Des. Technol.* **2013**, *11*, 90–106. [CrossRef]
64. Ekeskär, A.; Rudberg, M. Third-party logistics in construction: The case of a large hospital project. *Constr. Manag. Econ.* **2016**, *34*, 174–191. [CrossRef]
65. Jang, H.; Russell, J.S.; Yi, J.S. A project manager's level of satisfaction in construction logistics. *Can. J. Civ. Eng.* **2003**, *30*, 1133–1142. [CrossRef]
66. Janné, M. Construction Logistics in a City Development Setting. Ph.D. Thesis, Linköping University, Linköping, Sweden, 2020. Available online: https://www.diva-portal.org/smash/get/diva2:1474794/FULLTEXT01.pdf (accessed on 7 November 2022).
67. Kim, S.-Y.; Nguyen, V.T. A Structural model for the impact of supply chain relationship traits on project performance in construction. *Prod. Plan. Control* **2017**, *29*, 170–183. [CrossRef]
68. Ghanem, M.; Hamzeh, F.; Seppänen, O.; Zankoul, E. A New Perspective of Construction Logistics and Production Control: An Exploratory Study. In Proceedings of the 26th Annual Conference of the International Group for Lean Construction (IGLC), Chennai, India, 16–22 July 2018; González, V., Ed.; pp. 992–1001. [CrossRef]
69. Vidalakis, C.; Tookey, J.E.; Sommerville, J. The logistics of construction supply chains: The builders' merchant perspective. *Eng. Constr. Arch. Manag.* **2011**, *18*, 66–81. [CrossRef]
70. Kin, B.; Verlinde, S.; Macharis, C. Towards a Sustainable Urban Freight Transport System—Axes for Intervention. In Proceedings of the Logistics Research Network Annual Conference, Southampton, UK; Chartered Institute of Logistics and Transport (CILT): London, UK, 2017. Available online: https://www.researchgate.net/publication/325719493_Towards_a_sustainable_urban_freight_transport_system_-Axes_for_intervention (accessed on 18 October 2022).
71. City Vitality and Sustainability (CIVITAS). *Smart Choices for Cities: Making Urban Freight Logistics More Sustainable (CIVITAS Policy Note)*; European Commission, CIVITAS: Brussels, Belgium, 2020; Available online: https://civitas.eu/sites/default/files/civ_pol-an5_urban_web.pdf (accessed on 25 October 2022).
72. Diana, M.; Pirra, M.; Woodcock, A. Freight distribution in urban areas: A method to select the most important loading and unloading areas and a survey tool to investigate related demand patterns. *Eur. Transp. Res. Rev.* **2020**, *12*, 40. [CrossRef]
73. McKinnon, A.; Ge, Y. The Potential for Reducing Empty Running by Trucks: A Retrospective Analysis. *Int. J. Phys. Distrib. Logist. Manag.* **2006**, *36*, 391–410. [CrossRef]
74. Crainic, T.G.; Ricciardi, N.; Storchi, G. Advanced freight transportation systems for congested urban areas. *Transp. Res. Part C Emerg. Technol.* **2004**, *12*, 119–137. [CrossRef]
75. DG MOVE European Commission. Study on Urban Freight Transport. 2012. Available online: https://civitas.eu/sites/default/files/2012_ec_study_on_urban_freight_transport_0.pdf (accessed on 30 October 2022).
76. Sankaran, J.; Gore, A.; Coldwell, B. The Impact of Road Traffic Congestion on Supply Chains: Insights from Auckland, New Zealand. *Int. J. Logist. Res. Appl.* **2005**, *8*, 159–180. [CrossRef]
77. Berden, M. Analysis of Construction Logistics Calculation Models and Factors that Obstruct their Development. 2017. Available online: https://www.civic-project.eu/sites/default/files/content/2017_06_01_d.2.1_final_anoniem.pdf (accessed on 14 October 2022).
78. Vrijhoef, R. Reducing the Environmental Impact and Improving Efficiency of Construction Transport. In Proceedings of the Joint CIB Symposium Going North for Sustainability: Leveraging Knowledge and Innovation for Sustainable Construction and Development, 23–25 November 2015; London South Bank University: London, UK, 2015. Available online: https://repository.tudelft.nl/islandora/object/uuid:00e799d8-daba-42b1-ade3-059dc0b768ff/datastream/OBJ/download (accessed on 1 November 2022).
79. Muerza, V.; Guerlain, C. Sustainable Construction Logistics in Urban Areas: A Framework for Assessing the Suitability of the Implementation of Construction Consolidation Centres. *Sustainability* **2021**, *13*, 7349. [CrossRef]

80. Berroir, F.; Guernaccini, P.; Boje, C.; Maatar, O. Reducing Construction Logistics Costs and Embodied Carbon with CCC and Kitting: A Case Study. In Proceedings of the 29th Annual Conference of the International Group for Lean Construction (IGLC29), Lima, Peru, 14–17 July 2021; Alarcon, L., González, V., Eds.; IGLC: Lima, Peru, 2021; pp. 935–944. [CrossRef]
81. Building Research Establishment (BRE). *Construction Site Transport: The Next Big Thing*; BRE: Watford, UK, 2003; Available online: https://www.bre.co.uk/pdf/constructiontraffic.pdf (accessed on 27 October 2022).
82. Dhawan, K.; Tookey, J.E.; GhaffarianHoseini, A.; GhaffarianHoseini, A. Greening Construction Transport as a Sustainability Enabler for New Zealand: A Research Framework. *Front. Built Environ.* **2022**, *8*, 871958. [CrossRef]
83. Commerce Commission New Zealand. Residential Building Supplies Market Study—Preliminary Issues Paper. Wellington, New Zealand. 2021. Available online: https://comcom.govt.nz/__data/assets/pdf_file/0025/273553/Residential-building-supplies-market-study-Preliminary-Issues-paper-17-December-2021.pdf (accessed on 2 November 2022).
84. Guan, W.; Rehme, J. Vertical integration in supply chains: Driving forces and consequences for a manufacturer's downstream integration. *Supply Chain Manag. Int. J.* **2012**, *17*, 187–201. [CrossRef]
85. Chopra, S.; Meindl, P. *Supply Chain Management*; Pearson Education Limited: Boston, MA, USA, 2013; Available online: https://mu.ac.in/wp-content/uploads/2021/02/Logistics-and-Supply-Chain-Management-Sunil-Chopra-1.pdf (accessed on 11 October 2022).
86. Krejcie, R.; Morgan, D. Determining Sample Size for Research Activities. *Educ. Psychol. Meas.* **1970**, *30*, 607–610. Available online: https://home.kku.ac.th/sompong/guest_speaker/KrejcieandMorgan_article.pdf (accessed on 30 October 2022). [CrossRef]
87. Howard, D. The Basics of Statistical Process Control & Process Behaviour Charting: A User's Guide to SPC. 2003. Available online: https://nzbef.org.nz/wp-content/uploads/2019/05/Guide-Statistical-Process-Control.pdf (accessed on 1 November 2022).
88. Dhar, S.; Chaudhuri, P.; Chakraborty, B. Multivariate Quantile-Quantile Plots and Related Tests Using Spatial Quantiles. 2010. Available online: https://www.isical.ac.in/~{}statmath/report/88866-10.pdf (accessed on 11 November 2022).
89. Chicco, D.; Warrens, M.J.; Jurman, G. The coefficient of determination R-squared is more informative than SMAPE, MAE, MAPE, MSE and RMSE in regression analysis evaluation. *PeerJ Comput. Sci.* **2021**, *7*, e623. [CrossRef]
90. Devendra, D. (Ed.) *Travelling Salesman Problem, Theory and Applications*; InTech: Rijeka, Croatia, 2010; Available online: http://www.exatas.ufpr.br/portal/docs_degraf/paulo/Traveling_Salesman_Problem__Theory_and_Applications.pdf (accessed on 11 November 2022).
91. Bondy, J.; Murty, U. *Graph Theory with Applications*; Elsevier Science Publishing, Co.: New York, NY, USA, 1976; Available online: https://www.zib.de/groetschel/teaching/WS1314/BondyMurtyGTWA.pdf (accessed on 11 November 2022).
92. McKinnon, A. *Performance Measurement in Freight Transport: Its Contribution to the Design, Implementation and Monitoring of Public Policy*; OECD: Paris, France, 2015; Available online: https://www.itf-oecd.org/sites/default/files/docs/mckinnon.pdf (accessed on 2 November 2022).