# Addressing effective construction logistics through the lens of vehicle movements


Abstract

Construction logistics is an essential part of Construction Supply Chain Management (CSCM). However, limited attention has been paid to this issue in the New Zealand construction industry. The purpose of this paper is to contribute to the knowledge about what hampers efficiency in transporting construction materials and plants to a construction site. The intention is to gain detailed understanding of the practice and obstacles in efficient construction logistics and thus identify interventions to improve logistics efficiency, especially using the numbers of vehicle movements to the construction site as an indicator. A case study approach was adopted with on-site observations and interviews. Observations were performed during constructions on-site from the start of construction to "hand-over" to the building owner. A selection of construction suppliers and subcontractors involved in the studied project were interviewed. Significant intrinsic and extrinsic interventions necessary to enhance construction logistics were acknowledged from the data analysis. These include both qualitative and quantitative data. These intrinsic and extrinsic interventions, such as implementing appropriate logistics tools that suits individual site and introducing traffic management costs, offer plausible explanations regarding how to improve the efficiency in construction logistics through optimising transportation movements to the construction site.



Key words: construction logistics, vehicle movements, construction supply chain management, New Zealand


## Introduction

Logistics is defined as "the process of strategically managing the acquisition, movement and storage of materials, parts and finished inventory (and the related information flows) through the organisation and its marketing channels, in such a way that current and future profitability is maximised through the cost-effective fulfilment of orders" (Gattorna and Day, 1993). For the construction industry, logistics comprise planning, organisation, coordination, and control of the materials flow from the extraction of raw materials to the incorporation into the finished building (Agapiou et al., 1998). Main aspects of construction logistics include whole project logistics, supply logistics, and on-site logistics (Sobotka et al., 2005). The success of the project heavily depends on the coordination of the on-site and external logistics in all aspects.

Addressing the logistics issue in construction can influence customer service levels as well as the economic and environmental performance of supply chains. Building materials and construction components, along with human resources, are the first and foremost important requirement for construction. Logistics provide customer service by ensuring materials and resources are appropriate and available for construction operations (Wegelius-Lehtonen and Pahkala, 1998). Furthermore, research suggests that improved logistics will reduce the costs incurred in the system by low productivity, and save on indirect costs associated with the transportation and handling of construction materials (Shakantu et al., 2003). Also, environmentally, transportation of construction materials is responsible for approximately 10% of the greenhouse gas emission in UK (DTI, 2004) . Consequently, improved logistics performance can deliver significant savings to the industry while promoting sustainability and reducing the environmental impact of construction. Thus, effective construction logistics should provide appropriate trade-offs involving costs and service in the supply chain by integrating materials supply, storage, processing and handling; manpower supply, schedule control; site infrastructure and equipment location; physical site flow management and information management (Shakantu et al., 2008).

Bowersox et al. (2007) claims that “few consumers fully understand how dependent our economic system is upon economical and dependable transportation”. It is especially the case in the construction industry, since the industry does not elect where it conducts its productive activities, and therefore has to move where the work is. Consequently, transportation is the single largest element of logistics cost (Bowersox et al., 2007). Considering that materials usually account for between 30% and over 50% of the cost of a building project (Fellows et al., 2002), transportation costs represent approximately 39 to 58% of total logistics costs. The transportation costs of material thus represent a large percentage of the cost profile of the construction industry. Therefore, a small percentage cut in transportation costs could bring a sizable increase in profits.

Given the significant expenditure involved in the transport related activities and the unique suitability of construction for benefiting from an improved transport capability (due to the high volume/low value of construction materials) it is paradoxical that transport has attracted very limited interest of all activities within the construction supply chain management concept. Although transportation is one of the most important aspects of logistics management (Shakantu et al., 2003), the operational management of transportation in the construction industry is confined to dock level operations (Stank and Goldsby, 2000) and storage of construction material on-site (Said and El-Rayes, 2011). Consequently, there appears to be a significant need for an enhanced understanding of transportation in a construction context in order to deliver the full benefits from adoption of efficient construction logistics. The objective of this research sought to address how construction logistics efficiency can be improved through optimising vehicle movements to the construction site. Theoretical perspectives underpinning the construction logistics are discussed in subject sections, offering insights into factors affecting the numbers of construction vehicle movements.

## Theoretical perspectives of construction logistics

Several authors have examined construction logistics practices in different countries to establish the drivers and barriers to efficient logistics methods (Omar et al., 2010, Blumenthal and Young, 2007, Wegelius-Lehtonen, 2001). Major barriers are around the awareness of logistics costs, characteristics of the construction industry, and practices in the construction industry. A summary of which is presented in Table 1.

| | |
|---|---|
| Awareness of logistics costs | Invisible logistics costs |
| | Lack of understanding the problem |
| | Disconnect between investment in construction logistics and benefit |
| | Business case not yet demonstrated |
| | No record data relating to logistics performance |
| | No way to extract savings from improved methods |
| Characteristics of the construction industry | Fragmentation of the industry |
| | An immature collaborative culture |
| | “Arm’s length” relationship |
| | Disconnect between designers and the supply chain |
| Practices in the construction | Lack of leadership (“champions”) in advocating efficient |

| | |
|---|---|
| industry | construction logistics |
| | Inadequate commitment from management |
| | Ineffective Information and Communication Technology (ICT) systems |
| | Under-utilisation of the existing technology |
| | Culture reluctant to change the way of doing things without personal gains |

Table 1: Barriers in implementing efficient construction logistics

These barriers identified form the literature are more or less related to strategic management issues generally. Limited research has been carried out in investigating barriers at the operational level, especially concerning transportation and vehicle movements.

Transportation costs can be reduced by either increasing the volume delivered per shipment or reducing the distance it travels. The larger the overall shipment and the shorter the distance materials is transported, the lower the transportation cost per unit. Therefore, shipment consolidation and/or local sourcing are fundamental in reducing transportation costs, i.e. fewer vehicles, carrying more, moving shorter distance, less frequently. As a result, cost reduction is achieved by the reduction of vehicle movements. Furthermore, construction sites can be considered as heavy inbound logistics system where the inbound flow is much heavier than the outbound flow. Indeed the construction of a building is where the finished product has no warehousing, special transportation arrangements, or packaging. The inbound side is far more demanding requiring coordination of hundreds of vendors, manufactures and suppliers. The number of vehicle movements at construction sites can therefore serve as a performance measure of logistics efficiency. Since the objective of effective construction logistics is to provide a system framework to encompass appropriate trade-offs between cost and service in the supply chain, various factors that have impact on vehicle movements at construction sites can be categorised into cost related and service related factors.

Cost related factors can be further classified into monetary and non-monetary factors. Low density, high volume products (common characteristics of construction materials) are shipped with higher variable costs than high density counterparts. Therefore, these variable costs, in turn, are essential factors affecting total numbers of vehicle movement to a construction site. These critical cost elements include fuel, labour cost, tax and road tolls, among others.

From the non-monetary aspects, high transport requirement results in high social costs as well as a wide range of associated negative environmental impacts in the form of congestion, road accidents, environmental pollution, and noise generation (Shakantu et al., 2008).

New Zealand has a history of low density urban development. The largest city Auckland is notable for it “Urban Sprawl” (Dixon and Dupuis, 2003, Ministry of the Environment, 2005). The city also has a substantial reliance on road transportation since public transport system has historically not seen substantial investment. Consequently, it has experienced many problems, such as traffic congestion, unsustainable energy use, and overloaded urban infrastructure. Growing road congestion generates social costs at the local and regional level, which includes related pollution and road accidents.

Furthermore, transportation is the major determinant of logistics environmental performance, due to the consumption of considerable amounts of energy required for the transportation of construction materials and the associated large amount of emissions generated. Two general approaches to reduce the environmental impact of industry identified in the logistics literature are to either introduce more energy efficient technology, or to organise logistics in a different way. Environmental friendly logistics structures are characterised by fewer movements, less handling, shorter transportation distance, or direct shipping routes and better utilisation.

The aim of logistics customer service is to ensure that construction materials are appropriate and available for construction operations. Thus, service related factors affecting vehicle movements are planning, training, loading and logistics management strategy. Due to the inherent fragmentation of the construction industry, a lack of coordination and communication, inefficient planning and on-site logistics, perpetuate the problem of logistics in the construction industry. The early and accurate scheduling of materials planned to a time schedule and keyed to the master plan for material delivery is highly desirable from the project management point of view. However, frequently this is unachievable either because there is not enough detail information at the commencement of a contract, or there are considerable variations during the contract delivery.

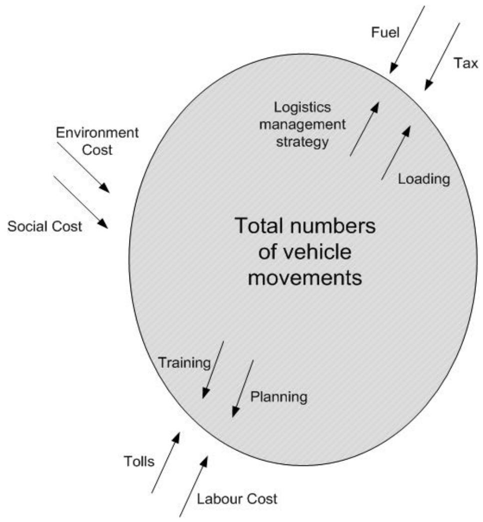


**Figure 1: Factors affecting the construction logistic**

Accordingly, a model encompassed these essential factors that have impacts on the logistics efficiency is presented in Figure 1. The total numbers of vehicle movements are represented by the size (volume) of the balloon in Figure 1. Internal 'pressure' to increase vehicle movements comes from a range of factors such as poor training and planning, inefficient loading, and logistics management strategy. The factors that will reduce the truck movements to the site (and thus the volume of the balloon in the model) are high fuel price, levies, road tolls, labour cost, environment and social costs. If these factors are tuned to its optimism in accordance with the site condition and supply chain members' circumstances, the total numbers of vehicle movements are expected to be the minimum. Consequently, the effectiveness of construction logistics to the site should be maximised. The model thus provides a guide for data collection to investigate possible interventions to improve logistics efficiency.

# Research methodology

The guiding purpose of this study was to gain detailed understanding of the practice and obstacles in efficient construction logistics at the operational level. The focus of the work is on identification of main contributors to inefficiency in construction logistics. It also seeks to recognise the "challenges" to efficiency, as well as questions of how and such behaviour occurs. The emergence of how and why questions resulted in choosing interviews, documents, and observation as the research method, whey they were seen as superior to other methods with the stated objective. The studies in this work were carried out as case study with a qualitative and quantitative approach. The purpose was to enhance knowledge of how vehicle movements process works, what problems arise, why the problems arise in the studied project and how intrinsic and extrinsic interventions could increase its efficiency. Case studies are appropriate when the research problem requires understanding of complex phenomena that are not controlled by the researcher and when the research questions have a how and why nature (Yin, 2009).

It is important to select a critical case that can explicitly demonstrate the “how-problem” (Yin, 2003). In the first place, a commercial project in the largest city by population and area in NZ reflects typical problematic issues for construction logistics. The case study described in this paper has been developed from a commercial project hosted by AUT University. The construction site was located in central Auckland, implying special requirements in terms of logistics and physical distribution. Auckland is notable for it “Urban Sprawl” (Dixon and Dupuis, 2003, Ministry of the Environment, 2005). The city also has a substantial reliance on road transportation since public transport system has historically not seen substantial investment. The $100 million project consists of a 13 level tower block with roof top plant room surrounded with lecture theatre and student facility. The new construction integrates several existing buildings on campus. The construction has three stages: ground works, structure, and fit-out. The contract was fixed price, with the client being allowed certain flexibility in the scope without extra charge.

Also, the firm acting as main contractor of the project is the leading contracting organisation by company capitalisation and volume of work in NZ. Maintaining a dominant position in the construction industry implies either cost advantage or technical advantage over the remainder of the market. As such it may be deduced that this contractor must therefore represent NZ “Best Practice”. It was anticipated that this practice may approximate World Class, but may not actually achieve it. However, it is reasonable to assume that the company represents the best competitiveness that NZ has to offer in this area.

Boundary issues, such as what is and what is not part of the case, are important to address in all case studies (Dubois and Gadde, 2002). Since the research purpose is to develop the knowledge of construction logistics at the operational level, the study covers the process from planning on site through order and logistics to the materials on the construction site. In designing the case study, the firms from the main contractor to subcontractors and their suppliers were included. The main contractor had a 48 first tier subcontractors working in the case study project. These subcontractors usually had three to seven subcontractors or suppliers working for them respectively.

Special attention has been paid to the numbers and patterns of vehicle movements, since it is expected that appropriate interventions to improve construction logistics can be identified through analysing these elements.

## Data collection

Data were collected through interviews with main contractor, subcontractors and their suppliers and on-site observations. The model of “Factors affecting construction logistics”, as shown in Figure 1, was used as guidance for interviews. Questions areas about each factor were probed. The interview respondents were practitioners involving procurement of materials and plants process in the supply chains of the studied case. The procurement process includes ordering, planning, supplying and delivering the materials to the site. The respondents were chosen for their specific knowledge and position to provide relevant information about the process.

Interview participants’ characteristics are summarised in Table 2. The participants were categorised into three groups: main contractor (5.6%), subcontractor (68.5%), and material supplier (25.9%). A majority of participants were from the first tier subcontractor list. Material supplier firms were chosen from the major suppliers of the first tier subcontractors.

| Characteristics | Category | Number | Percentage |
|---|---|---|---|
| Participants | Main contractor | 3 | 5.6% |
| | Subcontractor | 37 | 68.5% |
| | Material supplier | 14 | 25.9% |
| Total | | 54 | |

**Table 2: Participants’ profile**

The objective of the interviews was to enhance knowledge of how the process appears and how the organisation was arranged. In addition, the interviews focused on how the contractors relates to the other ones in the supply chain. These interviews provided insight into occurrences of challenges and the causes of inefficiency in construction logistics. The participants were all skilled in their particular fields, but the process and vehicle delivery pattern of their firms’ deliveries was not well documented. This lack of documentation made systematic analysis problematic. Therefore, the need for on-site observation of vehicle movements emerged, as supply chain levels closer to the project level tend to be more adept at retaining knowledge of and experiencing with issues at the operational level than those removed from project level operations

On-site observations were performed during construction on-site, as well as during weekly coordination meetings held between the main contractor and its subcontractors. These were documented through notes, photographs and audio recording. The depicted scenes give an opportunity for participants to reflect on specific situations in retrospect. As noted by Scott and Garner (2013), observing behaviour gives opportunities to make sense of a larger context and draw conclusions that the individual subjects might have difficulty notice. Extensive observations were also made on the construction site to confirm information given by the respondents, the on-site observations also enabled gathering of information that the participants were unable or unwilling to fully disclose in interviews. These data were analysed as a whole, reduced to focus on the main questions of the paper and then presented in a reduced from. The causes of problems were analysed, and generalisation of the causes were carried out using principles of supply chain management.

## Key Findings

The main aim of this paper was to identify the main contributors to inefficiency and to recognise the questions of how these challenges occur. The key findings section of the paper is focused on presenting the nature of these critical factors, and the issues affecting construction logistics efficiency as found in the studied case.

### Just-in-time or Just-in-case

In the case study project, it is observed that logistics efficiency varies significantly between different materials in accordance with their supply chains. Depending on the characteristics, construction materials can be categorised into four representative supply chains, make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO), and design-to-order (DTO) (Stavrulaki and Davis, 2010). It was observed that the order driven "pull" type materials (MTO, ATO, DTO) were delivered with high efficiency, normally just-in-time (JIT). However, materials falling in the manufacturing driven "push" category (MTS) were delivered at relatively low efficiency.

Since the main contractor was not involved in any material procurement, therefore, the question relating to material delivery strategy were answered by the participants from subcontractor and material supplier categories. Table 3 suggests that 41.2% of firms delivered construction materials and plant in an ad hoc manner, while 21.6% of the firms delivered JIT. 37.3% of the participants mentioned that their deliveries were done both JIT and ad hoc, depending on the materials.

| Delivery Strategy<br>Participant category | Just-in-time | Delivery ad hoc | Hybrid |
|---|---|---|---|
| Subcontractor | 17.6% | 29.4% | 25.5% |
| Material Supplier | 3.9% | 11.8% | 11.8% |
| Total | 21.6% | 41.2% | 37.3% |

**Table 3: Material delivery strategy**

The main reason of high efficiency of "pull" type construction materials delivery is to avoid damages and losses on the site. Building materials often require large storage capacity, often unavailable on site. Storage facilities on site are generally temporary structures or compounds with limited protection from weather conditions. The conditions in which the materials are stored often leads to damage from ingress of water and movement of people, plant and equipment. Theft of stored materials is also not uncommon. This damage and loss of material from site, is euphemistically called "shrinkage". For materials in the MTO, ATO and DTO categories, long lead-times are often normal. If shrinkage does happen, it will cause significant delay to the project programme. Therefore, the majority of items in the "pull" category, for example structural steel and curtain wall panels, were delivered in JIT manner to avoid the prolong storage on site and possible damage. These materials were coordinated for delivery mainly during the weekly coordination meetings, and a confirmed delivery window was allocated by the site manager to secure crane availability. Thus, these construction materials were delivered with reasonable efficiency.

For generic materials that were ready "off the shelf", such as paint, tiles, and water proof membrane, they were ordered just-in-case (JIC). There was therefore a lack of coordination between project managers and their foremen. Project managers asked their foremen to check on the status of materials. Foremen normally were not sure either about the quantity stocked on the site or/and the quantity needed for next two to three days. They relied solely on intuition and experience with previous shipments. To "play safe", the site foremen usually ordered more than they really needed on the site. Also, the expectation of shrinkage made over-ordering a normal practice to avoid shortage and delay, which cause substantial extra costs. Most construction material suppliers and/or build merchants are familiar with JIC ordering. Thus, materials were often delivered to site at a level less than that actually ordered. Suppliers take the position that the contractor does not need the amount ordered. Furthermore the process by which order volumes were established and communicated was at best rudimentary. Through on-site observation, it was noticed that at several occasions, some foremen or supervisors listed the needed materials on any available piece of paper or cardboard without giving full details. These lists were normally faxed to the material suppliers as they were, or photocopied first. Consequently, some critical information was missed through the ordering process, which in turn eventually resulted in an absence of accountability regarding the availability of materials. As a result, these material deliveries were undertaken on an ad hoc basis, with more truck movements relative to the small amounts delivered due to inaccurate order communication.

## Planning

From site observation, it was noticed that there was a lack of planning at many levels. At the main contract level, planning of material delivery was limited. The main contractor normally managed the critical resources of carnage and the loading bay. At the observed site, the management of these critical logistical resources was minimal. For crane management, the main contractor used a white board to allocate the operating time for all subcontractors and their suppliers. Subcontractors and suppliers rang the office to book the crane, the time slot was therefore marked on the white board to avoid double booking. However, there was no monitoring of the booking. No estimate was made as to whether the time length booked was adequate for the delivery schedule. As a consequence, the material as delivered often required substantially more or less time to transfer to the allocated storage/workstation. If the delivery was over the booking time, other trucks would have to wait at the loading bay resulting in non-productive time "waste". Sometimes, the queuing trucks had to either wait on adjacent city roads, or alternatively drive around the CBD to wait for an opportunity to offload materials and/or pick up waste. This also reflected that the main contractor had no control of loading bay.

In the case study, it was also found that there was a lack of planning of material deliveries and unloading among the subcontractors and their site workforce. Since there were no formal procedures for purchasing, project managers and/or site supervisors of the subcontractors have to deal with different procedures in ordering materials through different channels. It was also noticed that the suppliers rarely gave feedback to the site personnel on whether they can deliver the needed materials. Often materials were delivered to site with as little as ten minutes of notice time. This created significant disturbance and wasted time, as managers had to organise an ad hoc team to offload and received the delivered materials. These unplanned deliveries constantly created scheduling conflicts and inefficient loading.

The interview results suggest that the predominant emphasis of material planning is to optimise the material delivery, as shown in Table 4. Little attention has been paid to logistics efficiency. The industry only recognises the final leg of materials delivery as being important. Most participants (83.3%) believe that the ultimate aim of construction logistics is to eliminate delay in material delivery. The main reason for this position being is that the successfulness of a project is normally judged by how well the project is able to deliver against its objectives of building to budget, programme and quality. Project management primarily uses the concept of time management to monitor the programme schedule. Therefore a material delivery delay to a task on the critical path is immediately interpreted as a delay for the whole project. Thus it can be rationalised why the "materials delivery" focus of the respondents is as it is. Furthermore, there is no commitment to providing efficient logistics at the management level of either the main contractor or the subcontractors. The explanation given by the participants of such behaviour is that the transportation costs were not managed or measured as an important performance target. This may reflect the fact that prices of materials are quoted in the form of "as delivered". Therefore, the additional costs of more frequent, low efficiency movements are largely hidden from both clients and the contractors. Indeed there is no direct incentivisation to monitor a KPI that is invisible and unregarded.

| | Main Contractor | Subcontractor | Material Supplier | Total | % |
|---|---|---|---|---|---|
| Improve logistics efficiency | 1 | 7 | 3 | 11 | 20.4% |
| Optimise purchasing planning | 2 | 29 | 12 | 43 | 79.6% |
| Reduce waste of material handling | 0 | 3 | 1 | 4 | 7.4% |
| Reduce material delivery delay | 3 | 32 | 12 | 47 | 87.0% |
| Optimise site planning | 2 | 6 | 3 | 11 | 20.4% |

**Table 4: Understanding of material planning**

## Truck movement patterns

For the period of construction, the total number of vehicle movements to the observed site was approximately 6,300. Figure 2 illustrates deliveries occurring throughout the day following no specific pattern. The histogram appears to be multimodal a skewed normal. The histogram also shows that almost one fifth of arrivals occur before 8:00 am while 55.8% of the arrivals occur during either in the early morning (08:00am to 10:00am) or early afternoon (12:00am to 2:00pm). The diagram illustrates that the vehicle arrival times produce a smooth distribution. Indeed, vehicles arrivals on delivery points start after 6 and increase rapidly before peaking at the time interval between 9am to 10am. Then, taper down as time passes creating a strongly skewed distribution. In the studied project, 67.8% of delivers took place before midday.

The deliveries were most carried out from 8am to 11am (38.2%), as illustrated in Figure 2, which parallels to the peak time of city traffic. These truck movements not only put extra burden on the existing saturated city traffic, but also reduce logistics efficiency. Some truck drivers complained about tight space for manoeuvring in the city roads during peak traffic. These construction vehicle movements impose negative social and environmental impact by adding to the problem of congestion and environmental pollution.

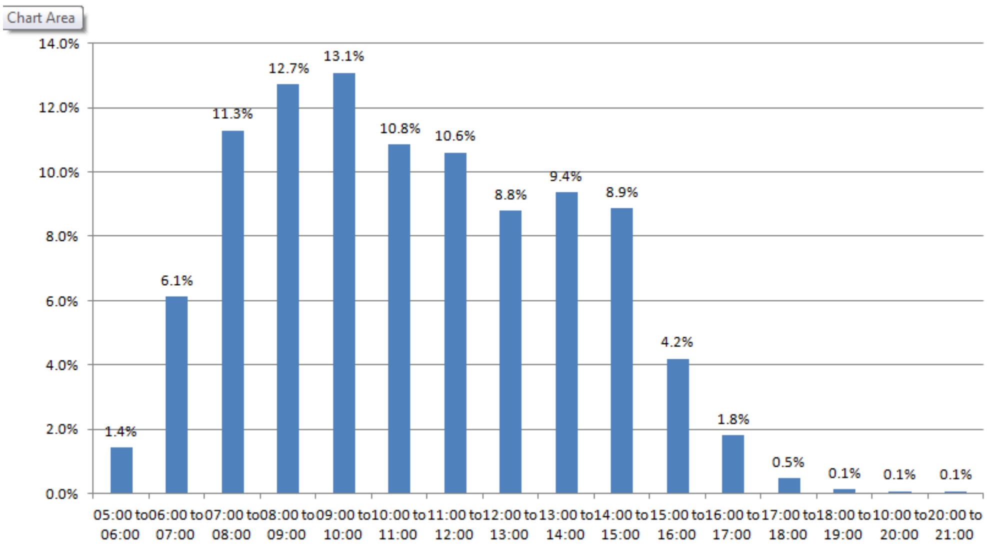


**Figure 2: Truck delivery time**

It can also be seen that being a heavily "inbound" industry, significant numbers of vehicles (86.9%) were unloading materials or equipment at the site. High percentage of these vehicles (more than 70%) drove away from the site unloaded. Furthermore, the data of vehicle movements show that in terms of transport distribution, of all vehicle movements observed, 80.1% were classified as material delivery and 18.9% as construction and demolition (C&D) waste removal. The ratio approximately to 4.2 materials delivery journeys to one waste removal journey. It was observed that the logistics of building materials and C&D waste were not integrated and the vehicle movements for both material delivery and C&D waste removal were sub-optimal. The field observation established that significant amount of materials delivery vehicle movements (more than 45%) were empty runs to their return journey and 35% of C&D waste removal vehicle movements were empty runs on their forward journey. Compare to the similar study carried out in South Africa (Shakantu et al., 2008), it appears that the ratio at the observed site is higher than the counterparts in SA. During the construction process, some of the waste removal companies arrived site with empty bins and exchanged the filled bins back to either the landfills or company recycle plants. It could be speculated that the implementation of reverse logistics strategy is the reason of a higher ratio. However, the empty runs for both delivery and waste removal vehicles are largely the result of the failure by the construction industry to back-haul. Thus it in turn highlights the potential for integration of materials and waste, which would ultimately improve the logistics efficiency.

Compared to the construction programme, it could be seen that the numbers of delivery vehicle and its type alter accordingly. During the period of ground works and structure, large percentages of vehicles (77.2%) into the construction site were heavy vehicles with more than three axles. However, in the fit-out stage, it is observed that smaller vehicles (vans and utilities) arrived more often (41%) than previous two stages (22%). Provided that most of the materials used in the ground and structure stages were MTO and DTO with heavy volume, large vehicles were employed to deliver with reasonable efficiency. At the fit-out stage, materials were delivered in smaller amounts but more frequently. It in turn reflects the material ordering of JIT and JIC.

# Discussion

As the main aim of the paper was to identify the main contributors to inefficiency and to propose interventions for improvement, considering this increased knowledge about logistics efficiency of the construction industry was essential to improve its performance.

## Main contributions to inefficiency

The major problems observed through analysing the data collected were:

1) Logistics efficiency varies in accordance with materials supply chain characteristics.
2) Suboptimal planning of material delivery and unloading.
3) Delivery construction materials during peak hours, therefore adding to congestion.

4) Inadequacy of material delivery and C&D waste integration.

Factors affecting the construction logistics, cost related factors, both monetary and non-monetary factors are not measured and largely ignored, especially the possible environmental and/or social impact occurred by the truck movement, (see Figure 1). This is reflected in the peak hour delivery and inadequate integration of delivery and C&D waste removals. Factors in the service related sector were insufficiently managed in the observed site. Materials that are order driven were planned and unloaded more efficiently than those manufacturing driven. Because of this, it was observed on the studied case that inadequate planning of material delivery and unloading hindered the project progress and caused inefficiency.

Furthermore, the number of vehicle movements is not formally monitored at construction sites in NZ. This important indicator of logistics efficiency is normally only used for the purpose of a traffic management application to the local council at the start of the project. The accuracy of this estimated number is not checked by the council either. Indeed the only reason that this study was possible was by site personnel making a special effort to monitor movements on behalf of the researcher.

These findings are related to understanding and implementing CSCM. It is noticed that there is inadequate awareness of CSCM and logistics efficiency, confirming that the critical part of operational tools and techniques for effective CSCM is not well recognised or understood (Ying et al., 2013). Limited implementation of CSCM is largely due to lack of commitment from the management level and skills at the operational level. It is obvious that these possible improved areas did not attract enough attention from the practitioners. From the research, there is a lack of transparency in costs throughout the construction process. Decisions on choosing suppliers and quantities of materials are made by evaluating the quoted “cost as delivered” per unit. Since the cost of transportation is embodied in the delivery cost, there is no way of identifying how much cost is attributed by suboptimal transport planning. Unless there is a differentiation between the elemental costs, it is difficult to identify who benefits from an effective logistics system. Those who may be required to do things differently do not necessary gain benefits from changing to an optimal transportation planning model. None of the interview respondents were even slightly aware of the quantum of money that was embodied in the transportation of materials to site, which could be 39 to 58% of total logistics costs (Coyle et al., 2003).

At present the lack of knowledge is masked by lack of immediacy in recognising that there is a problem at all. It is hard to solve a problem that the industry does not recognise that it has. As noted by LeBoeuf (1985), "what gets measured gets done. What gets measured and fed back gets done well. What gets rewarded gets repeated", if the costs of construction logistics that is embedded in the "material price" are not addressed and the importance of the vehicle movements as a pivotal indicator not recognised, there will be limited opportunity to engage the industry to improve construction logistics performance.

## Interventions for improving logistics efficiency

As discussed in the previous section, the success of construction project depends on the coordination of the on-site and external logistics. The numbers of vehicle movements is therefore capable to interpret the competence of this coordination by providing a rational base line for loading bay and crane management to facilitate logistics efficiency. As a result, the numbers of vehicle movements, in a way, links transportation, inventory and warehousing that are essential elements of effective construction logistics. However, the results of the study suggest that little attention has been paid to vehicle movements and it was not measured and managed by the practitioners.

To change existing behaviours in the industry, according to the Diffusion of Innovation (DoI) theory, the process begins with the recognition of a problem or need and through five steps: knowledge, persuasion, decision, implementation and confirmation (Rogers, 2003). The case study findings strongly emphasise the need for interventions building on the fact that the potential benefits to the industry are obvious.

The interventions can be categorised into intrinsic and extrinsic ones. The intrinsic interventions shall mainly focus on increasing the profits by improving construction logistics performance, while the extrinsic prompt the awareness of logistics costs and its efficiency.

For most practitioners, the key of improving construction logistics performance is to possess two abilities in order to operate efficient construction logistics. First, they must understand what are the available tools and techniques. Secondly, they must understand the circumstances they are in. It is not only a difficult task but also a critical one as certain tools and techniques are likely to be only appropriated under certain circumstance. The research results suggest that the industry practitioners do not recognise the importance of either construction logistics or material planning.

In addition, every construction site has a different set of constraints that affect construction logistics. The nature of the constrains will depend on a number of circumstances, for example, the location of the site, the project scope, the working environment, the neighbourhood adjunct to the site, and the social policy of the client and the local government (Sullivan et al., 2011). The delivery of equipment and materials may be affected by factors on and off-site, such as: Physical constraints, including the traffic systems around site (one-way systems), the lack of storage space, and restricted access due to existing structures. Indeed, the tools and techniques that are likely to be required will have to change in accordance with the circumstances change (Cox and Ireland, 1993). Therefore, the intrinsic interventions are to implement appropriate tools and techniques that suit the site circumstances. To achieve this, commitment of management level and knowledge of operational staff is necessity.

However, previous research executed in New Zealand (Ying et al., 2013) does not present a positive environment to apply proposed intrinsic interventions. The absence of formal education and training at the management and operational level in the NZ construction industry is considered to be a key aspect of lack of theoretical understanding in CSCM and construction logistics. Thus, developing training programmes targeting both levels respectively is critical in implementing intrinsic interventions. The management level needs to understand the essence of CSCM philosophy and commit the firms to improve logistics efficiency. The training programmes for operational staff shall concentrate on intensifying planning and ordering process. These training courses would not only benefit the individuals who gain the knowledge and practice in daily work, also benefit the employed firms by reducing logistics costs. It would eventually benefit the industry as a whole for increasing logistics efficiency among various supply chains.

As noticed in the case study, the social and environmental impacts caused by construction logistics were largely unrecognised. It is evident that the NZ construction industry has not been showing very much concern about the environmental issues. Therefore, extrinsic interventions involving government interference is necessary. As, without it, there appears to be less incentive for the private sector to invest and/or investigate improved logistics methods. The main government intervention would be to bring the awareness of the hidden transportation costs embedded in material costs. This might be achieved in various ways by creating conditions for government setting the boundaries for construction logistics performance using DoI approaches. Knowledge of CSCM and logistics efficiency shall be promoted by central and local government to senior management level in the industry. Persuasions of improving performance can be done through legislation by phasing or introducing traffic management costs to recover social and environmental costs so that vehicle movements would be managed to avoid unnecessary extra costs. To set a model of best performance, it would be endorsed by decisions of setting traffic minimising plan or traffic logistics plan as one of non-price attributes for government projects procurement. It can also be reinforced in making logistics planning as an explicit part in Resource Management Consent application, especially for any projects in the CBD area. Leading by practice, the importance of improving construction logistics may be understood by the construction industry and therefore eventually change the existing behaviours.

## Conclusion

Using the numbers of vehicle movements as guidance for data collection, the evidence provided in the case study demonstrates significant inefficiency in construction industry logistics. The main problems observed on site were low logistics efficiency for manufacturing driven materials, and suboptimal planning of material delivery and unloading. The truck movement patterns suggest that deliveries occurred mainly through morning peak hours. The patterns also indicate the inadequacy of material delivery and C&D waste integration.

Through interviews involving construction suppliers and subcontractors, the main contributors to inefficient construction logistics found in the case study were:

1. Factors affecting construction logistics efficiency are either inadequately managed or overlooked.
2. No attention was paid to the numbers of vehicle movement itself.
3. Insufficient awareness of CSCM and logistics efficiency.
4. Unawareness of logistics costs due to material costs quoted “as delivery”.

This study then proposes both intrinsic and extrinsic interventions to address the obstacles in efficient construction logistics. By introducing these interventions, it is conceivable that construction activities are conducted more sustainably. This can be achieved by maintaining the materials flow into sites while reducing the total numbers of vehicle movements.

Most notably, this is the first significant study to our knowledge to investigate construction logistics efficiency using the numbers of vehicle movements. It is evident that managing the numbers of vehicle movements can address the challenges in planning, loading, material ordering and other essential aspects in construction logistics and in turn bring a sizeable profit increases to various members in supply chains. The case study provides information about main areas of interventions necessary to enhance construction logistics. These interventions offer plausible explanations in improving logistics efficiency through optimising transportation movements to the construction site.

The work presented here focuses on understudying “what” factors are affecting the numbers of vehicle transits and “how to” agenda of procedural actions plans. It provides a starting point to begin the task of developing predictive simulations of the likely effects of various factors. Thus, further research will aim to normalise the number of vehicle movements in accordance with the characteristics of construction projects, such as site condition, construction character, and material quantities. Once this indicator can be quantified in certain accuracy, it can not only assist the practitioners to optimal material deliveries to the site, but also be used as benchmark to evaluate logistics efficiency.

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