Supply Chain Management Driven Logistics Efficiency in the New Zealand Construction Sector

Kamal Dhawan

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Auckland University of Technology
Faculty of Design and Creative Technologies
School of Future Environments
Built Environment Engineering Department

Abstract

New Zealand (NZ) construction typifies fragmentation, with MSMEs being the primary sectoral component. 65.5% of the approximately 67000 operating businesses are sole trading operators, while 32.5% are 'small' (up to 19 employees). The construction supply chain (CSC) is extensive and trans-disciplinary, therefore, prone to inefficiencies at the boundaries between its component segments and domains, further accentuated by the project-centric delivery paradigm. As a corollary, there exists a significant opportunity for consolidation and improved efficiency through de-fragmentation. This study aims at illustrating the potential for improving efficiencies and the associated impacts through the application of supply chain management principles.

Vertical integration of the CSC and its management from the supplier-end vis-à-vis the project perspective are acknowledged de-fragmentation strategies. While component elements remain individually independent in terms of ownership, their management is integrated above the tactical level of the supply chain. The outcomes are improved operational philosophy and higher efficiencies. Quantifying the impacts of vertical integration, however, is challenging due to the lack of tangibility. This can be effectively overcome by focussing on the CSC's transport component and its quantifiable parameters.

The NZ construction sector presents certain narrow segments where vertical integration has been effectively implemented. The study investigates transport operations in the context of plasterboard, where the distribution function has first been integrated as an extension of manufacturing, and then outsourced on a second-party logistics (2PL) model.

To accord tangibility to the outcomes of this 'forward vertical integration', the study examines operational transport data over a three-month period to quantify improved performance compared to the conventional (fragmented) echeloned CSC. It also demonstrates operations research-based planning as a tool for further resource optimisation, discussing potential sustainability outcomes. Finally, qualitative methods enable substantiation of data analysis to understand the 'whys' and validate tangible implementation pathways from research outcomes.

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List of Abbreviations/Terms

Abbreviation/Term	**Expanded form**
2PL	Second Party Logistics
3PL	Third Party Logistics
4PL	Fourth Party Logistics
ABC	Activity Based Counting
ALCOA	Attributable Legible Contemporaneous Original
Ara Ake	A government funded entity set up to develop clean energy technologies for New Zealand
A-S-I(-F)	Avoid-Shift-Improve(-Fuel) framework
ATO	Assemble-to-Order
AUAS	Amsterdam University of Applied Sciences
AUT	Auckland University of Technology
AUTEC	Auckland University of Technology Ethics Committee
B2B	Business to Business
B2C	Business to Customer
BCA	Building Consent Authority
BE	Built Environment
BM	Builders’ Merchant
BRANZ	Building Research Association New Zealand Ltd.
BRE	Building Research Establishment (UK)
BU	Business Unit
C&DW	Construction and Demolition Waste
CCC	Climate Change Commission (New Zealand)
CCNZ	Commerce Commission New Zealand
CIVIC	Construction in the Vicinities Innovative Co-creation
CLM	Council of Logistics Management
CLSC	Closed Loop Supply Chain
CO2-e	Carbon-dioxide equivalent (measure of GHGs)
CSC	Construction Supply Chain
CSCM	Construction Supply Chain Management
CSCMP	Council for Supply Chain Management Professionals
DC	Distribution Centre
DCT	(Faculty of) Design and Creative Technologies, Auckland University of Technology
DfD	Design for Deconstruction

DfX	Design for X (where X is a downstream impact or process)
DG	Director General
DP	Decoupling Point
DRP	Distribution Requirements Planning
DTS	Direct-to-Site
EOL	End-of-Life
ERP	Enterprise Resource Planning
ETO	Engineer-to-Order
EU	European Union
FL	Forward Logistics
FTL	Full Truck Load
GC	General Contractor
GDP	Gross Domestic Product
GHG	Greenhouse Gas
Hapū (Māori)	Clan; unit of hundred to several hundred people of several families or extended families in a defined portion of tribal territory
HDV	Heavy Delivery Vehicle
ICT	Information and Communication Technology
IEA	International Energy Agency
IF-TOLD	Intermodal, Fuel, Technological, Operational, Logistical, Demand
IPCC	Intergovernmental Panel on Climate Change (UN)
Iwi (Māori)	Māori tribe, usually consisting of several related hapū
JIT	Just-in-Time
LAN	Local Area Network
LCC	Life Cycle Cost
LP	Linear Programming
LPG	Liquefied Petroleum Gas
LSP	Logistics Service Provider
LTL	Less-than-Truckload
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MBIE	Ministry of Business, Innovation and Employment, New Zealand Government
MD	Merchant Delivery
MfE	Ministry for the Environment, New Zealand Government
MiMiC	Minimising impact of construction Material flows in cities: Innovative Co-Creation
MoT	Ministry of Transport, New Zealand Government

MSCM	Manufacturing Supply Chain Management
MSE	Mean Squared Error
MSME	Micro, Small, and Medium Enterprise
MTO	Make-to-Order
MTS	Make-to-Stock
NPA	Non-price Attribute
OECD	Organisation for Economic Cooperation and Development
PM	Project Management
PPP	Public Private Partnership
Q-Q	Quantile-Quantile (plot)
R-squared	Co-efficient of Determination
RDC	Regional Distribution Centre
RL	Reverse Logistics
RMSE	Root Mean Squared Error
ROI	Return on Investment
ROS	Return on Sales
RPDA	Relational Project Delivery Arrangement
SACTRA	Standing Advisory Committee on Trunk Road Assessment (UK)
SC	Supply Chain
SCF	Supply Chain Forum
SCM	Supply Chain management
SMAPE	Symmetric Mean Absolute Percentage Error
SPSS	Statistical Package for Social Sciences (IBM)
StatsNZ	Statistics New Zealand
TCO	Total Cost of Ownership
TIMBER	Technology Infrastructure Market Behaviour Energy Regulation
TSP	Travelling Salesman Problem
UFT	Urban Freight Transport
UN DESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
VI	Vertical Integration
VOC	Volatile Organic Compounds
VRP	Vehicle Routing Problem
WAN	Wide Area Network
WHO	World Health Organisation
WM	Waste Management
WRI	World Resources Institute

Awards

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DCT contestable funding (2022-2023) - ‘Smart mobility as a sustainability enabler for New Zealand’

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which, to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

27 January 2023

Signature

Date

Co-Authored Works

Publication of book titled ‘Sustainability and Construction: The Global Context and the New Zealand Perspective’ contracted with Elsevier. The book has been co-authored with Professor John E. Tookey, Professor Ali GhaffarianHoseini, and Associate Professor Amirhosein GhaffarianHoseini.

A list of co-authored journal and conference publications during the period of research is at Appendix G.

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Ethics Approval

Ethics approval for this research was accorded by AUTEC as follows: -

- Initial approval – Vide memo number 20/272 dated 11 September 2020
- First amendment – Vide memo number 20/272 dated 22 March 2021
- Second Amendment – Vide memo number 20/272 dated 10 March 2022

Copies of the memos are at Appendix A.

Chapter 1 Introduction and Rationale for the Study

1.1 Background

2050 will see circa 68% of the world's population living in urban areas, from 55% in 2018 (UN DESA, 2019). Urban population growth increases the demand for construction, renovation, and repair of built assets. The built environment (BE) needs to keep up with developing standards and increasing visitors, residents, and urban functions.

1.2 The Construction Industry: A Preamble

Du-Plessis (2002) defines construction as follows: -

> The process for the realisation of human settlements and the creation of infrastructure that supports development, including extraction and beneficiation of raw materials, their conversion into construction materials and components, the implementation of construction from feasibility to deconstruction, and operation and management of the built environment (p. 2)

Typically, 13% of the global GDP comes from construction. In addition, construction presents employment opportunities, produces and upgrades infrastructure, and supports contributing business streams (McKinsey & Company, 2017; Shakantu *et al*., 2008). Figure 1.1 illustrates the construction value chain, while Figure 1.2 presents the actors and sectors involved.

Figure 1.1

The construction value chain

Note. (World Resources Institute, India, 2021)

Figure 1.2

Sectors and actors associated with construction

Note. (Hürlimann *et al.*, 2022)

A project-based industry, construction is peripatetic; therefore, it moves to where the work is (Shakantu *et al.*, 2008; Vrijhoef & Koskela, 2000; Wegelius-Lehtonen, 2001). It generates infrastructure (the end product) where it is needed (Ekeskär & Rudberg, 2016; Janné & Fredriksson, 2019) and requires time-bound delivery and removal of materials and resources from each construction site (Lindén and Josephson, 2013; Quak *et al.*, 2011 (in Dutch), as cited in Balm & Ploos van Amstel, 2017; Shakantu & Emuze, 2012).

This entails the building sector moving into populated urban regions, such as big cities and urban areas. Construction projects exhibit individuality in terms of uniqueness, unlike manufacturing which standardises. From a project bespoke SC converging on to the construction site to direct all materials to customised in situ operations centred around a single 'product' (construction project). Repetitive reconfiguration of project organisations during various phases (e.g., design, site preparation, construction, and commissioning) creates temporary SCs. The CSC is project bespoke, peculiar to the project and the involved actors, with minimal standardisation (DG MOVE European Commission, 2012; Dubois & Gadde, 2002b; Guerlain *et al.*, 2019b; Janné & Fredriksson, 2019; Koskela, 1992; Naismith *et al.*, 2016; Seth *et al.*, 2018; Voordijk, 2000; Vrijhoef & Koskela, 2000; Wegelius-Lehtonen, 2001; Ying *et al.*, 2013, 2014). Therefore, each project exhibits a logistical pattern customised to its operations at a given time in its lifecycle.

Despite increasing competition and economic demands, most construction enterprises operate on precedence without a coherent business strategy or procedure. Processes do not exhibit effective integration and are typically not based on SCM best practices. An antagonistic relationship results from a heavy dependence on contractual penalties rather than participants agreeing on techniques for accomplishing sound financial objectives. Such operational approaches invariably produce a competitive, possibly hostile, and transactional profit-generating environment, fundamentally damaging the project through discord and litigation.

Discouraging responsible proponents, it attracts bidders who want to win at any cost. Anomalies lead to adversity in working relationships, increased costs of transactions, and encourage a 'best-for-individual' as opposed to 'best-for-project' culture (Cox & Ireland, 2002; Dubois & Gadde, 2002b).

The construction industry is intrinsically fragmented, hence, individualistic. The focus of involved parties lies on the achievement of individual objectives, and maximisation of their margins, without consideration for consequences to other participants or to the project itself (Ekeskär & Rudberg, 2016; Fernandes *et al*., 2017; Naismith *et al*., 2016; Navarro-Correcher *et al*., 2018; Tiwari *et al*., 2014; Voordijk, 2000). Fragmentation occurs at two levels, i.e., industry- or company-level (owing to firm segregation) and project-level (because of disintegrated construction processes and entities) (Alashwal & Fong, 2015).

Hierarchical boundaries between functional units create a third level, which is negligible due to the comparatively deeper process fragmentation. While intra-organisational borders may be unimportant in terms of fragmentation, the project envelope surrounding most project environments has some boundaries that have a substantial impact. These are project organisation limits (expertise, hierarchy, and culture), as well as project management (PM) boundaries (knowledge, action, and social) (Alashwal & Abdul-Rahman, n.d.). Complexity of projects, demands on delivery, high specialisation, activities localised on-site, regulation, complexity of services, and segmentation of the market contribute to fragmentation (Alashwal & Fong, 2015).

Entities and processes are the two main components of fragmentation. The ‘entities’ component entails disintegrated specialisation, situated knowledge, and the inability of specialists to collaborate effectively, whereas the ‘processes’ component disaggregates construction into multiple stages *viz* conception, design and planning, construction, operation and maintenance, renovation/refurbishment, and disposal) (Alashwal & Abdul-Rahman, n.d.).

Specialisation in the project-based delivery model exacerbates fragmentation due to stakeholders/actor diversity, design being delineated from actual construction, professional insularity, cumbersome hierarchies and systems for executing projects, aggressive tendering, disjointed procedures, project organisations, and combative interactions (Dubois & Gadde, 2002b; Egan, 1998; Fernandes *et al*., 2017; Smith *et al*., 2004; Wegelius-Lehtonen, 2001) within the enveloping project-based delivery model. Fragmentation in project-based delivery manifests in three dimensions, i.e., *Horizontally, Vertically*, and *Longitudinally* (Jones *et al*., 2021; Shakantu & Emuze, 2012; Sheffer & Levitt, 2012; Ying & Roberti, 2013) (Figure 1.3): -

- **Horizontal** Delivery of interdependent, supporting, or associated products and services by different specialists within or around a process stage implies the disaggregation of organisations and workforce into various disciplines, trades and crafts. These are dyadically bound through contractual relationships, which promote split incentives forming a communication/information-sharing barrier.

- **Vertical** Dissociation of firms and workforce across various project delivery stages originating from the delineation of responsibility between project phases (e.g., design, planning, process and product definition, construction, operation, and maintenance), while sequential arrangements encourage least price-based rather than value-based appointments.

- **Longitudinal** organisations manage different projects simultaneously and appoint different teams between projects, with major voids in the diffusion of knowledge and information stemming from a deficiency of effective communication, thus hindering knowledge sharing. In addition, team continuity is disrupted at the end of a project, with reassignment leading to the team members carrying away tacit, accumulated knowledge with them.

Figure 1.3

Fragmentation in the construction industry

Note. (Jones *et al*., 2021)

For a holistic perspective, construction needs to be considered at four levels *viz* on site, as the complete life cycle of the project, as a business venture and its associated domains, and as the wider process for creating human settlements (Irurah, 2001):-

- **The Site** The most common interpretation of actions leading to the realisation of a built asset site activity. At the most basic level of understanding, it can be thought of as a stage in the overall construction project life cycle.
- Upstream and downstream actions cover a broader range of challenges than those under the contractor's direct control.
- **The Project** The construction project cycle works across various key stages *viz* feasibility, design, construction, commissioning, operation, maintenance, decommissioning, life-extension/refurbishment, and disposal, with life cycle interventions forming only a small part of the scope of activities allied to it.
- **The Industry** Construction forms a sizeable part of the economy, contributing substantially to most countries' GDP and employment generation.
- Moreover, in association with sectors such as material production and distribution, transport, property, and finance, it substantially impacts society and the environment, influencing the world's character.
- *Construbusiness,* a Latin American phrase, comprehensively describes the construction industry (John *et al*., 2001).
- **The Concept** The concept of construction refers to the overall human settlement construction process, including planning, design, and implementation.

Fragmentation in construction prevents an integrated approach and continuity in work, directly influencing management philosophies and implemented business models (Balm & Ploos van Amstel, 2017; Kesidou & Sovacool, 2019).

Figure 1.4 and Figure 1.5 illustrate the manifestation of fragmentation and the market push leading to it, respectively.

Figure 1.4

The current fragmentation of the construction industry

Note. (Ribeirinho *et al*., 2020)

Figure 1.5

The market push leading to fragmentation in the construction sector

Note. (Ribeirinho *et al.,* 2020)

Extensive physical boundaries circumscribe the construction industry from materials extraction through manufacture, assembly, built asset construction, maintenance, replacement of buildings and/or their systems, waste management, disposal of individual systems, and finally, the complete building structure (Kibert, 2007). Consequently, it contributes substantially to socio-economic development, conversely exemplifying significant resource consumption as a result of its operations.

As per 2019 UN data, 35% of the world's energy consumption and 38% of global emissions are directly associated with the construction sector (UNEP, 2020), the origin being upstream (embodied, including construction related energy) (Chastas *et al*., 2016), as well as downstream (operation and maintenance) of the actual construction process.

Material use in construction is associated with significant natural resources, owing to the sector's large materials footprint. As a result, the sector has a substantial footprint in GHG emissions, energy usage, materials production, construction activities, and issues associated with waste management and reverse logistics (Construction & Demolition Waste - C&DW). Furthermore, as a result of significant resource requirements, production and consumption of building materials, and energy and resource utilisation during operation and maintenance, construction has significant sustainability impacts (World Resources Institute [WRI], 2021).

Materials and components used in construction are high-volume/low-cost compared to other industries. Therefore, in addition to transporting large quantities of materials, the industry also needs to transport equipment, machinery, the associated workforce, and the generated C&DW to, from, and between construction sites during the currency of one or more concurrent projects, and to operating bases or a new construction site on completion of one or more projects (Balm & Ploos van Amstel, 2017; DG MOVE European Commission, 2012; Shakantu *et al*., 2008; Shakantu & Emuze, 2012; Ying & Roberti, 2013).

The movement of resources is the common denominator of all construction activity. Optimisation of movement, or more broadly logistics, therefore, throws open possibilities of economisation and improvement of profitability directly, with a range of direct and indirect benefits across all sustainability dimensions (environmental, social, and economic).

1.3 The Supply Chain and its Construction Context

1.3.1 The Supply Chain

Simply put, the Supply Chain (SC) may be considered *"…a series of activities and organisations that materials move through on their journey from initial suppliers to final customers"* (Anca, 2019, p. 210). Each individual product is associated with a unique SC. The product SC may be long or short, simple or complicated, being an aggregation of involved and interconnected entities, making the service or product sought by the final customer available. The description of the SC may be in the form of a map summarising the complete journey from one part to the other through actors and establishments *viz* raw material suppliers, manufacturers, logistics hubs, service providers, transporters, wholesale facilities, retail outlets, etc. (Waters, 2009, as cited in Anca, 2019). Figure 1.6 illustrates a typical SC network.

Figure 1.6

A typical supply chain network

Note. (Lambert *et al.*, 1998)

1.3.2 The Construction Supply Chain

The structure and functioning of a construction supply chain (CSC) have certain typical characteristics: Materials directed onto the construction site through a converging SC to assemble the 'product' (the built asset) on-site; A singular product (the built asset) around which the 'manufacturing plant' is set up, unlike manufacturing where the manufacturing facility processes multiple products; A temporary and repetitively reconfiguring SC (causing fragmentation, instability, and dissociation of the design process from construction); and, A one-off and unique product, therefore, an MTO SC

(Vrijhoef & Koskela, 1999, 2000). Figure 1.7 compares the Generic, Manufacturing, and Construction SCs.

Figure 1.7

A comparison of generic, manufacturing, and construction supply chains

Note. (Behera *et al*., 2015; Vrijhoef & Koskela, 2000)

Certain factors, which emanate from the above characteristics, and substantially affect CSCs and their functioning are: The project, especially logistics are substantially client-influenced; Multiplicity of business purposes, actors, and methods fragments the SC; Varied stakeholders (clients, design consultants, construction contractors, and suppliers belonging to different organisations creates a maze of relationships including flows of information, material, services, and finances between them); An environment rife with conflict, mistrust, and profit-orientation from transactional buyer-supplier relationships; Temporarily configured organisations (project-based orientation resulting in fragmentation, adversarial relationships, and opportunistic environment); Conservative risk-driven perspectives create inertia to change in construction related organisations; The owner commences and terminates a ‘make-to-order’ (MTO) SC related to the construction project; Fragmentation leads to substantial collaboration opportunities that need to be explored; and, Cyclical demand for the artefact (built asset) as a result of its non-transportability and durability (Behera *et al*., 2015).

The CSC needs to be viewed from the perspective of the evolution of construction. During the twentieth century, construction became increasingly distributed with increasing complexity. In the twenty-first century, relationships are undergoing rapid change as a consequence of new types of buildings, evolving contracting and project delivery models, with increasing dependence of work delivery on digital infrastructure. Contracting now permits assistance for design from several parties other than designers, and evolving procurement methods permit packaging out the design effort, recognising distributed expertise across the industry to overlay it with construction. Current relationships within the construction domain have evolved from the client-architect-contractor triad into a polygon of practice, having an increasing involvement of sub-contractors in a variety of design roles through product engineering, testing, and management (Tombesi & Whyte, 2013). Figure 1.8 illustrates this transformation.

Figure 1.8

Transformation of construction practice

Note. (Tombesi & Whyte, 2011)

The increasing complexity of construction projects stems from technical difficulty (forms, functions, structures, procurement, and financial strategies), social difficulty (stakeholders and actors with competing and/or divergent objectives) and uniqueness of design (design problem, design process, and design practitioner). Combined with reducing timelines, increasing accountability, and focusing on improving working conditions, along with the evolution of delivery paradigms (e.g., Design and Build, Public Private Partnership (PPP), and Relational Project Delivery Arrangements (RPDAs), this has led to a transformation of the sector. The acquisition takes place with incomplete design, and contractors become responsible for design, construction, and facility management (Andersen *et al.*, 2005; Sebastian, 2005; Tzortzopoulos & Cooper, 2007). ‘Operational adhocracy’, on the common ground between science and art, and analysis and iteration, is the fundamental driver of construction in the current context (Sebastian, 2005).

The construction process differs fundamentally from manufacturing (where most management parallels are drawn from). Some attributes of construction design are: nonrepetitive, single execution process, an exponential increase of cost of changes along the project progress, tendency for change of requirements during design, variability in the design process (the source of the value creation), and inherent expandability of design (with the possibility of a better solution).

Different specialists deliver the design stage execution in several temporary sequences (Bølviken *et al.*, 2010). Design, executed by both in-house specialists and consultants, translates the client's aspirations into drawings and specifications. This documentation is used for procuring, manufacturing, assembling, commissioning and operating individual building elements and the project as a whole. Project requirements mentioned in the Brief are accurately interpreted through planned management of the design process, with a project plan consisting of a harmonised format of design analysis and technical verification reports (Akbiyikli & Eaton, 2011). Three types of CSCs participate in the execution phase of a construction project *viz* the **Primary SC** for delivery of material required for the actual construction process, the **Support Chain** that enables implementation of the construction process through delivery of materials, equipment, and expertise, and the **Human Resources SC** concerned with providing labour (Butković *et al.*, 2016; Cox & Ireland, 2002; Muya *et al.*, 1999).

1.3.3 Supply Chain Management

Supply Chain Management (SCM) views issues across the entire SC and not just across the adjacent entity. It aims to improve transparency, alignment, configuration, and coordination, regardless of organisational or operational boundaries (Cooper & Ellram, 1993). From its definitions, SCM has three attributes describing it: **The objective** - Collaborate across the entire system for cost-effectiveness; **The role** - Produce artefacts that conform to consumer needs; and, **The scope** - Strategic, operational, and tactical business activities, that efficiently integrate manufacturers, suppliers, wholesalers/retailers, logistics service providers (LSPs), and customers or end users (Li, 2014, as cited in Anca, 2019). As a result, individual optimisation by entities of the SC leads to sub-optimal results. In contrast, integrating goals, objectives, and activities between BUs, therefore, managing relationships, leads to an optimised SC. Within the dimensions of role, scope and objectives of SCM, it differs from the traditional materials management approaches and business/operational process control in the following aspects (Cooper & Ellram, 1993; Cooper *et al.*, 1997; Houlihan, 1988; Van der Vorst, 2004) (Table 1.1): -

- The SC is considered a single process, with responsibility in various segments, not fragmented between functional areas (manufacture, purchase, sales, distribution, etc.).
- SCM requires strategic decisions, with the concept of supply being common to every SCM function, as each function contributes to competitiveness.
- SCM considers inventories as a last resort for balancing business operations.
- SCM requires an integrative (not interfacing) approach.

Table 1.1

Difference between the Traditional and the Supply Chain Management approaches

Element	Traditional Management	Supply Chain Management
Inventory management	Independent	Joint reduction in channel inventories
Total cost	Minimise firm cost	Channel-wide cost efficiency
Time horizon	Short-term	Long-term
Information sharing	Current transactions	Planning and monitoring
Channel coordination	Single contact between channel pairs	Multiple contacts between levels in firms and levels in channels
Compatibility of philosophy	Not relevant	For key relationships at least
Joint planning	Transaction based	Ongoing
Supplier base	Large for competitiveness	Small for coordination
Channel leadership	Not required	Required for coordination focus
Risk & reward sharing	Not needed	Long-term sharing
Speed of operations, inventory, and information flows	Warehouse orientation, interrupted by barriers, localised to channel pairs	Distribution centre orientation, interconnecting flows, quick response across channels

Note. (Cooper & Ellram, 1993)

Being integrative, SCM seeks a change from individual business process management (localised to a BU) to SC processes integrating various activities across BUs. Table 1.2 illustrates key business processes which can be effectively integrated.

Table 1.2

Business processes capable of being integrated

Business process	General description
Customer Relationship Management	Service level agreements with key customers
Customer Service Management	Real-time availability of shipping dates and product availability through interfaces with production and distribution
Demand Management	Balancing customers' requirements and firm's supply capability
Order fulfilment	Meeting customers' needs dates
Manufacturing Flow Management	Based on customer needs
Procurement	Strategic planning with suppliers to enable manufacturing flow management and product development
Product development and commercialisation	Supplier and customer integration to reduce time-to-market
Returns	Alignment to realise efficient return of re-usable items

Note. (Van der Vorst, 2004)

1.3.4 Construction Supply Chain Management

In addition to industry peculiarities and complexity, increasing global competition, cost pressure, and market uncertainty drive SCM in construction. CSC assumes that customer service improvement, cost reduction, and sustained competitive advantage are possible through upstream and downstream cross-value chain collaboration (Adetunji *et al*., 2008).

The definition of Construction Supply Chain Management (CSCM) implicitly includes these characteristics *viz "A system where suppliers, contractors, clients and their agents work together in coordination to install and utilise information in order to produce, deliver materials, plant, temporary works, equipment and labour and/or other resources for construction projects"* (Hatmoko & Scott, 2010; Tran & Tookey, 2012).

Influenced heavily by Manufacturing Supply Chain Management (MSCM), CSCM primarily focuses on coordinating the delivery of discrete material quantities and associated resources and services (including specialised engineering) to specific construction projects. MSCM, on the contrary, focuses on modelling the production volume. Furthermore, CSCM applies a system lens to the production activities of independent elements (sub-contractors and suppliers) while focusing on globally optimising these, as opposed to traditional methods, which optimise the planning, controlling, and contracting functions separately (Tiwari *et al.*, 2014; Tran & Tookey, 2012).

While the usual perspective of SCM implementation in construction is ‘contractor’ or ‘site-centric’, integration of the activities of actors outside the construction site requires an independent perspective of the particular supplier business or firm (of products, services, or both). Figure 1.9 brings out the various tiers in a CSC.

Figure 1.9

Various tiers in a construction supply chain

Note. (Department for Business, Innovation and Skills (UK), 2013)

The CSC is extensive. In the present context, its evolution is typified by diverse stakeholders and actors, delineation of design and construction, disaggregation of professional expertise across the industry, and competitive bidding. Contextually, the construction costs attributable to the CSC are many and can be listed ad-infinitum.

Considering that there are at least three types of SCs in action on any site or project, a simple classification may be difficult. However, as a matter of understanding, costs in a CSC may be categorised based on the parties involved in the transaction, whether they are external or internal, and whether they are incurred for direct or indirect resources (Figure 1.10).

Figure 1.10

Costs in a construction supply chain

Note. (Department for Business, Innovation and Skills (UK), 2013)

1.4 Logistics in Construction

1.4.1 Logistics and the construction context

The Council of Logistics Management (CLM) (now Council for Supply Chain Management Professionals - CSCMP) defined Logistics in 1986 as,

> 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 (CSCMP, 1986, as cited in Cooper *et al*., 1997)

This definition of logistics and the discussion of SCM in the preceding section makes clear that while logistics is primarily about materials and the associated information flow, SCM has the flow of information, materials, finances, workforce, and capital equipment within its purview. Table 1.3 illustrates the key differences between SCM and logistics.

Table 1.3

Key differences between Supply Chain Management and Logistics

Note. (Lummus *et al*., 2001)

Ambiguity surrounds the SCM-Logistics relationship. Four perspectives are typically considered for viewing the relationship *viz* (Calis *et al.*, 2018; Larson & Halldorsson, 2004): -

- The **Traditionalist** perspective considers SCM as specialised logistics.
- **Relabelling** considers SCM and logistics as interchangable.
- **Unionist** considers SCM a superset of logistics, with SCM being relatively complex as a result of more variables and involvement of different parties.
- **Intersectionist** considers commonality of certain (not all) elements/activities between them both.

Figure 1.11

Perspectives on the relationship between Supply Chain Management and Logistics

Note. (Calis *et al.*, 2014)

CSCMP has defined logistics management as follows: -

> Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfilment, logistics network design, inventory management, supply/demand planning, and management of third-party logistics services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution--strategic, operational, and tactical. Logistics management is an integrating function, which coordinates and optimises all logistics activities, as well as integrates logistics activities with other functions including marketing, sales manufacturing, finance, and information technology (CSCMP, n.d.)

Logistics is an interdisciplinary domain (Tepić *et al.*, 2011) that integrates managing the physical flow of goods/services and the related information. Elements comprising logistics are movement, transport, warehousing, storage, packaging, material handling/manipulation, management of inventory, stocks and orders, forecasting, production planning, procurement, service pitched at the level of the customer, location of manufacturing facilities and warehouses, and waste management.

1.4.2 Construction Logistics

Logistics, in the context of the construction industry, may be taken as: -

> The scope of construction logistics concerns all supply and disposal shipments of building materials, construction equipment and construction personnel to and from the construction site (Quak *et al.*, 2011 (in Dutch), as cited in Balm & Ploos van Amstel, 2017)
>
> Construction logistics is the entire complex of measures aimed at getting the right equipment, the right materials and the right workers with the right level of quality to the right construction site at the right moment and at minimum cost to meet the customer's requirements (Quak *et al.*, 2011 (in Dutch), as cited in Balm & Ploos van Amstel, 2017)

Construction logistics are concerned with preparing, coordinating, control, and managing the flow of products from processing of raw materials processing to final application of the finished product in a project, and the reverse logistics of removing waste and finally disposing it off (Agapiou *et al.*, 1998; Ying & Tookey, 2014). The logistics process provides a framework for integrated decision-making regarding inventory, warehousing, transport, materials handling, and industrial packaging.

Efficient construction logistics require planning, management of loading and unloading zones, warehousing (internal and external to the construction site), on- and off-site handling of materials, and transportation for linking actors and channels of a logistics system (Construction in the Vicinities Innovative Co-creation [CIVIC], 2018; Ekeskär & Rudberg, 2016; Janné & Fredriksson, 2019; Lindén & Josephson, 2013; Lundesjo, 2011; Thunberg & Persson, 2013; Transport for London, 2013).

Construction logistics is comprised of the following (Serra & Oliveira, 2003; Sobotka *et al.*, 2005; Ying *et al.*, 2018): -

- **Whole-project Logistics** View the construction site from a production system perspective. Part of multiple logistics chains, whole-project logistics execute complex processes within budget, time, and space constraints.

- **Supply Logistics** Responsible for delivery of products from external sources (outside the construction site boundaries), e.g., material, equipment, machinery, and workforce for construction activities. Supply logistics comprise management and planning of resource/material planning and procurement, transportation, processing, and maintenance.

- **On-site Logistics** On-site material and resource flow coordination.

Complex systems with diverse stakeholders comprise construction logistics. These are concurrently engaged on- and off-site in wide-ranging activities, processes, and systems. These can be conveniently grouped into the three domains of organising and planning, transportation, and activities taking place on-site (CIVIC, 2018; Janné, 2020).

Activities in these domains typically establish clear interconnections between the SC and the construction site, with possible integration. This increases the efficiency of the SC and on-site activities and processes. It also improves coordination with local stakeholders, adding value. However, optimisation demands a high degree of integration, coordination, and awareness (CIVIC, 2018).

The Transport Component of Construction Logistics

Most of the activities comprising logistics are business processes (except transportation and warehousing) and not physical ones (Szymonik, 2012). Transportation is the largest element of logistics (Bowersox *et al.*, 2002; Madadi *et al.*, 2009). This is accentuated in the construction domain as a result of the low-cost/high-volume characteristic of materials used in the construction domain vis-à-vis other industries (Balm & Ploos van Amstel, 2017; Lovell *et al.*, 2006; The Bellona Foundation, 2020; Ying & Roberti, 2013).

In addition to the energy, emissions, and costs triad associated with it (Smith *et al.*, 2003; Szymonik, 2012; Ying *et al.*, 2014), transport has direct (e.g., noise, congestion, and pollution) and indirect impacts (e.g., health, ecosystem, and quality of life) (Chatziioannou *et al.*, 2020).

Construction logistics costs are invariably embodied in the material cost without distinction (Ying & Tookey, 2014). However, transport in construction does not get the attention it deserves, even though a substantial proportion of urban goods-vehicle movements related to construction. Hence, construction deliveries are referred to as ‘hidden’ logistics in literature (Balm & Ploos van Amstel, 2017; Shakantu *et al*., 2003; Shakantu *et al*., 2008; Verlinde, 2015; Ying & Roberti, 2013; Ying & Tookey, 2014), their costs being referred to as ‘hidden’ costs.

Transport data from the European Union (EU) estimates half the freight transportation being construction-related (Balm and Ploos van Amstel, 2017). Another estimate places the construction-related component of urban freight transport in Europe at about 30% (Guerlain *et al*., 2019b; Muerza & Guerlain, 2021). These benchmarks are an indicator of the magnitude of the contribution of transport to construction logistics.

Construction transport peculiarities need to be placed in context. Despite being a sub-set of freight transport, construction transport differs from freight transport due to the nature of the CSC (bespoke operations and fragmented composition) (Alashwal & Fong, 2015; Guerlain *et al*., 2019b; Jones *et al*., 2021; Sheffer & Levitt, 2012), typical patterns of usage stemming from the project delivery paradigm (Sezer & Fredriksson, 2021; Ying *et al*., 2014), construction bespoke transport equipment spread (Guerlain, Renault, & Ferrero, 2019a), and the responsibility for management of construction logistics vested with the construction industry, distinct from city logistics management both in character and the onus (Janné & Fredriksson, 2021).

Construction site deliveries are unlike the delivery of consumer goods. This is primarily driven by the size-independent material intensity of construction sites, and the compulsion of aligning supplies to site requirements, which is, more often than not, irregular over the course of a day (Quak *et al*., 2011 (in Dutch), as cited in Balm & Ploos van Amstel, 2017). The low-cost/high-volume nature of construction materials (raw materials and finished or semi-finished input materials) indicates substantial transportation requirements even for modest levels of construction (Balm & Ploos van Amstel, 2017; Shakantu *et al*., 2003; Shakantu *et al*., 2008; Shakantu & Emuze, 2012; Ying & Roberti, 2013).

There are an unduly large number of empty trips comprising inbound traffic flows to a construction site and outbound traffic flow from it as part of urban distribution of construction material (Crainic *et al*., 2004; DG MOVE, European Commission, 2012; McKinnon, 1996). Construction material delivery vehicles are nearly fully loaded during the onward trip to sites, while they return fully empty. An opposite trend is exhibited by vehicles carrying Construction and Demolition Waste (C&DW) from construction sites (empty on the onward trip and loaded on the return trip from the site) (Amsterdam University of Applied Sciences [AUAS], 2017; Shakantu & Emuze, 2012).

The material distribution business manages the efficiency of the transport function from a localised (own business) perspective, ignoring the impacts of this ‘self-centric’ efficiency-based distribution on the transportation system as a whole, and its adverse impacts on the area where it conducts business (Crainic *et al.*, 2004). Non-synchronisation of activities between adjacent construction sites causes congestion in the transport network, leading to potential underutilisation. The waste removal fleet being over and above the material delivery fleet leads to increased vehicular traffic.

Space on construction sites (typically urban) being at a premium leads to a paradoxical situation in the current scenario. Full truck load (FTL) deliveries can potentially cause congestion of the working space, leading to avoidable damage to material and material wastage due to overstocking on the construction site. In actual operations, most material delivery vehicles travel only partly loaded on the onward trip segment, and empty on the return segment. These typical manifestations of construction industry fragmentation cause increased transport and production costs as well as an increase in unwanted impacts and externalities.

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

Transportation efficiency is a maximisation function and per unit transportation cost is a minimisation function. Increased efficiency per trip, reduced travel distance, and larger shipments can reduce per-unit transportation costs, which fundamentally depends on the consolidation of loads and/or local sourcing, i.e., higher loads carried by fewer vehicles, for shorter distances, less frequently. The following transport cost drivers may be considered from the perspective of the CSC *viz* (Vidalakis & Sommerville, 2013): -

- **Distance** Optimal location of warehouses can minimise travel-related costs. However, construction customers operate in a geographically changing area. Hence, a ‘continuously shifting’ scenario.

- **Weight** Combining individual shipments into larger loads can increase transportation efficiency.

- **Density** Building materials and components are typically low-cost/high-volume. Therefore, even though they may generate the need for more transport, it does not automatically imply a proportional increase in income.

- **Stowability** Inclusion of products having different shapes, types, and sizes makes physical grouping difficult in boxes/pallets.

- **Liability**: These pertain to damage to the material during transportation and increased packaging to protect materials from adverse on-site storage conditions.

- **Market factors** Fluctuating materials demand for construction can lead to sporadic delivery, defeating any efforts to integrate the transport function.

Builder’s Merchants

Due to their unique positioning in the CSC, Builders’ Merchants (BMs) represent a storage and consolidation point as the primary intermediary between the manufacturer and the contractor. Manufacturers of construction materials and components sell goods through three typical models, i.e., direct to the customer, sale of a limited range of goods through a specialist stockist, and a BM. The BM may be associated with an administrative role of order processing for the contractor and paying the manufacturer (invoicing the goods with actual deliveries directly undertaken by the manufacturer to the customer’s premises). Alternatively, the BM may buy the goods from the manufacturer and sell them from their stocks.

An unstated but critical economic function of a BM is to provide working capital for the construction by extending a line of credit to most contractors. A fluctuating market demand compels the retention of high safety stocks. BMs bear the inventory carrying cost, which may be anywhere up to 20% of the inventory cost itself annually (Agapiou *et al*., 1998; Bowersox & Closs, 1996; Vidalakis & Tookey, 2005; Vidalakis *et al*., 2011), including the invested capital. They, therefore, play a pivotal role in industry performance by offsetting risk and providing credit. From the transportation perspective, time and distance components directly govern the complexity of a logistics system. These are essential transport parameters, and the links an organisation utilises to bridge the distance between the different nodes in the logistics system, both deterministic yet build stochasticity in a system (Coyle *et al*., 2003, 2009). Figure 1.12 presents the CSC from the transport perspective, necessarily assuming the routing of all supplies through the BM.

Figure 1.12

Transportation function of the construction supply chain through the builder's merchant

Note. (Vidalakis *et al*., 2011)

1.5 Transport and Sustainability

Optimisation of transport will lead to a major sustainability push for the construction logistics domain, especially because even modest construction requirements have a high transportation component. Objectives supporting sustainable transport goals are (Litman, 2021):-

- Transport system diversity Modal choice, location, and pricing options, particularly those that are affordable, efficient, and healthy.

- System integration Integrating various components of the transport system, e.g., transit access, and integrated planning of land use and transport.

- Affordability Across the cross-section of economic strata comprising society.
- Resource (energy and land) efficiency Policy encouragement of efficiencies of energy consumption and land utilisation.
- Efficient pricing and prioritisation Parking, roads, insurance, and fuel prices, management of facilities as enablers of modal efficiency and higher trip value.
- Land use accessibility (smart growth) Policies for supporting mixed, compact, connected, and multi-modal land use development. This improves transport options within improved land use accessibility.
- Operational efficiency Efficient management of transport agencies, service providers, and facilities, with maximised quality and minimised costs of service.
- Comprehensive and inclusive planning Comprehensive (considering all significant options, objectives, and impacts), Integrated (inter-sector/jurisdictional/agency co-ordination in decision-making), and Inclusive (ensures participation of all those affected).

Figure 1.13 summarises the goals of sustainable transport and presents a framework for sustainable freight transport.

Figure 1.13

Sustainable transport goals

Note. (Litman, 2021)

Figure 1.14

Framework for sustainable freight transport

Note. (Richardson, 2005)

The following indicators and metrics give an idea of relevance of sustainability to freight transport (Mihyeon, Jeon, & Amekudzi, 2005): -

- **Economic** Population density, economic efficiency, employment, accessibility measures, public expenditure, growth potential, Green GDP, GDP per unit energy use, tax revenues, internalisation instruments, and employment to population ratios.

- **Transportation related** Length of railways and main roads, parking facilities, freight tonne-kilometers (km) (by mode, purpose), total km driven (VMT or VKT), unit sales of vehicles, traffic volumes, vehicle use, transportation subsidy, passenger and cargo turnover, per capita fuel consumption versus urban density, mixed land use, length of public transport network, extent and density of transport infrastructure, land area occupied by transport infrastructure, investment in maintenance versus quantum of infrastructure, share of taxes in fuel prices, real changes in the cost of transport, vehicle fleet composition, transport intensity, capacity of transport infrastructure, external costs by mode, percentage of low emission vehicles vs total vehicles, road utilisation index, quality of delivery services, change in level of road congestion over time, fuel prices, load factors for freight transport, and percentage of movement in congestion conditions.

- **Environmental** GHG and CO_2 emissions, fossil fuel consumption, per capita transportation energy use, emissions (NO_X, volatile organic compounds (VOC), sulphur dioxide, methane, black smoke, lead, etc.), land use, emission intensity, waste/recycling, noise level/cost, green area, toxic substances in urban area, per capita energy use, non-fossil fuel use, wetland losses and creation, overall freight transport energy efficiency, air pollution cost, ozone depletion, sprawl, ecological footprint, reuse of EOL vehicles, disposal of used tyres, reported environmental costs and liabilities, acid rain, and solid waste (vehicle scrapping, motor oils, tyres etc.).

- **Safety** Deaths and injuries, accidents, accident costs, and cases of serious health or pollution effects.

- **Socio-cultural or equity related** Exposure to vehicle noise, air quality satisfaction, and population exposed to exceedance of air pollutants.

From the above, it is apparent that it is not only the means of transport which contribute to sustainable transportation and its assessment. Sustainability may be assessed individually for the means (mode), application (urban, highway, freight, passenger, private, public, etc.), planning, purpose (land use, community issues, etc.), infrastructure (highways, urban roads, bridges, etc.), transportation systems, contribution towards SD, transportation system modelling, being illustrative sustainability analysis perspectives.

1.6 The New Zealand Construction Sector

The New Zealand (NZ) construction sector has certain peculiarities. Its primary composition is Micro, Small, and Medium Enterprises (MSMEs) (Seadon & Tookey, 2018). 32.5% of the nearly 67000 operating construction businesses are ‘small’ (up to 19 employees), while nearly 65% are single person operations. Governmental, consenting, and regulatory bodies, and circa 150 professional groups and industry bodies add to the context (Ministry for Business, Innovation and Employment, New Zealand Government [MBIE], 2021; Statistics New Zealand [StatsNZ], 2019). The NZ construction sector adopts an improved philosophical stance rather slowly, primarily due to its unique geographical location (Naismith *et al*., 2016). Concept introduction and implementation are invariably delayed, typically behind UK initiatives by anywhere up to eight years. Voids in understanding, knowledge, and skills, specifically in logistics, stand out starkly as challenges to upgradation initiatives (Ying & Tookey, 2014). The sector's performance (productivity) over the last 40 years has been sub-optimal (Figure 1.15).

Figure 1.15

NZ construction sector productivity: A historical perspective

Note. (Curtis, 2018)

2019 saw an increase of circa 7.2% in the NZ construction sector, and improved GDP contribution (from 6.29% to 6.33%) year-on-year. Despite the pandemic, it touched the expected NZ$ 43 billion benchmark by 2021 (MBIE, 2017, 2019, 2021; StatsNZ, 2019). It is expected to grow to about NZ$ 48.6 billion by 2024 (MBIE, 2021). The impact of COVID-19 has created substantial uncertainty in the sector, whose impact will be seen over an extended period. The forecast for the industry as of late 2020 is as follows: Residential activity is likely to be hit hardest; Non-residential activity has peaked; and, Infrastructure activity will continue trending upwards (MBIE, 2020b). Beneficial contributions and detrimental impacts of the NZ construction sector are illustrated in Figure 1.16 and Figure 1.17, while Figure 1.18 illustrates its main actors/stakeholders.

Figure 1.16

Beneficial contributions of the NZ construction sector

Figure 1.17

Detrimental impacts of the NZ construction sector

Note. (BRANZ, 2021)

Figure 1.18

Primary actors in the NZ construction supply chain

Note. (BRANZ, 2021)

1.7 The New Zealand Construction Supply Chain: An Overview

The NZ construction materials SC is not standardised and varies for different materials/products as well as types of construction projects (e.g., sale of products through merchants (BMs) or direct procurement from manufacturers or importers.

In addition, the CSC has multiple levels through which construction materials pass before being used in construction (Commerce Commission New Zealand [CCNZ], 2021).

The NZ construction materials SC is comprised of the following components (from the supply to the demand end) (Figure 1.19): -

- At the wholesale supply level, several domestic manufacturers specialise in a particular supply such as timber or cement. Additionally, material is imported into NZ by other international companies specialising in the building supplies business.
- Five major merchants manage most of the distribution of building supplies. Some of these are specialist suppliers for builders and trade customers, while others conduct business through retail outlets.
- In addition to these five major BMs, several smaller businesses (merchants and retailers) manage various product ranges and have a varying presence across NZ.
- Physical construction is undertaken by a wide range of stakeholders/actors, *viz* large group home builders, small-to-medium enterprise builders, sub-contractors, and Do-it-Yourself (DIY) builders.
- The preference of consumers at the end-user level shapes the choice of materials and the structure types being built.
- A major part of the demand for urban construction is driven by public and Iwi/Hapū (developer) end-users. They operate stand-alone as well as in partnership with others.
- Some products exhibit a much greater degree of direct sales (e.g., window joinery is almost entirely direct-to-market sales). In contrast, others, such as insulation and roofing, are installed by specialists.

Figure 1.19

The NZ construction materials supply chain

Note. (CCNZ, 2021)

In addition to manufacturers, importers and suppliers, merchants, builders, and owners, the other significant participants and stakeholders in the NZ construction materials SC are (CCNZ, 2021): -

- Architects and other specifiers (e.g., designers and quantity surveyors) exert a significant influence on the product and material selection and the types of structures being built.
- Building Consent Authorities (BCAs) are vested with the responsibility of issuing consents and inspecting new constructions Building Code compliance. Each of NZ's district and city councils is associated with a BCA.

- Industry bodies that provide representation, regulation, and research functions for the industry, e.g., NZ Construction Industry Council, NZ Building Industry Federation, NZ Green Building Council, and other trade-related organisations and associations.

- Industry bodies undertaking research and certification, e.g., Building Research Association New Zealand (BRANZ), who substantially influence new product introduction in the NZ construction market.

1.8 Rationale and Significance of the Study

1.8.1 The Research Opportunity from SC-Transport Confounding

The construction logistics problem is typically viewed from the contractor’s perspective, who needs to manage all suppliers at the project level. The issue has its genesis primarily in the limited storage space on any construction site.

This (on-site) coordination addresses a project's horizontal and vertical fragmentation; it, however, disregards longitudinal fragmentation between projects. The SC perspective, however, reverses when viewed from the supplier’s viewpoint (Figure 1.20).

Figure 1.20

The construction supply chain from the contractor’s and the supplier’s perspectives

Note. (Vidalakis & Tookey, 2005)

The presence of five major BMs in the NZ CSC prompted research into the transport ramifications of the de-facto consolidation services provided by them to customers (contractors/developers) as a means to quantify transport utilisation from the supplier’s viewpoint.

While research evidences certain logistics (transport) optimisation taking place at the level of a construction project/site, examination of the CSC from a supplier’s perspective represents a niche area of longitudinal defragmentation.

The conspicuous absence of the classical construction consolidation centre concept in NZ also encourages this research to investigate the implicit adoption of a consolidation centre model for the supply of construction materials, albeit in a part of the SC. In the context of the ‘First Emissions Reduction Plan’ recently issued by the Ministry for the Environment (MfE, 2022c), transport optimisation directly impacts emissions from the construction sector. The sustainability perspective, therefore, creates the imperative for such research.

1.8.2 Builders’ Merchants-Transport Aggregation

BMs supply a wide variety of essential construction materials to the sector, with significant over-the-counter deliveries to the buyer. These deliveries are for both ‘heavy’ (sand, bricks, blocks, and aggregate) and ‘light’ (fixtures, fittings, tools, plumbing, and heating supplies) materials.

Typically, BMs may operate at the national, regional, and local merchants. Those operating at a national scale may have national and/or regional distribution centres (RDCs), with local depots/warehouses serving specific geographical areas for interfacing with customers.

The transport function of these depots is not an entity in itself; rather, it is a derived demand existing to serve the purpose of materials delivery to the customer.

The fleet of depot is typically small and serves a local customer network which may include the residents, construction sites, and bigger construction businesses or organisations. Planning of delivery trips is based on the staff's knowledge about the local routes and locations. While regional and national merchants maintain centralised control over their fleet, which is managed professionally by a nominated manager, at the depot level, the depot manager, who is not a transport professional, manages the transport fleet.

The focus of depots is customer service and not efficiency of transport utilisation. Orders are typically accepted a day in advance for the ensuing day's work.

The core KPIs typically used in evaluating the transport function (vehicle fill, empty running, time utilisation, deviation from schedule, and fuel consumption), are not all relevant to BMs' delivery operations. Certain other KPIs that may be used effectively for assessment in the BM context are: -

- **Number of runs per day** The number of trips the vehicle undertakes for delivery.
- **Number of drops per run** The number of deliveries in each trip.
- **Kilometres per drop** The average distance between drops in a delivery trip.
- **Number of drops per day** The number of drops per vehicle per day.
- **Value per drop** The (invoiced) value per drop or delivery.
- **Fuel consumption** Kilometres run per litre of fuel consumed.
- **Fuel used per drop** Average quantity (litres) of fuel consumed per drop.
- **Cost per drop** Aggregated fixed and variable costs per drop.
- **Percentage of constrained loads** The proportion of vehicles whose capacity in terms of payload, deck area, or volume got exhausted during loading.
- **Deviations from schedule** The percentage of trips that incurred delay along the journey or during unloading beyond a specified length of time.
- **Time utilisation** The manner in which a vehicle is employed during the course of a day to include running, breaks, loading, awaiting departure after loading, delays, awaiting work (empty or stationary, therefore, idle), or being serviced, maintained, or repaired (therefore, not available for work).

Not all of the above KPIs have been used in this study; some have been directly used for evaluating efficiencies of the transportation function under investigation, while others have been used in formulating and analysing generalised models. SC reconfiguration to include direct supplier deliveries, the inclusion of backloads, and consolidation are certain typical solutions for improving transport efficiency in this sector.

1.9 The Research Framework

1.9.1 Problem Specification

Fragmentation is an identified challenge in the construction sector. Transport is identified as a major contributor to the sector due to the low-cost/high-volume character of construction materials. Evidence-based decision-making in the construction freight/logistics domain is constrained by a general dearth of pertinent data. Data relates to individual freight journeys with a general lack of an SC perspective, amongst others (McKinnon, 2015). These present barriers to quantifying optimisation as a result of implemented SC models and assessing further improvement potential of implemented SC and/or logistics models. Transport, inherent to most SCs, forms a fundamental element that can lead to improved sustainability of most SC processes. The problem under investigation pertains to the supply of plasterboard by the manufacturer (in Auckland) through the adoption of two logistics models: -

- **The first model** represents a disaggregated SC with three nodes of interest, i.e., the manufacturer (warehouse), the BM network, and the consumers or construction sites. The model has two links (Manufacturer – BM and BM – Construction Site) linking three nodes for both information and material movement. Each one of the nodes has storage as one of its primary functions.

- This model has substantial time and space associated with the intermediate node (the BM), where material arrives in bulk from the manufacturer and departs in bulk or retail to consumers (construction sites). Therefore, it is referred to as the BM distribution model or ‘Merchant Delivery’ (MD) for purposes of this thesis and represents the ‘distributor storage with carrier delivery’ logistics model (Chopra & Meindl, 2013).

- **The second model**, running in parallel with the BM distribution (MD) model, is a vertically integrated model with forward vertical integration (VI) between the manufacturer and the transport function. In this case, the material is invoiced by the BM but delivered directly by the manufacturer to the construction site.

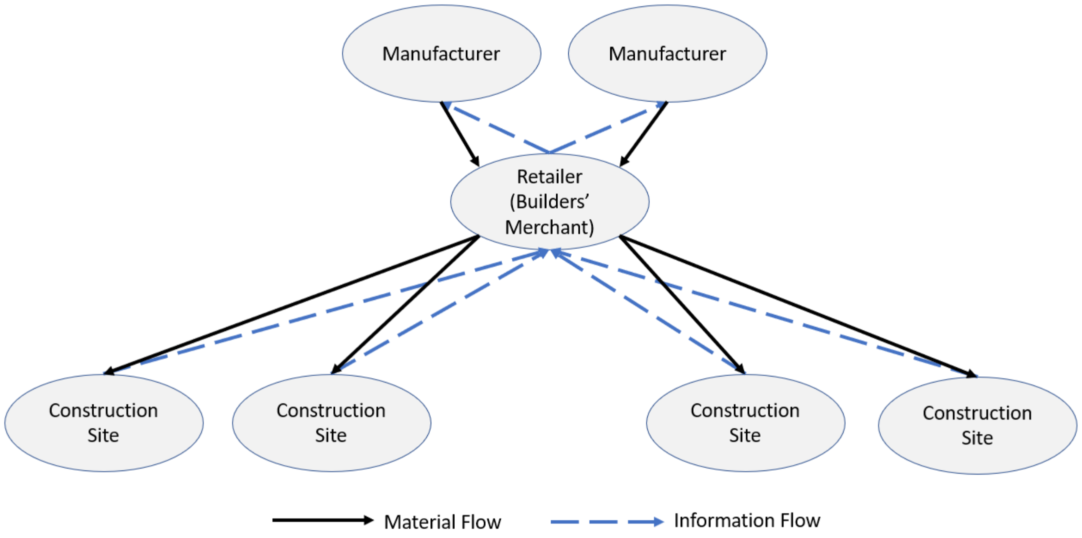
- The model again exhibits three nodes, however, with three links as opposed to the first model. Two of these represent links for the flow of information associated with invoicing and delivery through the BM (Construction site – BM and BM – Manufacturer), while the third one represents the physical transportation link (Manufacturer – Construction site).

- For purposes of this thesis, this model is referred to as the 'Direct to Site' (DTS) model and is a manifestation of the 'Manufacturer storage with direct shipping' logistics model (Chopra & Meindl, 2013).

The two models are illustrated in Figure 1.21 and Figure 1.22, respectively.

Figure 1.21

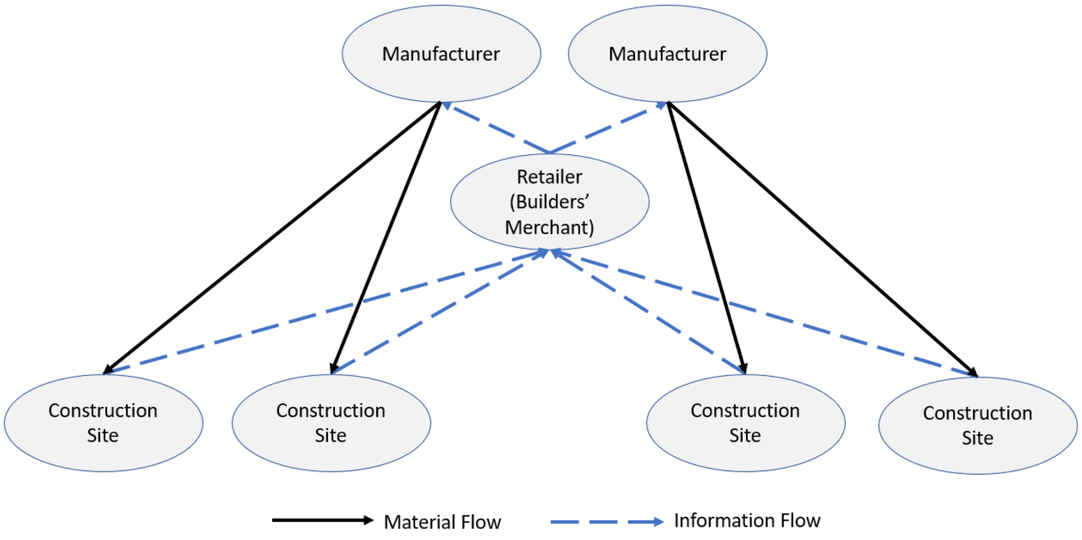
The 'Merchant Delivery' model



Note. (Based on Chopra & Meindl, 2013)

Figure 1.22

The 'Direct to Site' delivery model



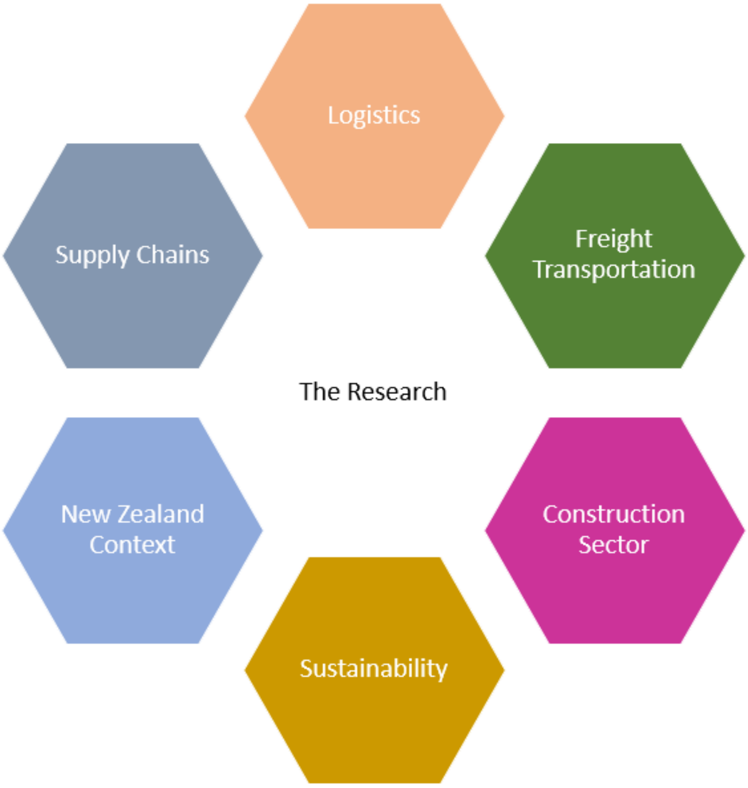
Note. (Based on Chopra & Meindl, 2013)

1.10 Domanial Positioning of the Study

The topic of research lies at the intersection of SCs, logistics, the construction context, transportation, and sustainability with the NZ focus (Figure 1.23).

Figure 1.23

Domanial positioning of the study



This has connotations for the literature review (which is likely to be intensive in-depth, and extensive in the range of literature referred) and associating research outcomes with business and operational practices, as well as sustainability impacts (in the form of inferences and interpretations of the research outcomes, their validation, and recommendations therefrom).

1.11 Research Framework Development

1.11.1 Developmental Methodology

The Design Science approach was adopted for developing the research framework. Design science focusses on development and validation of prescriptive knowledge. An abridged design framework was employed to include three activities to arrive at the desired artefact (the research framework as a ‘model’ manifestation of an artefact of design science) (Dresch & Lacerda, 2015; Johannesson & Perjons, 2014).

The description of the three activities is as follows: -

- **Problem Explication** This activity was based on existing explicit descriptive knowledge (Johannesson & Perjons, 2014, p. 25) through an exhaustive literature review pertaining to the positioning of the study at the intersection of various domains i.e., supply chain management, logistics, and their construction context, freight transport, sustainability, and the NZ context.
- The problem explication points to a new solution (prescriptive knowledge) for a known problem from existing descriptive knowledge, manifesting ***Exaptation as a research contribution.***
- The research problem is stated as follows:

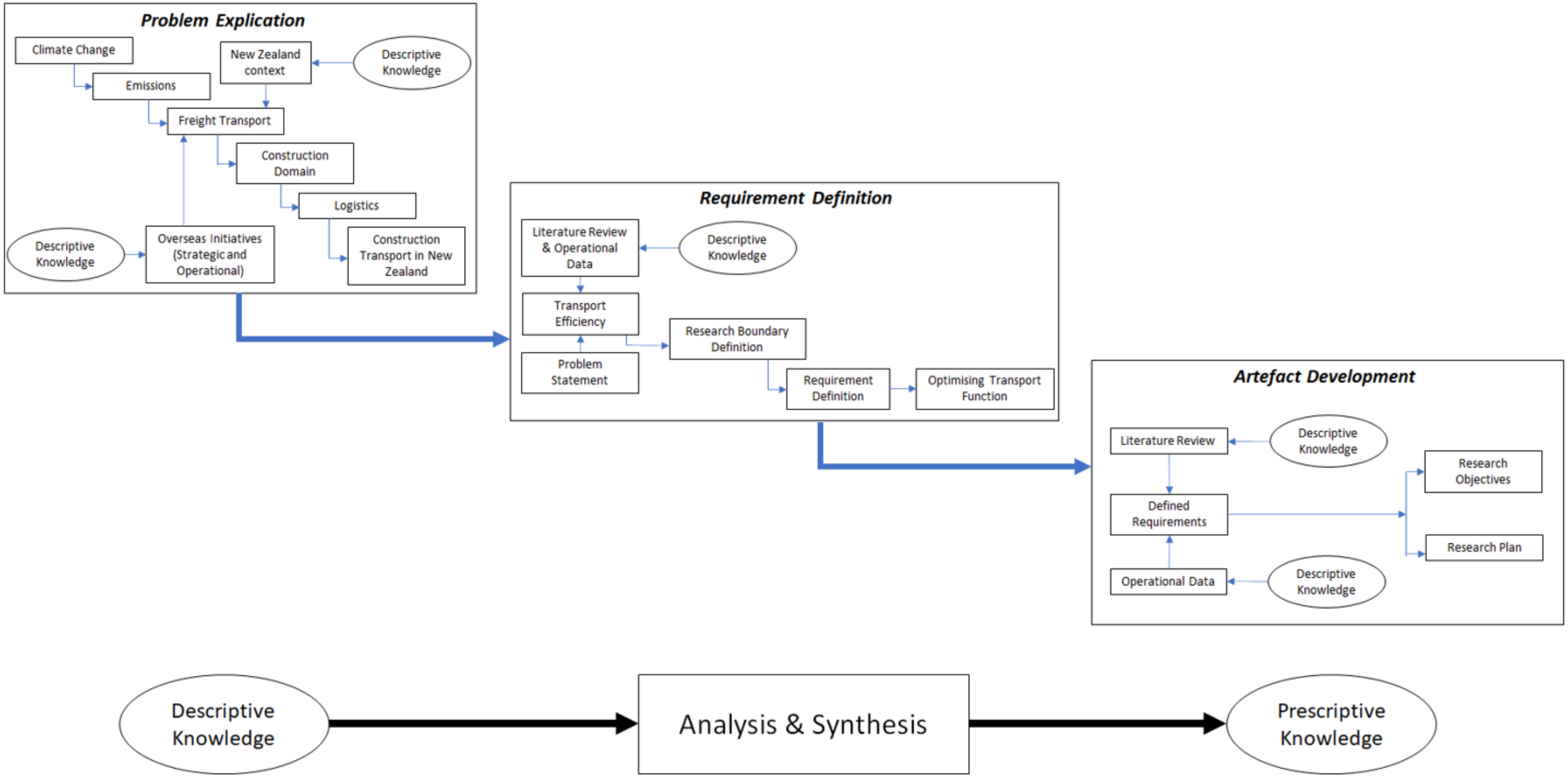
  > The problem addressed by this study pertains to the transport optimisation achieved, and further optimisation potential for the transport function in a specific and narrow segment of the NZ CSC as a result of implemented SC structures. This is directly associated with an existent void of construction logistics understanding in general and specific to the region.

- The novelty of the proposed research lies in instantiation of known artefacts (models, paradigms, techniques) for employment by implication.
- **Requirement Definition** Based on descriptive knowledge available from the literature, and operational data from the industry of interest (in the instant case, the NZ construction sector).
- **Design and Development of Artefacts** The artefact in the instant case is the research framework (research aim, hypothesis, questions and objectives), based on understanding of preceding work available, building up of research on it, and the potential succeeding actions.

Figure 1.24 illustrates the research framework developmental methodology adopted for the study.

Figure 1.24

Research framework development



Note. (Based on Johannesson & Perjons, 2014)

1.11.2 Research Framework

Research Problem

Sustainability impacts of optimising construction logistics in NZ.

Research Gap

A research gap in the CSC analysis from the supplier's perspective (specifically including the BM in the distribution channel) to assess the sustainability impacts of adopted SC practices, and potential for further improvement, specific to manufactured construction materials, exists in NZ.

Research Aim

To examine the sustainability impacts of vertical integration in a specific segment of the NZ CSC.

Research Hypothesis

It is hypothesised that vertical integration in a supply chain will improve logistics (specifically transportation) efficiency.

Main Research Objective

To quantify the improvement in transport efficiency accrued as a result of forward vertical integration, the potential for further efficiency improvement using superior operational planning, and the potential for integrating reverse logistics in the existing logistics model.

Research Questions

RQ1. What metrics should be considered for assessing the sustainability impacts of transport on the logistics function in a CSC?

RQ2. What is the supply model adopted in the supply chain under consideration, and how does it achieve optimisation over a standard echeloned CSC?

RQ3. What is the potential for reducing the gap between available and utilised truck capacities for forward deliveries?

RQ4. What are the potential sustainability benefits of integrating reverse logistics within the existing fleet configuration of the supply chain under review?

RQ5. What is the scope of fleet management within the existing domestic environment from the outcomes of the investigation?

RQ6. What are the SCM implications of the outcomes of the investigation?

Research Objectives

RO1. Investigate available metrics and select those appropriate and adequate for benchmarking vehicle movements for manufactured construction materials and those relevant to the sustainability impacts of diesel-based freight transport.

RO2. Examine the supply model adopted for the case under examination, compare it to an echeloned supply model, and quantify the transport optimisation achieved in terms of selected metrics.

RO3. Based on truck movement data, quantify the potential for improving operational efficiencies of transport in the model under examination.

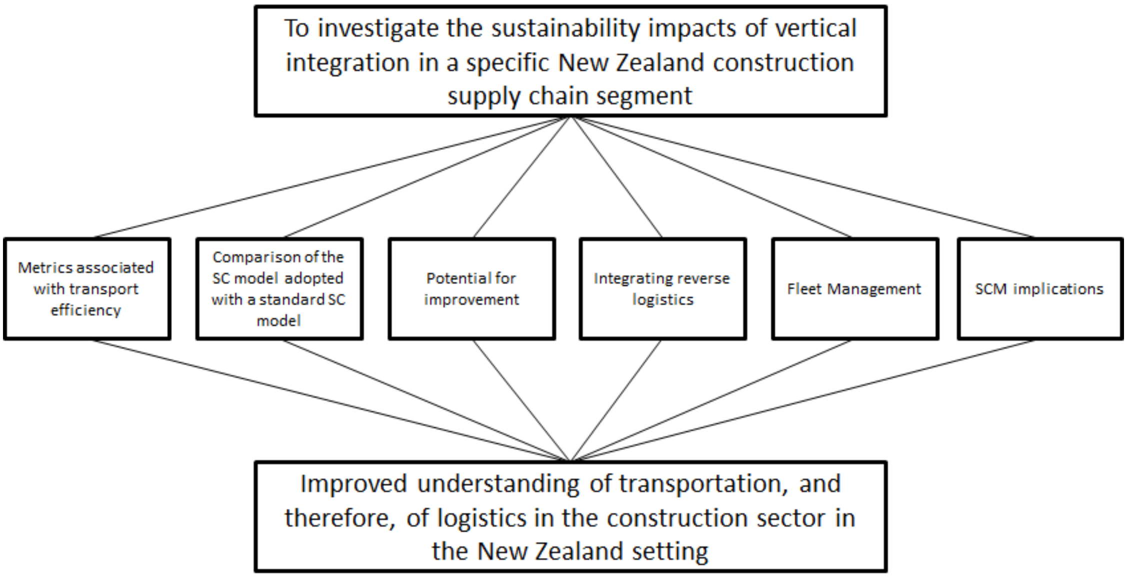
RO4. Quantify improved sustainability from transport optimisation by possible integration of reverse logistics in the adopted logistics model.

RO5. Discuss fleet management opportunities based on the analysis undertaken.

RO6. Discuss the SCM implications of the investigation.

Figure 1.25

The research framework



Note. (Author)

1.12 Summary of Research Methodology Adopted

Examining the ultimate and the extended SCs, especially in the construction domain, which is trans-disciplinary and inter-domanial by nature, is likely to be a laborious endeavour, probably requiring years' worth of documentation of practices and statistics for arriving at conclusions at the end of which the assumptions could potentially change. On the other hand, examining a small part of the SC and generalising the outcomes/results is likely to provide much more value for strategy, operations, as well as academic richness in a much shorter timeframe.

A field study with quantitative methods, validated qualitatively, provides a robust means to explore the existing situation pertaining to operational logistics. In the instant case, the investigation assumes even higher importance since operational data from freight transport is very scarce. However, the opportunity to examine transport operations, even if they are pertaining to a very narrow segment of the NZ CSC, based on the availability of data, can provide further insights into potential improvements of transport operations and, therefore, logistics and the overall SC in the short-term, as well as rich pointers for strategic interventions towards improved sustainability in the long-term.

The generalisability/transferability of results can be effectively mapped based on a decomposition of the sector and the operations being studied into elemental domains/areas of interest. The study is contextual to the Auckland region, in the settings of a particular manufacturer-cum-supplier, who holds circa 94% of the market share (CCNZ, 2021) for plasterboard in NZ.

1.13 Delimitation of the Scope and Key Assumptions

Logistics management integrates information, transportation, inventory, warehousing, materials handling/manipulation, and packaging. The distribution function in logistics is under focus, especially with the current global sustainability imperative. This research investigates the workings of the transportation function in a narrow segment of the NZ CSC (plasterboard) based on vertically integrating transport for distribution.

The aim is to bring out the efficiencies achieved, quantify the benefits of forward VI, and quantify the potential for further efficiency improvement through optimising the transport function based on scientific planning and, therefore, integration of transport planning and operations.

In doing so, the overall sustainability of transport is addressed with insights into SCM issues such as strategic business decisions, fleet management, and ways of doing business. This research is not intended to be an all-encompassing expose of logistics and SCM in the construction industry.

1.14 Justification of the Research

Construction is extensively based on the transportation of materials, be they bulk, retail, or with the disaggregated sector, and may even include services. Construction materials being low cost/high volume, the requirement of transport is apparent, as is its quantum. Related to these are transportation costs, which may be between 39%-58% of logistics costs (Bowersox *et al*., 2002; Coyle *et al*., 2003, 2009).

Disaggregation and fragmentation of the industry produce many working parts in a construction project, producing inefficiencies at the boundaries of these interacting domains or elements. Conversely, a higher opportunity to address these inefficiencies. The opportunity for addressing inefficiencies through optimisation, maximisation, or minimisation of logistics functions, specifically transportation elements, comes with the pre-requisite of understanding the construction industry context of transport operations.

The current state of knowledge of logistics in general and transportation in particular within construction is limited. This is for a wide variety of reasons, the most acute ones being that transportation costs (logistics costs) invariably get merged into the cost of the material and, therefore, cannot be disaggregated, and the immense scarcity of transport data (be it operational or financial) since it is universally considered ‘commercially sensitive’.

The result is an overall shortage of work on the actual workings of the logistics process in the construction industry, with the role of efficient logistics largely disregarded. In addition, SCM in construction typically tries to ‘adopt’ concepts from the manufacturing domain, where-as the fundamental nature of the two has substantial divergence. Consequently, it has also ignored the role of efficient logistics.

The typical logistics perspective in construction is through the lens of a contractor, even though the connected transport could invariably form a part of other SCs (construction projects). Though some literature has viewed the CSC from the supplier's viewpoint, such studies are far between due to the preponderance of the project delivery method in the construction domain.

The NZ context of the construction sector has certain typical attributes *viz* geographical isolation, the time lag in terms of adoption of philosophies and concepts, and a void in the overall knowledge of construction logistics being the major ones. 93% of NZ's freight is transported by road, a third of it construction related. A comparison with similar statistics for Europe and North America will likely highlight the relative preponderance of road transport in NZ construction.

Put together, the peculiarities of logistics and particularly transport in construction in general, the viewpoint of the CSC from the project side, an overall lack of knowledge of logistics, and a dearth of transport-related data, when seen from the NZ perspective, present a clear and relevant research opportunity.

The seizing of this opportunity has been facilitated by the availability of a transportation model implemented in a very narrow segment of the NZ CSC, producing the SC perspective as well as the data required for analysing the benefits of the implementation. Ergo, the justification for research and the opportunity to add to the contextual NZ knowledge corpus. Sustainability leanings of the research outcomes provide even higher impetus.

1.15 Key Assumptions

The following are the key assumptions for this research: -

- There exists an intrinsic inefficiency in the freight transport domain pertaining to construction, which stems from the inherent fragmentation of the construction and transport domains.
- A simplistic consideration of distances and loads, leaving out the temporal stochasticities, from a preliminary assessment of the plasterboard distribution model.

- The transportation system aims to maximise tonnages delivered and minimise delivery time.

- There is no pattern in the employment of transport on any given day; availability and allocation are random.

- The solution provided by the selected software platform is optimal, and has been singularly considered, without considering the possibility of any variants (e.g., in the case of the transportation model, the solution provided by the solver module in MSExcel is considered optimal without considering the three variants of the transportation model).

- Any truncation of data either due to cleaning, filtration, or due to processing limitations will only have a marginal impact on the results/outcomes.

1.16 Chapterisation of the Thesis

The thesis has been chapterised to introduce the research imperative and its key concepts, leading to a research framework, an exhaustive literature review of the various constructs involved in the research problem to be addressed, the adoption of a research methodology from the philosophical treatment of the subject, data analysis, a discussion of the outcomes of data analysis, and concluding remarks.

Chapter 1 provides an overview of the construction industry and brings into focus the SC, logistics, and transport and their association with the construction industry as its essential comprising elements.

Of specific interest is the discussion of BMs as an integral part of the CSC, less as stockists rather more as builders’ bankers in providing lines of credit. This aspect cements their presence and role in the CSC.

The chapter next focuses on the construction industry in NZ and the associated SC, bringing out its attributes.

It finally addresses the research framework, culling it out from the opportunity generated through a confounding of the CSC-BM-Transport triad in the context of a narrow segment of the NZ construction industry, forming the basis of the thesis.

Chapter 2 reviews the literature pertaining to elements based on disaggregation of the research problem in focus *viz* the construction industry and its fragmentation, SCs, logistics as an integral part of SCs and their management, the construction context of SCM and logistics, BMs as one of the essential elements of CSCs, freight transport and sustainability aspects associated with it, and the extent of involvement of transport (as a sub-set of freight transport) with the construction sector.

Transport (and, therefore, construction transport) and its sustainability aspects are discussed in detail to associate transport optimisation with inherent sustainability benefits.

A discussion of freight transport realities in NZ follows. The chapter then brings out the inferences from the discussion of SCs, Logistics, and Transport for the study.

Finally, it closes with a remark on the relevance of the literature review to the problem being studied.

Chapter 3 establishes the research methodology for this research. It commences with a discussion of the problem description attributes, followed by the theoretical underpinnings of research.

Next, the chapter discusses the theoretical background to research *viz* the three primary research paradigms, i.e., Positivist, Interpretivist, and Pragmatist. Based on these discussions, the chapter next posits the study, arriving at the primary and the secondary research methods with justification.

This is followed by a discussion of the research design, including the conceptual framework, data collection, sampling, analysis, modelling, and simulation approaches. Finally, the chapter concludes with a discussion of the assumptions and limitations of the study.

Chapter 4 analyses the development of the research problem through an assessment of various options and their limitations.

The final research problem is selected around assessing the transport operations pertaining to the ‘Direct to Site’ delivery of plasterboard by a manufacturer, achieving forward VI of the distribution function as an extension of manufacture.

The chapter discusses the acquisition of data, its cleaning, analysis, and drawing of inferences from the analysis results. It investigates the impact of the DTS model on loading efficiencies, capacity utilisation, and the regional sales pattern.

Finally, the transportation model from operations research is applied to the transport operations ‘as executed’ to assess the potential for further efficiency improvement.

A short discussion on the simplification of the problem from a Vehicle Routing Problem (VRP) to a Travelling Salesman Problem (TSP) follows, with the application of the Hamiltonian Path/Loop approach to finding the shortest route for the given number of deliveries of a truck based on outputs of the transportation model.

Finally, the inferences drawn are validated through discussion with the relevant functionaries of the company.

Chapter 5 transforms inferences drawn from data analysis into tangible business cases. It commences by generalising the transport operations into a model comprised of loads and distances.

The aspect of backhaul as a means to integrate reverse logistics is next discussed in terms of potential implementation mechanisms and quantification of potential efficiency improvements. Finally, the improved transport efficiencies are converted into tangible figures pertaining to the reduction in emissions and their monetised impact.

The chapter next discusses fleet management imperatives emerging from the analysis, changes in ways of doing business, specifically non-price attributes in tendering and contracting, integrated planning process, further increasing distribution through the DTS model, and presenting a graphical solution for selecting a payment model.

The last part of the chapter discusses the impact of the sales pattern in designing a distributed DTS model to support the ongoing urban development in Auckland by suggesting locations for zoned warehouses (specifically in the context of manufacturing facilities outside Auckland).

A section on the validation of the research outcomes based on the presentation of these to the appropriate functionaries of the company sums up the discussion chapter.

Chapter 6 concludes the study. It commences by revisiting the research framework for orientating the reader before concluding the work done. It then reviews the research methodology adopted and lists out the general findings and inferences therefrom.

This is followed by a summary of the analyses undertaken, the outcomes and the inferences. It, next, discusses the limitations of the research, and goes on to bring out the contribution to knowledge.

Thereafter, it provides an overall conclusion to the study, and then briefly brings out the answers to the research questions, closing the circle which started from the research framework in Chapter 1.

Finally, the recommendations for policy, logistics management, and future work are discussed before closing the discussion with concluding remarks.

Chapter 2 Literature Review

2.1 The Approach to Literature Review

The domanial positioning of the study guides the literature review, which comprises the specific aspects of each domain at the intersection of which the study is posited (Section 1.10).

2.2 Supply Chains and Supply Chain Management

Five schools of thought characterise SCs and Supply Chain Management (SCM) progressively (Bechtel & Jayaram, 1997): -

- **Functional Chain Awareness School** recognises the existence of associated areas of functionality (chain of functional areas) across a business unit (BU).
- **Linkage/Logistics School** recognises the chain from suppliers to end users, addressing material flows through it.
- **Information School** emphasises information flow between SC actors.
- **Integration/Process School** adds value by adopting the systems approach to integrate SC areas into a set of processes representing a system.
- **Future School** focuses on transactions and relations supported seamlessly by a demand-driven pipeline.

2.2.1 Definitions

Literature defines the SC from two perspectives, i.e., focussing on basic SC elements, encompassing a beginning and an end, with the intermediate space occupied by the flow of goods (commencing with raw materials, followed by activities resulting in value addition, finally transferred to the consumer), and a comprehensive view of the SC by integrating extra activities. From these perspectives, certain important definitions of an SC in literature are: -

- *"A structured manufacturing process wherein raw materials are transformed into finished goods, then delivered to end customers"* (Beamon, 1998).

- *"Supply chain refers to the organisation's network that is involved in the diverse processes and activities that generate value in the form of goods and services in the hands of the end customer"* (Christopher, 1998).
- *"A set of three or more entities (organisations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer"* (Mentzer *et al*., 2002).
- *"A chain starting with raw materials and finishing with the sale of the finished good"* (Tecc.com.au, 2002, as cited in Janvier-James, 2012).
- *"Supply Chain is the group of manufacturers, suppliers, distributors, retailers and transportation, information and other logistics management service providers that are engaged in providing goods to consumers. A Supply Chain comprises both the external and internal associates for the corporate"* (Chow & Heaver, 1999, as cited in Janvier-James, 2012).
- *"The combined and coordinated flows of goods from origin to final destination, also the information flows that are linked with it"* (Little, 1999, as cited in Janvier-James, 2012).
- *"A general description of the process integration involving organisations to transform raw materials into finished goods and to transport them to the end-user"* (Pienaar, 2009, as cited in Janvier-James, 2012).
- *"Supply Chain as life cycle processes involving physical goods, information, and financial flows whose objective is to satisfy end consumer requisites with goods and services from diverse, connected suppliers"* (Ayers, 2001, as cited in Janvier-James, 2012).
- *"A connected set of resources and processes that starts with the raw materials sourcing and expands through the delivery of finished goods to the end consumer"* (Bridgefield Group, 2006, as cited in Janvier-James, 2012).
- *"Starting with unprocessed raw materials and ending with the final customer using the finished goods, the supply chain links many companies together; the*

> *material and informational interchanges in the logistical process stretching from acquisition of raw materials to delivery of finished products to the end user. All vendors, service providers and customers are links in the supply chain"* (Council of Supply Chain Management Professionals [CSCMP], n.d.).

2.2.2 Supply Chain Complexity

SCs are classified into three categories based on their degree of complexity *viz* Direct, Extended, and Ultimate SCs. A 'Direct SC' comprises a business unit, a supplier, and a customer, participating in product, information, funds, and services flows upstream as well as downstream. When parties supplying to immediate supplier and customers of the immediate customer of the BU under consideration participate in these flows, the SC is referred to as an 'Extended SC'.

The 'Ultimate SC' includes all BUs involved in the complete upstream as well as downstream flows between the ultimate supplier and the ultimate consumer (Mentzer *et al*., 2002).

Figure 2.1 illustrates SC complexity.

Figure 2.1

Degrees of Supply Chain complexity

Note. (Mentzer *et al*., 2002)

SCs are formed in businesses to reduce inventory investment, enhance customer service, and increase the channel's competitive advantage (Cooper, 1993, as cited in Cooper & Ellram, 1993).

2.2.3 Supply Chain Life Cycle

Like all other business entities and projects, an SC also has a life cycle, evolving from its setting up through maturing and final dispersal of elements (when the SC outlives its requirement) (MacCarthy *et al*., 2016).

The inherent fragmentation in the construction industry and the temporary nature of organisations, set up both for the project as well as its individual stages and processes, makes the concept of the SC life cycle significant. Four stages characterise the SC life cycle (MacCarthy *et al.*, 2016): -

- **Emergence** An SC emerges upon being set up. At this time, it may be called a new SC. In this earliest SC life cycle part, different technologies and SCs may compete, all of which may not succeed. The emergence of a new SC may disrupt existing ones.

- **Growth** During this phase, the SC sees rapid growth in its use. This is accompanied by improvement in performance and the stabilisation of its processes and enabling technologies. A physical SC would see increased throughput, while a virtual SC could see the increased intensity of information, knowledge sharing, and services.

- **Maturity** Consistency in demands on an SC marks its maturity phase. A high level of certainty in its operations exists, enabled by strong underlying technology and processes. As a result, the quantum of changes in the SC is minimal as a result of actions triggered by consistency and maturity of demand.

- **Decline** Declining demands on the SC or its substitution by another SC result in decreasing throughput. It may also be the outcome of acquisitions and mergers.

Factors affecting SC performance in its operating phase are: Supply network configuration (centralisation or dispersal of production and sourcing); Strategy for delivery (means to reach the customer *viz* delivery ex-plant, ex stock-point, ex-retailer, or from some other nominated location); Decoupling point (DP) between the customer and the order *viz* Engineer/Make/Assemble-to-Order (ETO/MTO/ATO), Make-to-Stock (MTS), or a combination of these; Strategic upstream inventory positions; Strategic capacity positioning (additional upstream capacities to absorb oscillating demands); Transportation mode (considering costs, lead-time, geography, environmental impacts etc.); Production technologies, Customisation and/or standardisation based process choice; and, SC relationships (contracting, information sharing, and governance, with suppliers and customers).

A brief discussion of these factors is as follows (MacCarthy *et al*., 2016): -

- **Technology and innovation** Technology influences the speed, transition dynamics, and probability of disruptive change and can make SCs more responsive by reconfiguring or eliminating processes.

- **Economics** SCs are influenced by both direct (cost of resources and processing) and indirect costs (transportation, energy, water, capacity investment, currency exchange and local inducements). These impact outsourcing strategies, SC configuration, associations, and networks.

- **Markets and competition** Affect the speed of SC development, customisation, and fulfilment solutions.

- **Policy and regulation** SCs are shaped by national and international policies (due to globalisation) and industrial politics, especially in the case of NZ (a deregulated import-dependent market and sustainability focussed government). These factors significantly impact infrastructure investments, tax benefits, and the skillset of staff planning and managing SCs.

- **Procurement and sourcing** SCs are shaped by sourcing products and raw materials. Sourcing policies, sourcing decisions, low-cost country sourcing, global sourcing, nearshoring etc., affect SC configuration. Innovation, flexibility, risk, and sustainability complement purely economic considerations.

- **SC strategy and re-engineering** SC strategy is differentiated from procurement/sourcing by its nature, scale, and effects. A changing competitive landscape, internal as well as external to the SC (better or customised service, new opportunities, and better operational/cost-based performance etc.), demands its reconfiguration or re-engineering.

2.3 Supply Chain Management

2.3.1 A Historical Perspective

From 1975 to 1990, most BUs were configured vertically, analysing and mapping their operations to understand the possible benefits of cross-functional integration (Kumar & Chandra, 2000). Logistics literature presented the term ‘Supply Chain Management’ in 1982.

At the time, the concept had an inventory management perspective with raw material supply as its primary focus (Oliver & Webber, 1982, as cited in Van der Vorst, 2004).

1990 saw the commencement of organisational structures aligning with processes rather than vice-versa. In addition, information technology (IT) tools such as Enterprise Resource Planning (ERP), Distribution Requirements Planning (DRP), e-commerce, and product data management etc., strengthened businesses and their processes.

Manufacturing paradigms (from where most management theories emerge) introduced concepts like Design for X (DfX), synchronous manufacturing, agile manufacturing, etc., shifting the economic focus from extracting maximum price advantage from immediate partners to the total cost.

Flexibility across production sites led to the review of processes and organisational functioning as a result of the shift from standardisation to customisation. Rule-based decision support for management made an appearance (Cooper & Ellram, 1993; Kumar & Chandra, 2000).

Theory lagged SC practice in the late 1990s, leading to fragmented islands of knowledge and preventing large-scale adoption of SCM (Min *et al*., 2019). SC optimisation, excellence, and integration are the focus areas of BUs for their structural as well as operational management *viz* arrangement of suppliers of goods and services, products and services demand, flow network management, business philosophy, and competitive advantage through coordination and synchronisation.

Integration efforts have focussed on organisational structure, coordination, relationships, intra- and inter-enterprise communication, operational orientation, sourcing, and resource (including cost) management (Cooper & Ellram, 1993; Kumar & Chandra, 2000).

2.3.2 Definitions

Some pertinent definitions of SCM from literature, in chronological order of their formulation, are as follows (LeMay *et al*., 2017): -

- *"Supply chain management deals with the total flow of materials from suppliers through end users..."* (Jones & Riley, 1985).
- *"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"* (Stevens, 1989).
- *"Supply chain management is an integrative philosophy used to manage the total flow through a distribution channel from the supplier to the ultimate user"* (Ellram, 1990; Macbeth *et al*., 1989).
- *"An integrative philosophy to manage the total flow of a distribution channel from the supplier to the ultimate user"* (Cooper & Ellram, 1993).
- *"... two or more firms in a supply chain entering into a long-term agreement; the development of trust and commitment to the relationship [...] the integration of logistics activities involving the sharing of demand and sales data [...] the potential for a shift in the locus of control of the logistics process"* (La Londe & Masters, 1994).
- *"Supply Chain Management incorporates the integration of activities taking place among facilities network that acquire raw material, transform them into intermediate products and then final goods, and deliver goods to customers through a system of distribution"* (Lee & Billington, 1995).
- *"SCM is the integration of business processes from end user through original suppliers that provides products, services and information that add value for customers"* (Cooper *et al*., 1997).

- *"SCM is the integrated planning, coordination and control of all business processes1 and activities in the supply chain to deliver superior consumer value at less cost to the supply chain as a whole whilst satisfying requirements of other stakeholders in the supply chain (e.g., government and NGO's)"* (Van der Vorst, 2004).

- *"The integration of key business processes from end-user through original suppliers, that provides products, services, and information that add value for customers and other stakeholders"* (Lambert *et al*., 2006).

- *"Management of a chain or of operations and centres through which supplies move from the source of supply to the final customer or point of use"* (Compton & Jessop, as cited in Quayle, 2006).

- *"Supply Chain Management is the maintenance, planning, and Supply Chain processes activity for the satisfaction of consumers' needs"* (Ayers, 2001, as cited in Janvier-James, 2012).

- *"Supply Chain Management refers to corporate business processes integration from end users through suppliers that provides information, goods, and services that add value for customers"* (Lambert *et al*., 2006, as cited in Janvier-James, 2012).

- *"Supply Chain Management refers to a set of methods used to effectively coordinate suppliers, producers, depots, and stores, so that commodity is produced and distributed at the correct quantities, to the correct locations, and at the correct time, in order to reduce system costs while satisfying service level requirements"* (Simchi-Levi *et al*., 2008, as cited in Janvier-James, 2012).

- *"…the integration of key business processes from end user through suppliers that provide goods, services and information that add value for customers"* (Supply Chain Forum [SCF], as cited in Janvier-James, 2012).

- *"A chain of facilities and distribution alternatives that performs the functions of obtainment of products, transformation of these products into intermediate and* *finished goods, and the distribution of these finished goods to customers"* (Ganeshan & Harrison, 1995, as cited in Janvier-James, 2012).

- *"…the systemic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole"* (Mentzer *et al*., 2002).

- *"Supply chain management is simply the management of transport or flow of goods and services, it also includes storage, shelf life, analysis of goods procured and goods sold logistics, etc. Supply chain management helps in planning and executing various supply chain activities of a particular organisation to build up a net value of the organisation, determining the current market trend related to the demand and supply of any goods or services and synchronizing the same for measuring the performance of the organisation"* (Jaggi & Kadam, 2016).

- *"Supply chain management (SCM) is defined as the integration of key business processes from end users through original suppliers that provide products, services and information which add value to customers and other stakeholders"* (Desai & Rai, 2016).

- *"SCM is the task of integrating organisational units along a supply chain and coordinating materials, information and financial flows to fulfil customer demands to improve the competitiveness of the supply chain as a whole"* (Dias & Ierapetritou, 2017).

- *"Supply Chain Management is the key business processes from end-user through original suppliers that provides products, services, and information that add value for the customer and other stakeholders"* (Wibowo *et al*., 2017).

- *"Supply Chain is defined as a system of organisations, people, activities, information, and resources involved in moving a product or service from supplier to customer. Supply chain activities involve the transformation of natural resources, raw materials, and components into a finished product that is delivered to the end customer. The network of organisations that are involved, through* *upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer"* (Kaina & Verma, 2018).

- *"SCM is known as the integration of business processes from end users through original suppliers that provides products, services, and information to add value for customers, SCM has become a source of competitive advantage for companies from various industries"* (Oleze *et al*., 2018).
- *"The process of planning, implementing, and controlling the operations of the supply chain with the purpose to satisfy customer requirements as efficiently as possible. SCM spans all movement and storage of raw materials, work-in-process inventory, and finished goods from point-of-origin to point-of-consumption"* (Martins & Pato, 2019).

2.3.3 SCM Perspectives

SCM may be viewed from three perspectives, *viz* as a philosophy for management, as activities for implementing this philosophy, and as processes for management (Mentzer *et al*., 2002).

SCM as a Management Philosophy

This perspective views the SC as a single entity using a systems approach instead of distinct functions being performed by fragmented elements (Houlihan, 1988).

It extends partnerships into the multi-organisational domain managing the entire flow of goods from the supplier to the final consumer (Ellram, 1990; Jones & Riley, 1985, as cited in Mentzer *et al*., 2002).

SCM is founded on the idea that the performance of each SC component influences the performance of all others (directly or indirectly), hence impacting the overall performance of the SC (Cooper *et al.,* 1997).

As a management philosophy, SCM emphasises the convergence and synchronisation of intra- and inter-organisational strategic and operational capabilities. Incorporating logistics and all other operations into the SC, it stimulates innovative solutions to focus on customer value generation (Langley & Holcomb, 1992), giving the SC a customer leaning.

The following attributes characterise it: A systems approach resulting in a strategic orientation and holistic view; Managing the complete flow of goods between the ultimate supplier and the ultimate customer; Cooperative efforts to achieve synchronisation and convergence at the intra- and the inter-organisation levels; and, A customer-oriented focus for value generation.

SCM as a Set of Activities to Implement a Management Philosophy

For implementing SCM as a philosophy, certain management practices need to be essentially adopted by the SC members.

These are as follows (Andel 1997; Anderson & Narus, 1990; Bowersox & Closs, 1996; Cooper *et al*., 1997; Ellram & Cooper, 1990; Heide & John, 1990; La Londe & Masters, 1994; Lambert & Cooper, 2000; Lassar & Zinn, 1995; Treleven, 1987): -

- **Integrated behaviour** BUs need to expand integration externally to include customers and suppliers, the coordinated effort responding dynamically to customer needs.

- **Information sharing** Readiness to make available strategic and tactical data (e.g., sales/marketing strategies, inventory, forecasts, etc.) to other SC members. It improves performance by reducing uncertainty, enabling efficient planning, and monitoring processes between members of an SC.

- **Risk sharing** Achieving competitive advantage through sharing of rewards as well as risks between members of an SC over the long term.

- **Co-operation** Coordinated and complimentary activities by SC members lead to superior mutual or mutually expected singular outcomes. Co-operation must be considered across the temporal dimension and management hierarchy, involving cross-functionality.

- Joint planning and joint control for evaluation at the local (member) and global (SC) level facilitate cooperation.

- **Joint action** Cooperatively undertaking focal activities through joint planning and evaluation involves long-term processes. Planning, control, and co-operation lead to cost and inventory optimisation and efficient product development. Quality Assurance/Control and design of delivery systems also form part of joint action.

- **Common goal and focus** Common goals and focus demonstrate policy integration across the SC, leading to resource optimisation by preventing redundancy and overlap.

- **Integration of processes** Cross-functional teams, integrated staff, and third-party service providers can all assist in process integration.

- **Partners for long-term relationships** The temporal extent of the relationship needs to extend beyond the contract life, with a limited number of partners facilitating increased cooperation.

Integration of SCs takes place in four stages (Lambert *et al*., 1998) (Figure 2.2): -

- **Stage 1 (Baseline)** Fragmented operations within individual BUs typically exhibiting large inventories, incompatibility between procedures and their controls, and segregated functionality.

- **Stage 2 (Internal focus on integration)** Emphasis on cost reduction, not improvement of performance, inventory buffers, internal trade-off evaluation, and reactive rather than proactive service delivery to the customer.

- **Stage 3 (Internal integration)** Visibility of functions from procurement through distribution, medium-term planning, tactical focus (strategic focus still not achieved), efficiency-based performance, linkage support through electronic systems, and reactive customer approach.

- **Stage 4 (External Integration)** SC integration expanded external to the BU to upstream to suppliers and downstream to customers.

The staged integration can be taken as a progression along the five schools of thought put forth by Bechtel & Jayaram (1997).

Figure 2.2

An integrated supply chain

Note. (Lambert *et al*., 1998)

SCM as a Set of Management Processes

A process is a specific order for work across temporal and spatial dimensions, comprised of a defined beginning, inputs/outputs, end, and structure (Cooper *et al*., 1997). All SC members must adopt a process approach outside their internal verticals, reorganising all SC functions as key processes, each focusing on fulfilling the customer's needs.

Member BUs need to be organised around these processes, typically for managing relationships, service delivery, demand, fulfilling orders, the flow of manufacturing, procurement, and development of products and their commercialisation (Mentzer *et al*., 2002).

The Concept of Vertical Integration

SC integration may be viewed from four perspectives *viz* Integration of organisations (customer, supplier, and internal integration), Integration of processes, Integration of the flows (products/services, information, money, and decisions), and Level of integration (Fabbe-Costes & Jahre, 2008; Kumar *et al*., 2017).

These translate into the degree of collaboration between the actors and the seamless flow of elements in the network (Ansaha & Akipelub, 2021).

The extent of control exerted by an organisation or a BU on producing its own inputs or supply material/resources and/or the distribution of its outputs is referred to as VI. It enables the reduction of transaction costs, at the same time improving the company's market power (Mpoyi, 2003). The literature attributes varied meanings to the concept of VI with the fundamental idea of internalising certain operations by a company or BU instead of involving an external stakeholder (Hamdaoui & Bouayad, 2019).

A formal definition for VI is *"…the combination of technologically distinct production, distribution, selling and/or other economic processes within the confines of a single firm"* (Porter, 1980, p. 300). Two forms of VI are identified in the literature: forward and backward (Barreyre, 1988; Rangan *et al*., 1993).

A perspective of upstream and downstream actors and SCs from the viewpoint of a BU will clarify the VI stance (Nicovich & Dibrell, 2007; Guan & Rehme, 2012): -

- Upstream actors can contribute value by converting raw materials into standardised commodities because they are located closer to the SC's material end. In addition, process and cost-oriented mechanisms that facilitate achieving lower costs are likely to result in a competitive advantage. This perspective is the 'backward' VI.

- Downstream actors, closer to the SC's consumption end, add value through publicity, positioning, and marketing. This is 'forward' VI, which provides manufacturers control over marketing. In such cases, distribution and selling risks become inherent.

Customer integration forms a part of the forward VI concept. It provides a BU or company with insights into the needs and requirements of a customer, presenting the advantage of better service. It also enables drawing on important information, e.g., buying patterns, product preference, and purchasing ability, for improved manufacturing and sales decision-making (Lotfi *et al*., 2013).

Forward VI of suppliers into a distributive stage can be motivated by a desire to achieve product differentiation, acquire or consolidate a market position, or develop a distinct image and brand loyalty (Etgar, 1978).

Contrary to commanding higher prices, suppliers may forego these to achieve long-term survival or, at times, a continuing monopoly in the market. One of the important mechanisms for achieving this is providing customers with a higher level of services in the distribution domain. The drivers for VI in a firm (with specific reference to forward VI) are as follows (Guan & Rehme, 2012): -

- **Technical complexity** The focus of value addition shifts away from manufacturing to service and maintenance in the case of products with high market penetration and comparatively longer life spans.

- **Differentiation** Distribution for product differentiation is invariably used in case the product attributes do not make them easily differentiable in the marketplace. This may be due to physical attributes compared to other products and/or consumer perception.

- **Higher margins** Downstream markets offer important benefits such as large new revenue sources, requiring fewer assets than product manufacturing.

- **Customer demand for integrated solutions** The focus of customers on their core competencies increases their reliance on suppliers to provide solutions integrable with their business processes.

- **Synergy** If a supplier is able to enter the consumer’s decision-making processes, very high business synergies can result. E.g., if a supplier is involved in the inventory management function of a customer, they can gain significant insights into timely and accurate demand information, enabling effective use of lead-time to change or modify manufacturing plans.

- **Learning** Customer information and knowledge gained through downstream or forward integration facilitates understanding of the customers’ perspectives on the supplier’s offerings (why or why not they may be desirable) and, therefore, the means to provide them, and future product/service development.

In logistics and SC literature, performance is considered a difficult and multidimensional construct. Fabbe-Coste and Jahre (2008) define firm performance as the measurement and establishment of causal links between the activities performed by an organisation and their outcomes.

Organisational or firm performance is perceived as a two-dimensional construct comprising operational and financial performance. When evaluating how SC integration impacts operational performance, the variables typically used are cost-effectiveness, quality, delivery speed, efficiency, and flexibility (Wong *et al*., 2011).

Financial performance may be assessed using parameters such as return on investment (ROI), return on sales (ROS), ROI/ROS growth, yield, and market share (Flynn *et al*., 2011). However, these may need to be considered only indicative since VI in an SC is multi-dimensional. Significant information loss is likely if summarised in a single statistic or parameter (Martin, 1986). Utilising different parameters or metrics, each associated with operationalising a particular integration dimension, is likely to provide complimentary insights into such a complicated phenomenon (Mpoyi, 2003).

In this study, the transport function in an SC integrating the distribution function (forward VI demonstrating customer integration) is being investigated as a measure of efficiency improvement.

2.4 The Construction Supply Chain and its Management

2.4.1 The Construction Supply Chain

The structure and functioning of a CSC have certain typical characteristics (Vrijhoef & Koskela, 1999, 2000): -

- A converging SC directing materials on-site for assembly of the built asset (the product).
- A singular product (the built asset) around which the ‘manufacturing plant’ is set up, unlike manufacturing, where the manufacturing facility processes multiple products.
- The temporary nature of the SC due to the involved project organisations being repetitively reconfigured based on the project requirements (leading to instability, fragmentation, and delineated design and implementation).

- Each project being a prototype (unique), hence the nature of the CSC being a Make-to-Order SC.

The above characteristics lead to the following factors impacting CSCs and their functioning (Behera *et al.*, 2015): -

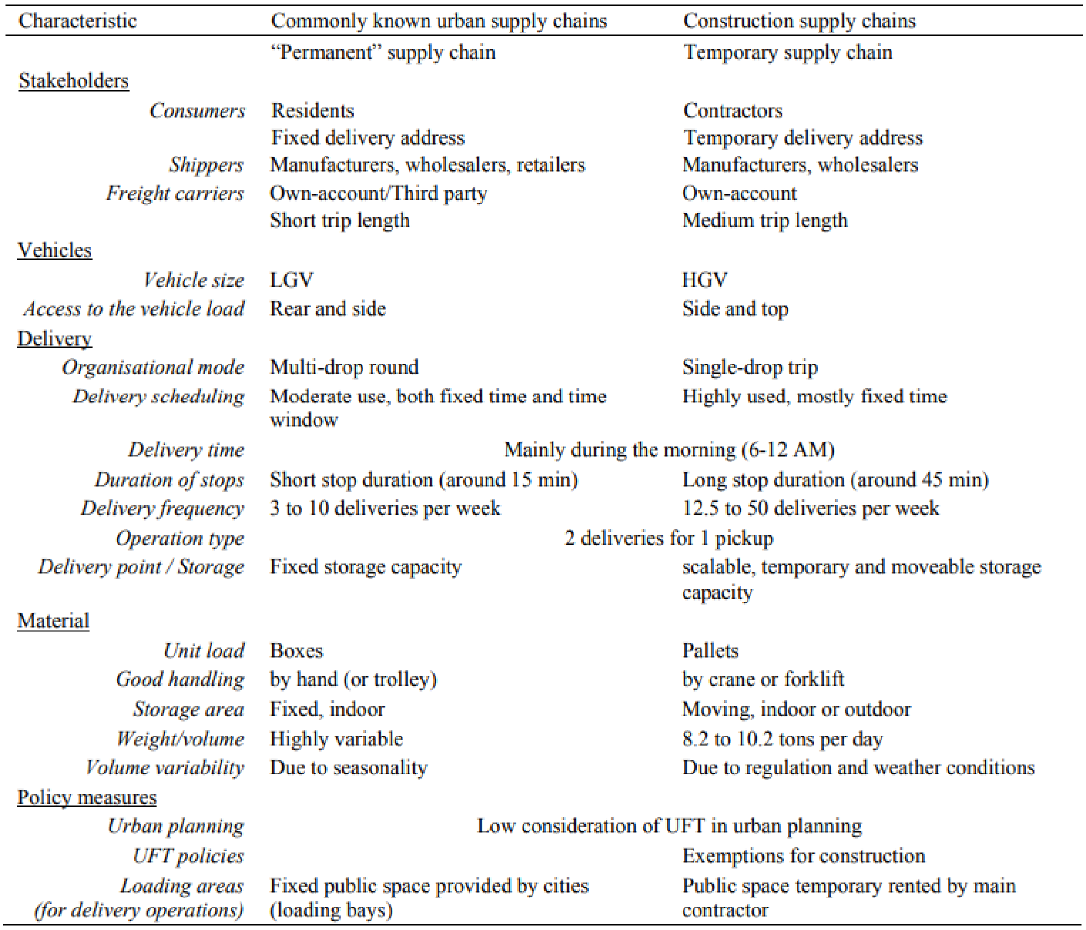
- The project, especially logistics are substantially client-influenced.
- Multiplicity of business purposes, actors, and methods fragments the SC.
- Varied stakeholders (clients, design consultants, construction contractors, and suppliers belonging to different organisations creates a maze of relationships including flows of information, material, services, and finances between them).
- An environment rife with conflict, mistrust, and profit-orientation from transactional buyer-supplier relationships.
- Temporarily configured organisations (project-based orientation resulting in fragmentation, adversarial relationships, and opportunistic environment).
- Conservative risk-driven perspectives create inertia to change in construction related organisations.
- The owner commences and terminates a ‘make-to-order’ (MTO) SC related to the construction project.
- Fragmentation leads to substantial collaboration opportunities that need to be explored.
- Cyclical demand for the artefact (built asset) as a result of its non-transportability and durability.

An understanding of its complexity needs to consider the large number of relationships that originate during the course of the project between the various actors and stakeholders.

A CSC's planning, management and operational issues are impacted by its fundamental differences from other common SCs (Guerlain *et al.*, 2018) (Table 2.1).

Table 2.1

Differences between construction supply chains and other common supply chains



Characteristic	Commonly known urban supply chains	Construction supply chains
	"Permanent" supply chain	Temporary supply chain
<u>Stakeholders</u>		
Consumers	Residents Fixed delivery address	Contractors Temporary delivery address
Shippers	Manufacturers, wholesalers, retailers	Manufacturers, wholesalers
Freight carriers	Own-account/Third party Short trip length	Own-account Medium trip length
<u>Vehicles</u>		
Vehicle size	LGV	HGV
Access to the vehicle load	Rear and side	Side and top
<u>Delivery</u>		
Organisational mode	Multi-drop round	Single-drop trip
Delivery scheduling	Moderate use, both fixed time and time window	Highly used, mostly fixed time
Delivery time	Mainly during the morning (6-12 AM)	
Duration of stops	Short stop duration (around 15 min)	Long stop duration (around 45 min)
Delivery frequency	3 to 10 deliveries per week	12.5 to 50 deliveries per week
Operation type	2 deliveries for 1 pickup	
Delivery point / Storage	Fixed storage capacity	scalable, temporary and moveable storage capacity
<u>Material</u>		
Unit load	Boxes	Pallets
Good handling	by hand (or trolley)	by crane or forklift
Storage area	Fixed, indoor	Moving, indoor or outdoor
Weight/volume	Highly variable	8.2 to 10.2 tons per day
Volume variability	Due to seasonality	Due to regulation and weather conditions
<u>Policy measures</u>		
Urban planning	Low consideration of UFT in urban planning	
UFT policies		Exemptions for construction
Loading areas (for delivery operations)	Fixed public space provided by cities (loading bays)	Public space temporary rented by main contractor

Note. (Guerlain *et al*., 2018)

Figure 2.3

Three components of the construction supply chain

Note. (Cox & Ireland, 2002)

Figure 2.3 illustrates the three types of CSCs that participate in the execution phase of a construction project *viz* the **Primary SC,** for delivery of material to be incorporated into the final construction project, the **Support Chain** focussing on equipment, expertise, and materials facilitating construction, and the **Human Resources SC** concerned with providing labour.

The component SCs of a CSC function as follows (Behera *et al*., 2015; Butković *et al.*, 2016; Cox & Ireland, 2002; Muya *et al*., 1999): -

- **Material flow** Initiated by orders from the contractor, materials are delivered on-site at agreed times by suppliers either all at once or as per the requirement of the site.

- There can be three types of delivery processes for materials, i.e., customised materials, standard materials, and small purchase delivery chains. Delay in material flow is linked to the material management quality, impacting labour efficiency significantly.

- **Labour flow** The management of labour flow on a construction project, most construction projects being labour intensive. Labour-related issues such as shortages, low skill levels, poor motivation, and low productivity levels may adversely impact the construction project.

- **Plant, equipment and temporary workflow** Construction project cost-effectiveness and delivery efficiency heavily depend on temporary works and equipment, which are the contractor's responsibility.

- This classification of workflow enables effective and efficient equipment and labour performance. Equipment shortages, low efficiency, breakdowns, and incorrect selection may impact the project adversely.

SCM is ideally suited for integrating internal and external actors because of the pervasive fragmentation in the construction industry. The emphasis needs to be on the project rather than the organisation due to the highly individualised requirements of construction projects and frequent SC redesign during the project life cycle. SCM best practices can improve scheduling (buffer design and placement for risk mitigation against changes and uncertainty), co-ordination with sub-contractors (linking resource management to the site), and accounting and production control by modelling of sub-contractor and supplier production (Tiwari *et al*., 2014). SCM may be undertaken at four different levels (Harland, 1996): -

- Integration of firm activities by managing the internal SC.
- Controlling a dyadic relationship between two directly related suppliers.
- Managing a network of businesses with which an organisation is not contractually related.
- Managing a network of associated organisations that are ultimately responsible for providing a product to customers.

Based on the above levels of SCM implementation, Vrijhoef & Koskela (1999, 2000) identify certain roles that CSCM may perform for improving the construction process as a whole, with the focus on the construction site, as well as the associated SC (illustrated in Figure 2.4): -

- **Focus on the impacts of the SC on site activities** Focus on the relationship between the construction site and the direct suppliers improves the dependability of material and labour flows. This prevents disruption, reducing the duration and costs of on-site construction activity. This focus best suits the contractor. Buffering may be adopted to achieve resource delivery dependability without addressing the complete SC.

- **Focus on the SC** May be adopted by suppliers to reduce inventory, logistics, and lead-time costs. Uncertain customer activities cause objective limitations. Problems plague the delivery process at both ends, the product definition being incomplete at the beginning, and changes in delivery schedule and chaotic conditions towards the end. The CSC needs to be shielded or made robust in relation to these.

- **Focus on transferring activities from the site to earlier stages of the SC** As a measure for improving site conditions or achieving activity concurrency (difficult on site due to many technical dependencies) towards time and cost reduction. This focus is typically adopted by suppliers and contractors.

- Transferring activities off-site (e.g., industrialised construction) changes the structure and, therefore, total process behaviour. As a result, the process becomes longer (requiring more substantial design inputs), has a longer loop for error correction, and requires higher dimensional accuracy.

- These factors make the overall process more complex and vulnerable to variability, even though the complexity of the on-site process is reduced. Transfer of activities off-site demands better SCM to take full advantage of the expected benefits.

- **Focus on integrated management for improving site production and the SC** This perspective subsumes site production into SCM. This focus may be initiated by multiple stakeholders, *viz* suppliers, clients, and/or contractors.

- Many existing initiatives are founded on the effectiveness of SCM when associated with stable SCs and standardised products (even if they need to be customised).

- These, however, restrict market opportunities and the broad spectrum of construction demand. On the other hand, measures such as introducing the agile paradigm may lead to exploiting profitable opportunities presented by market volatility.

Figure 2.4

The four roles of supply chain management in construction

Note. (Vrijhoef & Koskela, 2000)

In addition, Ekeskär & Rudberg (2016) and Fredriksson *et al*. (2021) define two more roles for CSCM *viz* a focus on the logistics of the construction site and logistics coordination with the local community. Further, Ekeskär *et al*. (2022) identify a seventh role *viz* coordination between multiple projects (effectively addressing lateral fragmentation).

2.4.2 CSCM Implementation

Implementing CSCM is divided into two schools of thought, one based on equitable distribution and the other based on power regime (Adetunji *et al*., 2008): -

- **School of thought 'A'** This propounds equitable relation-based collaboration resulting in operational efficiency and effectiveness as a solution to adversarial culture, fragmentation, and low profit margins. It identifies commitment (trading parties working towards sustaining the relationship), trust (parties acting for mutual benefit), and win-win scenarios (not acting opportunistically but towards a common goal) as crucial factors.

- This approach is a simplistic view of the difficulty in developing and maintaining inter-organisation relationships. Moreover, the nature and complexity of construction prevent this approach from being appropriate for all players in all circumstances.

- **School of thought 'B'** This school of thought propounds power regime-based collaboration for SCM-based strategic efficiency and effectiveness. The manifestation is in the form of a structural hierarchy consisting of suppliers dependent on a dominant player, who are effectively forced to pass value as they pose no threat to the flow of value appropriation to the dominant player. The possibility of pro-active SCM application in this scenario depends on high purchasing power, work pipeline certainty, and extensive domain competence and knowledge, enabling buyers (clients) to work collaboratively with other actors to achieve best-value objectives.

Both schools of thought agree on certain issues: Co-ordinated teamwork for internal and external alignment; Flexible, open, and adaptive organisations through cross-functional integration; Innovation driven by information exchange and knowledge transfer;

Effective communication; Willingness to share information; Mutual support and commitment to common goals; and, Continuous improvement.

Figure 2.5 illustrates the two schools of thought.

Figure 2.5

Schools of thought pertaining to construction supply chain management

Note. (Adetunji *et al*., 2008)

Integration in both cases is driven by competitive and/or operational advantages gained through higher efficiency and productivity, resulting in higher value addition and improved delivery of value to the client. General contractors (GCs), architects, or material suppliers can all act as system integrators. Competitive and operational advantage tends to be gained through applying multi-project management strategies in integrated SCs and building long-term relationships between closely linked actors. In practice, though, the outcomes of higher levels of integration and outsourcing may sometimes be obscure (Nobeoka & Cusumano, 1997).

2.5 Logistics and Logistics Management

2.5.1 Definitions

One of the initial definitions of Logistics, formulated by the then Council of Logistics Management (CLM) (now CSCMP) in 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 (CLM, as cited in Cooper *et al*., 1997)

The definition of logistics and the discussion of SCM in the preceding sections makes clear that while logistics is primarily about the flow of materials and associated information, SCM pertains to the flow of information, materials, finances, workforce, and capital equipment. CSCMP has defined the management of logistics as,

> Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfilment, logistics network design, inventory management, supply/demand planning, and management of third-party logistics services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution--strategic, operational, and tactical. Logistics management is an integrating function, which coordinates and optimises all logistics activities, as well as integrates logistics activities with other functions including marketing, sales manufacturing, finance, and information technology (CSCMP, n.d.)

2.5.2 A Historical Perspective

Broadly, the evolution of logistics may be categorised into four stages (Szymonik, 2012) *viz*: -

- **Stage One** The producers' market dominated the period up to the 1950s, with conceptually non-integrated fragmentary logistics operations in the silo-based BU organisation. These primarily pertained to Supply (source selection, purchase, inventory, and stockpiling); Storage (storage, packaging, and transportation); and, Distribution (supply order management, stocking of finished goods, transportation, and customer service).

- **Stage Two** Shifting of the market from a producers' market to a consumers' market, marked the 1950s to the 1970s era. Customer demand needed to modulate rapidly growing supply capability. Logistics solutions include physical distribution (timely delivery at the right price) and materials management (purchase, supply, or distribution). Both these were considered separate domains, associating materials management with supply and distribution with sales.

- **Stage Three** The 1980s and 1990s saw coordination emerge between supply and distribution, leading to one coherent operation. A systemic view of logistics undertakings and procedures began to be taken, with the objectives of profit maximisation, strengthening market position, and flexibility in adapting to the environment.

- IT and management were introduced into the domain as problem-solving tools, e.g., automatic identification (bar codes), Just in Time (JIT), Material Resource Planning (MRP), Activity Based Counting (ABC) etc.

- **Stage Four** 1990s onwards, logistics expanded external to the BU, adopting the domain of goods/services and the associated information flow, comprising Micro, Meta, Macro, Euro, and Global logistics.

- The period saw logistics development based on information systems, local/wide area networks (LAN/WAN), internet and intranet. The arrival of electronic markets saw the introduction of Business-to-Business (B2B) and Business-to-Customer (B2C) business models.

2.5.3 Logistics Processes

The physical implementation of logistics functions is enabled through logistics processes. These may be: -

- Orderly temporal sequences of successive conditions and changes (some physical state carries every process, and every new state/change has a previous state/change or external influence as its causative factor).

- A set of logically associated tasks and activities for achieving a business result.

- Changes through transforming input data into outputs, with due regard to adding value to a product/service, risk, and information.

Spatial and temporal attributes define logistics processes in the domain of the physical flow of goods/services (supply, distribution, and transport from origin to destination), the flow of associated information, and risk assessment for each action. Logistics processes may be defined on the basis of (Szymonik, 2012): -

- **Value creation** processes are classified as: Primary (Main) processes - Those that create value through direct relationships with customers; Secondary (support) processes - Those that create value through indirect relationships with customers; Tertiary processes - Those that create value through a conditional relationship with customers; and, Waste - Those that do not create any value, or do not have any relationship with customers.

- **Quantum of value-addition** Classified as: Executive processes - All important activities of BU associated with high value addition which the customer is willing to pay for (e.g., provision of transport services, warehousing, selection etc.); Support processes - essential but non-value-adding activities (e.g., packing, labelling); and, Developmental processes - Increase executive and support process efficiency (e.g., market research, product design, training etc.)

Logistics processes are comprised of: materials flow and procurement, information management (collection/processing/transmission), decision-making, stocking, infrastructure, costs, procurement, warehousing and inventory management, packaging, transport, management of waste, and service delivery (Ghiani *et al.*, 2004; Szymonik, 2012).

Material Flow Processes

Material flow processes enable improving the management of product flow processes by all logistics chain actors.

As a result, all activities are subordinated to value addition and achieving customer expectations while reducing logistics costs.

The ‘7R' principle governs material flow processes, i.e., seven rights (corrects) *viz* product, quantity, quality, time, place, information, and cost.

Management tasks such as planning, organising, controlling, coordinating, and decision-making assist in making material flow processes more efficient and effective (Ghiani *et al.*, 2004).

The primary classification of these processes is as follows (Nguyen *et al*., 2008): -

- **Real processes** The real sphere related physical processes leading to physical flows. These are described by real variables, e.g., selection, packaging, shipping, and warehousing.

- **Regulatory processes** These are management tools comprising non-physical processes. They reflect instantaneous situations, e.g., perception, collection, processing, and transmission of information, and decision-making.

Systems for the physical flow of materials may be classified based on the following: -

- **Logistics systems employed** Micro (within individual BUs); Meta (within the integrated system formed by the logistics systems of co-operating entities); Meza (VI meta-logistics subsystems); Macro (integration of flows with the wider economy); and, External (between suppliers and receivers).

- **Functional criteria** Include Supplies; Materials; Production; Outlets; Returns; Waste; Packaging; Marketing; and, Suppliers/Receivers.

The material flow process phases across the SC are: Raw material acquisition and processing; Processing of semi-finished material; Production of final products; Business activities concerning production and consumption; and, Product use. Managing end-of-life (EOL) issues of products is a reverse logistics component.

Information and Decision-Making processes

The resources and streams of information are a very important component of logistics, reflecting flow as well as enabling management. Decision-making requires obtaining information, its categorisation, encoding, storage, transmission, and use.

Information assists in implementing processes and is essential for realising supply, distribution, stocks, warehousing, manipulation and packaging of materials, transport, and procurement and logistics costs (Ghiani *et al*., 2004).

Logistics information processes are composed of: Systems for identification and codification of raw materials, products, finished goods, and commodities; Flow records (specifications, packing lists, orders, invoices etc.); Systems for coding; Grouping, processing, and aggregation of information (creation of databases and data] warehouses) to enable decision function realisation; and, Technical means for information emission, storage, processing and broadcast (Szymonik, 2012).

There are two types of logistics information flow, *viz* for directing and controlling the physical flow and for reporting and control purposes.

Flows in the former are opposite to the direction of the physical flows, originating from the market and flowing backwards in the form of demand forecasts etc. Processing transforms it, leading to production plans, programmes, and schedules. This is followed by its flow into the supply phase, leading to material demands, initiating purchase.

The latter flows along the direction of physical flows, reflecting the realisation of earlier planning decisions.

A logistics decision-making process starts when a problem regarding relocating goods/services and associated information appears. The decision-making process progresses as follows: Identifying the decision-demanding situation (e.g., transportation options); Identification and design of decision alternatives (a minimum of two ways of solving the problem); Assessment of alternatives and selection of the rational option (e.g., using DSSs); Creating conditions for the implementation of decisions taken; and, Control the decision impacts.

A decision is a non-random option selection that addresses one or more people through the acceptable variable set (Farahani *et al*., 2011).

Inventory Processes

Stock availability assures the continuity of economic processes. This depends upon the type of BU being considered. E.g., A manufacturing BU will have stocks of raw materials and finished products, a trading BU will have stocks of prevailing goods, and a service BU will have stocks of materials for realising services.

The basic factor influencing stocks is the planned supply of products, goods, or services. In a Just-in-Time (JIT) environment, stocks are considered irrelevant, a pointer to the basic reasons for stocking in the first place *viz* the inability/inadequacy of inflow and outflow stream synchronisation, and the manner in which random factors impact logistics processes (uncertainty, delays, fluctuating market needs, price variability, seasonality, rhythmic production requirements, economies of scale, quality of customer service, and transport viability being some).

Inventory is the stocks of goods for production (raw materials and semi-finished goods representing work-in-progress), ancillary/associated activities (operations and maintenance, repair), and service delivery (finished goods).

From the logistics management perspective, the phase during which goods flow through the logistics channel is referred to as the inventory process.

The following principles govern this: Inventory stocking in the logistics chain as a cost optimisation measure (with the expected service delivery level); Storage (type and quantity should allow synchronisation of demand and supply); Awareness of current and projected inventory flow levels, costs, and logistics chain/logistics environment developments across all component entities.

These factors influence stock parameters *viz* service delivery policy, staff availability, supplier and customer reliability, IT system capability, the macroeconomic situation, forecasts, intra- and inter-SC operations of the competition, negotiation skills, and the financial condition of the BU.

Stocks may be categorised as: Current - consumed in ongoing production activities; Cyclic - having demand seasonality; Safety - buffers against unforeseen circumstances for maintaining production rate; Speculative (excess inventory) - advance stocks created for supply or financial reasons. Inventory management primarily focuses on stock minimisation and optimal material flow to achieve the lowest possible operational costs (Chopra & Meindl, 2013; Ghiani *et al*., 2004).

2.6 The Functions of Logistics

Three main functions comprise logistics, i.e., order processing, inventory management, and freight transportation (Chopra & Meindl, 2013; Ghiani *et al*., 2004).

2.6.1 Order Processing

This is concerned with information flows in the logistics system, it includes: Requests for the product(s) by customers; Transmission and verification of orders; Availability checks;

Customer’s credit verification; Production of items or their retrieval from stocks; and, Packing and delivering along with shipping documentation. In addition, customers may need to be kept informed about the order status throughout the process.

2.6.2 Inventory Management

Inventory management is a fundamental issue for logistics planning and operations. It minimises operating costs and achieves customer requirements by managing stock levels.

The dimensions it considers may be customer-related (relative importance), transportation-related (policies), product-related (flexibility of production and economic significance of different products), and competition-related.

The interweave of inventory management and transportation policies leads to three distribution strategies (Farahani *et al.*, 2011; Ghiani *et al.*, 2004): -

- **Direct shipment** Direct shipping of goods from the manufacturer to the end-user, eliminating costs of a distribution centre (DC) and reducing lead times. Usually adopted for fully loaded trucks deliveries or for timely delivery of perishable goods.

- **Warehousing** Receipt and storage of goods by warehouses, which retrieve, pack, and ship items in response to an order. It has four major functions: Inward goods receipt, Storage, Picking Orders, and Shipping.

- The labour and inventory holding/carrying costs associated with storage and order picking make them the most expensive processes within warehousing.

- Warehousing may be centralised (one warehouse serving the whole market) or decentralised (dividing the market into zones, each served by a small warehouse).

- Decentralised warehousing reduces lead times due to proximity to customers, while centralised warehousing reduces operating costs due to economies of scale.

- For uncorrelated demands, a centralised system exhibits significantly lesser aggregate safety stock compared to the sum of individual decentralised system safety stocks.

- In addition, a centralised system lowers inbound transportation costs, while a decentralised system reduces outbound transportation costs.

- **Cross-docking** A facility for sorting and consolidating incoming shipments (from more than one source) and transferring them directly to outgoing transport without intermediate storage and associated activities.

- In a pre-distribution system, goods are assigned to a retail outlet before the dispatch of the shipment by the supplier. In contrast, cross-docking assigns goods to retail from the cross-docking facility.

- A successful cross-docking facility has certain key enablers *viz* high demand volume and low demand variability, products that are not difficult to handle, and customised information system coordination solutions.

2.6.3 Freight Transport

The transportation function of logistics permits production and consumption to be significantly displaced (temporally and spatially) from each other. This leads to the widening of the marketplace and creates a level playfield as it stimulates direct competition between suppliers who may be widely dispersed.

Freight transportation forms a substantial component of the costs of logistics, at the same time significantly impacting the level of service delivery to the customer. Therefore, transportation planning plays an important role in logistics system management.

There are three transportation alternatives: Private transport (a private fleet of owned/rented vehicles operated by a BU); Contract transport (contract-regulated direct shipments through a carrier); and, Common transport (transportation of goods through a carrier using common resources *viz* terminals, vehicles, crews, to fulfil transportation needs of several clients) (Chopra & Meindl, 2013; Farahani *et al.*, 2011; Ghiani *et al.*, 2004). The following are the key attributes of freight transport: -

- **Distribution channels** A distribution channel is a product's path from the manufacturer to the end-user. Marketing decisions are based on the appropriate combination of channels for each product. E.g., products may be sold by manufacturing firms to end-users directly or be distributed through intermediaries such as agents, brokers, wholesalers, retailers etc.

- Intermediaries provide the benefit of lower unit transportation costs but add a markup to the product cost.
- **Consolidation** Economies of scale in transportation may be fruitfully used to achieve logistics cost savings by consolidating small shipments into larger ones: -
    - **Facility consolidation** Long transporting distances for large shipments and short distances for smaller shipments.
    - **Multi-stop consolidation** One vehicle on a multi-stop route may serve less-than-truckload (LTL) pick-up/deliveries directed to different locations.
    - **Temporal consolidation** Achieving one large shipment by forward or backward adjustment of transportation schedules.
- **Modes of transportation** Ship, rail, truck, air, and pipeline are the basic transportation modes.
- These may be suitably combined to obtain door-to-door services. In order of per unit costs, these may be arranged as air, truck, rail, pipeline, and ship.
- **Transit time** The time taken by a shipment for movement between the origin and destination. It is a random variable influenced by weather and traffic conditions.
- **Intermodal transportation** Using multiple modes of transportation can result in a cost-to-transit time trade-off.
- There are only a handful of practical intermodal pairings *viz* air-truck (birdyback), train-truck (piggyback), and ship-truck (fishyback).

Figure 2.6 illustrates the commonly used logistics models, while Figure 2.7 and Figure 2.8 illustrate transportation channels and transit times, respectively.

Figure 2.6

Commonly employed logistics systems

Note. (Chopra & Meindl, 2013)

Figure 2.7

Channels in transportation

Note. (Ghiani *et al*., 2004)

Figure 2.8

Relative transit times for various transportation modes

Note. (Ghiani *et al*., 2004)

2.7 Managerial Issues in Logistics

2.7.1 Objectives

The main objectives of a logistics strategy are (Ghiani *et al*., 2004): -

- **Capital reduction** Reducing the investment level in the logistics system as much as possible (dependent on inventories and owned equipment) by employing public warehouses instead of private and using common carriers instead of exclusive ones. Capital reduction typically leads to higher operating costs.

- **Cost reduction** Minimising the total transportation and storage cost. E.g., operating privately owned warehouses and vehicles (if supported by the scale of operation).

- **Service level improvement** Customer satisfaction and, in turn, revenues are majorly affected by logistics service level. Increased revenues may be realised through improved logistics services, especially in markets typified by low-priced homogeneous products (where product features do not drive competition).

All fields of activity in a BU are composed of logistics processes in part. Isolation of these, followed by combining at the BU level, results in the creation of logistics departments that coordinate all the flows. A BU may implement three basic logistics system models (Sobotka *et al.*, 2005): -

- **Informal** The existing organisational structure coordinates logistic tasks pertaining to separate fields of activity in a BU.

- **Semiformal** A logistics manager coordinates the logistics processes of the complete BU. The logistics manager is external to internal sub-units/departments where activities take place.

- **Formal** A separate vertical takes over all logistics functions of the BU.

Logistics systems generally need to be analysed from different perspectives of logistical activities, depending on the type of analysis required. Four approaches are used to analyse logistics: materials management, cost centres, nodes vs links, and logistics channels (Bowersox *et al.*, 2002; Coyle *et al.*, 2003, 2009).

2.7.2 Materials Management (Inbound) vs Physical Distribution (Outbound)

Some organisations classify their logistics into materials management and physical distribution. This classification separates the movement and storage of raw materials into an organisation from the movement and storage of finished goods. From an inbound and outbound requirements perspective, logistics systems may be categorised as follows (Ayantoyinbo & Gegeleso, 2018; Shakantu, 2005): -

- **Balanced Systems** This is a system whereby a company has a balanced flow on both the inbound and outbound sides of its logistics systems (Frohlich & Westbrook, 2001).

- **Heavy Inbound Systems** This is a logistical system whereby the inbound flow is much heavier than the outbound flow. The construction and aircraft businesses are good examples. E.g., thousands of parts are shipped in for the manufacture of an aircraft, but once finished; it is simply flown, as a whole, to the customer (Coyle *et al*., 2003, 2009).

- **Heavy Outbound Systems** This is a logistics system in which the outbound flow is much heavier than the inbound. For example, oil companies require only crude feed for their operations but produce and ship a wide variety of products to various customers.

- **Reverse Logistics** Reverse logistics is a system where a company's outbound side of the logistics system sees reverse flows (Stock, 1992). E.g., returns for trade-in, repairs, salvage and disposal.

2.7.3 Cost Centres

Under cost centres, logistics management activities are broken down into cost centres or activity centres (Bowersox *et al.,* 2002). By looking at these activities as cost centres, possible trade-offs between and among them can be analysed, leading to lower overall cost and/or better cost-effectiveness. Though not directly, the idea of costs will be employed during the application of the transportation model for optimising the movement of trucks for material delivery. Uniform costs across transport operations will be used to optimise transport resources.

2.7.4 The Node-Link Model

Link-node, or graph, data models abstract away geographical detail and aim to capture only the topology of a road network. The representation of road networks obtained using these models is compact and often well-suited as a foundation for query processing. A typical link-node model captures a road network as a collection of nodes connected by directed links (Speičys & Jensen, 2008).

The logistics system is analysed in terms of nodes and links. Nodes are established spatial locations for the storage or processing of goods, i.e., plants and warehouses. On the other hand, the links represent that part of the transportation network which connects logistics system nodes, e.g., roads, waterways, and airways.

The node-link system can be either simple or complex, depending on the number of nodes and links involved. The node vs link perspective allows analysis of two basic elements of a logistics system – the plant and transport.

It also provides a convenient bottom line for system improvements by identifying time and distance relationships between nodes, and the periodicity/frequency, volume, and predictability of goods entering and leaving the system and those circulating within the system (Shakantu, 2005; Speičys & Jensen, 2008).

The analysis of these relationships enables benchmarking efficiency levels. However, there needs to be clarity on the relative importance of parameters, as well as the definition of the system boundary for analysis. The basic aim of this thesis is to establish fleet efficiency and find the means to improve it.

2.7.5 Outsourcing

Businesses invariably focus on their core activities, while the non-core activities are typically outsourced as a means to add value to operations. Outsourcing logistics activities tends to reduce fixed operating costs and improve service levels (Antoniolli *et al.*, 2015; Gadde & Hulthén, 2009). Outsourcing of logistics functions typically takes place in the following methods (Hrusecka *et al.*, 2015): -

- **Second-party logistics (2PL)** Involves the procurement of limited logistics services from a firm specialising in the service (e.g., packing, transportation etc.). This suits small BUs with a simple SC.
- **Third-party logistics (3PL)** Involves external logistics services (e.g. transportation, distribution services, warehousing, packaging etc.) by organisations external to the BU in focus. These are preferred by manufacturers

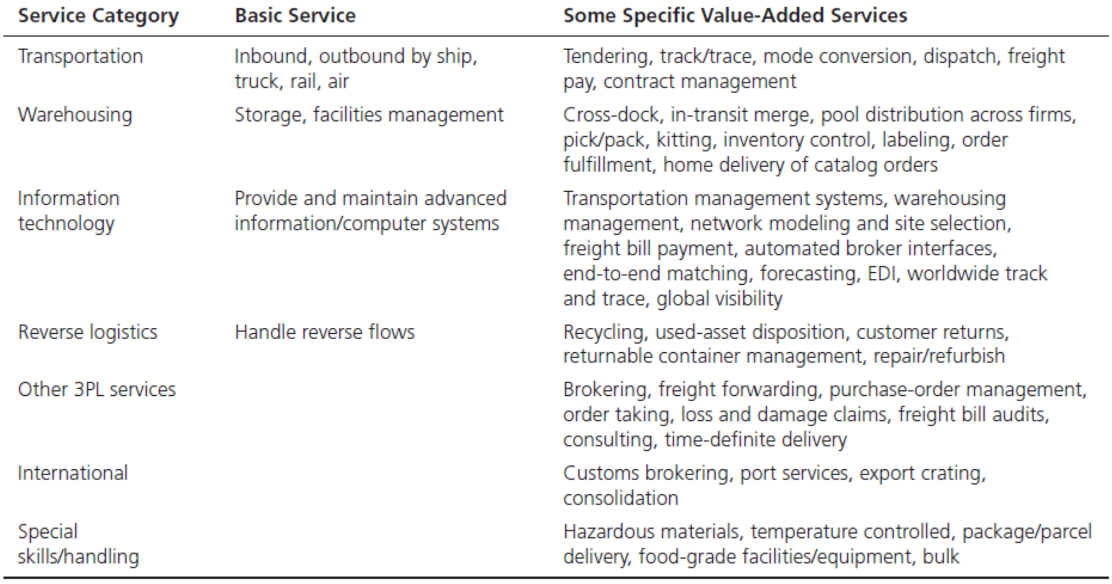
looking at reducing logistics costs or implementing verified strategies in the SC domain.

- The higher expertise gained by 3PL providers provides higher value addition for the customer. This is the most common type of logistics outsourcing.
- **Fourth-party logistics (4PL)** Amongst all logistics outsourcing models discussed here, 4PL represents the closest form of cooperation, where the service provider (4PL provider) manages individual 3PL service providers and optimises the complete SC.
- Large supranational organisations typically use this operational mechanism.

Figure 2.9 shows the typical logistics services that may be outsourced.

Figure 2.9

Typically outsourced logistics services



Service Category	Basic Service	Some Specific Value-Added Services
Transportation	Inbound, outbound by ship, truck, rail, air	Tendering, track/trace, mode conversion, dispatch, freight pay, contract management
Warehousing	Storage, facilities management	Cross-dock, in-transit merge, pool distribution across firms, pick/pack, kitting, inventory control, labeling, order fulfillment, home delivery of catalog orders
Information technology	Provide and maintain advanced information/computer systems	Transportation management systems, warehousing management, network modeling and site selection, freight bill payment, automated broker interfaces, end-to-end matching, forecasting, EDI, worldwide track and trace, global visibility
Reverse logistics	Handle reverse flows	Recycling, used-asset disposition, customer returns, returnable container management, repair/refurbish
Other 3PL services		Brokering, freight forwarding, purchase-order management, order taking, loss and damage claims, freight bill audits, consulting, time-definite delivery
International		Customs brokering, port services, export crating, consolidation
Special skills/handling		Hazardous materials, temperature controlled, package/parcel delivery, food-grade facilities/equipment, bulk

Note. (Chopra & Meindl, 2013)

2.8 Construction Logistics

CSCM has construction logistics as its essential part, both in terms of project management as well as costs (Ying & Tookey, 2014). The role of logistics in the CSC is emphasised by the cost/volume of construction material and the fact that the construction domain is peripatetic.

Figure 2.10 illustrates the logistics domain in the construction context.

Figure 2.10

The logistics domain in the construction context

Note. (Salagnac & Yacine, 1999)

2.8.1 Definitions

Logistics pertain to movement and the associated information, broadly speaking. When transposed to the construction domain, the following bespoke definitions emerge: -

- *"…a process of strategically managing the procurement, 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 are maximised through the cost-effective fulfilment of orders"* (Wegelius-Lehtonen, 2001).

- *"The scope of construction logistics concerns all supply and disposal shipments of building materials, construction equipment and construction personnel to and from the construction site"* (Quak *et al*., 2011 (in Dutch), as cited in Balm & Ploos van Amstel, 2017).

- *"Construction logistics is the entire complex of measures aimed at getting the right equipment, the right materials and the right workers with the right level of quality to the right construction site at the right moment and at minimum cost to meet the customer's requirements"* (Quak *et al*., 2011 (in Dutch), as cited in Balm & Ploos van Amstel, 2017).

2.8.2 The Construction Logistics Process

Construction logistics are spread out across an extensive SC. They involve management, coordination, and control of materials flow from raw materials processing to the final utilisation of products in a construction project, and reverse logistics of removing C&DW and disposing it off (Agapiou *et al*., 1998; Ying & Tookey, 2014).

Construction logistics are comprised of (Jang *et al*., 2003; Serra & Oliveira, 2003; Sobotka *et al*., 2005; Ying *et al*., 2018) (Figure 2.11): -

- **Whole-project Logistics** Views the construction site through the lens of a production system. It is a component of multiple logistics chains executing complex processes within space, budget, and time limitations.

- **Supply Logistics** Comprise delivery of resources from sources external to the construction site, e.g., material, workforce etc. Key components of supply logistics are management of suppliers and transportation and procurement and maintenance of resources.

- **On-site Logistics** Concerned with coordinating resource flows within the physical boundary of the construction site.

Figure 2.11

Components of construction logistics

Note. (Jang *et al*., 2003)

Construction project success depends heavily upon the coordination of the three components of construction logistics in all aspects (Ying & Tookey, 2014). Therefore, construction logistics, especially supply logistics and its transportation function, need to be understood from the perspective of zoning of a typical CSC's area of operations. Furthermore, it also needs to be understood that the logistics processes for supply and those on-site are entirely different since they are implemented in different (conceptual) zones, are associated with different SC levels, and require different intensities of coordination. Figure 2.12 illustrates these zones conceptually and their intersection with construction logistics, the actors typically involved in a construction project, and the construction site.

Figure 2.12

The intersection of operating zones, actors, transport, and the construction site

Note. (Fredriksson *et al*., 2021)

Construction logistics are distinctively influenced by construction characteristics *viz* (CIVIC, 2018): -

- A customised logistics set-up is required for each site, being unique and temporary.
- The material-intensive nature and requirement-based (typically irregular) supply characteristics of construction sites.
- The sequential organisation of construction site activities transmits delays through all activities, hence, the requirement of timely in the right quantities.

- Industry fragmentation manifesting through different construction companies, suppliers, and LSPs working in different temporary construction consortia. Fragmentation drives divergence in operational and management philosophies and inefficient resource utilisation.

The logistics process provides a decision-making framework at the intersection of inventory management, transportation, warehousing, and materials handling. Efficient construction logistics require planning, management of loading and unloading zones, warehousing (internal and external to the construction site), on- and off-site materials handling, and transportation for linking actors and channels of a logistics system (CIVIC, 2018; Ekeskär & Rudberg, 2016; Janné & Fredriksson, 2019; Lindén & Josephson, 2013; Lundesjo, 2011; Thunberg & Persson, 2013; Transport for London, 2013). Construction logistics processes can be conveniently grouped into the three domains of planning and organisation, transportation, and site activities (Figure 2.13).

Figure 2.13

Grouping of logistics activities on-site

Note. (CIVIC, 2018)

2.9 Construction Logistics Systems and Activities

Based on the three logistics models of a BU, four logistics systems are possible for a construction project *viz* Independent SCs for individual contractors (where each contractor independently selects suppliers and plans and schedules supplies), GC or other party managed centralised supply system (through their logistics departments), or a centralised supply system managed by an external logistics company, and a combination (Bengtsson, 2019; Sobotka *et al*., 2005). A graphical representation of these is in Figure 2.14.

Figure 2.14

Construction logistics systems

Note. (Bengtsson, 2019)

Activities within the three domains of Planning/organisation, Site, and Transport are associated with the following roles between them in the context of construction project logistics (CIVIC, 2018): -

- **Role 1** - Establishing a clear interface between the SC and the construction site.
- **Role 2** - Improving CSC efficiency.
- **Role 3** - Improving site process/activity efficiency.
- **Role 4 -** Adding value.
- **Role 5** - Integrating the SC with the construction site to the extent possible.
- **Role 6** - Effective coordination with local stakeholders.

2.10 Reverse Logistics

Organising, managing, and controlling materials flow from extraction to their application in a construction project comprise traditional logistics or forward logistics (FL). On the contrary, Reverse Logistics (RL) concentrate on the movement of products/goods and materials back to the market from the points of consumption (Hosseini *et al.*, 2014, 2015; Rogers & Tibben-Lembke, 2001). All activities associated with the collection, movement, storage, disassembly, and processing of used or outdated products (or product parts), packaging, and materials to ensure sustainable recovery comprise RL. They call for recovery or reclaiming value through the backward movement of products in the SC. Principally, there is a returning party who had the product and a receiving party attempting to redistribute, resell, or recover value. The four dimensions of the complete RL concept are (Brito & Dekker, 2002): -

- **Drivers** From the receiver's perspective, the driving forces behind organisations participating in recovery through acceptance of returns are economics, legislation, and extended responsibility (including sustainability).

- **Reasons** Considering the reverse flow of products/materials from the perspective of the returner/initiator, returns may be categorised as: Manufacturing returns (surplus materials, quality returns, and leftovers from production); Distribution returns (product recalls, commercial returns (e.g., unsold products, wrong/damaged deliveries), stock adjustments, and functional returns); and, Customer/user returns (e.g., warranty returns, service returns (repairs and spare-parts), end-of-use, and end-of-life - EOL).

- **Product characteristics** *viz* product composition (ease of disassembly, homogeneity of component elements, hazardous material presence, and ease of transportation), use pattern (location and duration of use), and deterioration (intrinsic deterioration, economic deterioration, homogeneity of deterioration, and repairability).

- **Processes and Actors** RL actors can be categorised into returners, receivers (suppliers, manufacturers, wholesalers, retailers), and collectors/processors (independent intermediaries, recovery companies (e.g., jobbers), reverse LSPs, waste collection agencies etc.). Four fundamental processes comprise RL *viz* collection, the combined inspection/selection/sorting process, re-processing or direct recovery, and redistribution (Figure 2.15).

Figure 2.15

Reverse logistics processes

Note. (Brito & Dekker, 2002)

2.11 Reverse Logistics in Construction

Construction RL includes the movement of materials, goods, and products towards secondary consumption points, e.g., secondary markets outside the boundaries of the construction industry (Thiery *et al*., 1995). A comprehensive illustration of the comparison of FL and RL in the construction industry is in Figure 2.16.

Figure 2.16

Forward logistics and reverse logistics in construction

Note. (Hosseini *et al*., 2015)

A comprehensive definition of RL in construction from literature is *"How the area of business logistics plans, operates and controls the flow of logistics information corresponding to the return of post-sale and post-consumption goods to the productive cycle through reverse distribution channels, adding value of various types to them: economic, ecological, legal, logistical, corporate image, etc."* (Nunes *et al*., 2009).

The significance of RL in construction stems from the industry having substantial negative impacts across all three sustainability dimensions, reiterating the potential resemblance between the ideal construction SCM and natural processes to consume resources efficiently without any residual waste (Hosseini *et al*., 2015).

An SC, wherein the loop of materials flow is closed, is called the Closed Loop Supply Chain (CLSC) (Chini & Bruening, 2003; Shakantu *et al*., 2003; Shakantu & Emuze, 2012). In a CLSC, materials are kept in the loop through systematic extraction from built assets scheduled for EOL disposal.

Products and materials can be reintegrated into new construction after necessary recovery processes or directly through secondary markets (Sassi, 2008).

The following terms in the context of Figure 2.15 and Figure 2.16 further explain RL activities in the construction domain (Rose & Stegemann, 2018): -

- *Reuse* Putting the material or component to new use after being extracted from the obsolete built asset with minimal processing.

- *Recycling* Refers to producing the same components of comparable quality by reprocessing a component or material.

- *Down-cycling* Production of a lower-grade material through processing discarded building material.

- The terms reusable and recyclable are mutually exclusive, with a reusable material or component *reusable* not necessarily including recycling and *recyclable* material or component not necessarily including reuse.

Figure 2.17 illustrates the RL possibilities for construction material, and Figure 2.18 illustrates recovery options for C&DW as part of RL.

Figure 2.17

Reverse logistics possibilities for construction material

Note. (Sobotka *et al*., 2017)

Figure 2.18

Recovery options for construction and demolition waste

Note. (Schultmann & Sunke, 2006)

RL uses various methods to provide scope for back-loading (backhaul) of components, finished products, waste, and reusable packaging from the consumer end to suppliers or manufacturers. Back-loads enable reduced costs for suppliers/manufacturers by using reverse material flow channels to add value. RL is a powerful strategy to build sustainability into construction logistics (Shakantu *et al*., 2009; Vaidyanathan, 2005). RL differs from Waste Management (WM), which is an outcome of successful RL implementation. WM refers to efficient and effective waste collection and processing, whereas RL streams products with recoverable value, directing them into a new SC.

RL intuitively points at the reverse flow direction of goods, materials, and products as mirroring forward flow. In real-life systems, materials, goods, and products are included in the RL system even if they deviate from the reverse route to the origin towards other potential channels and destinations (and not the exact points of origin), e.g., secondary markets. RL strategies present different potential benefits by virtue of the effort required for extracting value.

Figure 2.19 illustrates the relationship between strategies and their relative benefits.

Figure 2.19

Potential benefits vs effort required for reverse logistics practices

Note. (Pushpamali *et al*., 2019)

Each of the stakeholders in a construction project has a role and responsibility for RL implementation. The main tasks envisaged for the important stakeholders are (Hosseini *et al.*, 2014): -

- **Designers** Practicing Design for Deconstruction (DfD) principles (i.e., factor in ease of deconstruction and EOL reuse into building design); Promoting the use of salvaged materials in new designs and its communication to the design/construction team; and, Advising clients on the benefits of RL in general and the use of retrieved materials in particular.

- **Builders** Using salvaged materials to increase their demand and promote RL; and, Easy adoption of RL through appropriate construction methods.

- **Demolition sub-contractor/salvaging companies** Deconstructing and dismantling old buildings as an alternative to demolition; Knowledge management pertaining to RL benefits, accessibility, salvaged products, collection centres, recovery routes, and suppliers to reduce associated uncertainties and risk; Deploying mechanisation for deconstruction and reducing risks, cost, and time through operational optimisation; and, Training for enhanced productivity.

- **Policymakers** Making RL viable through landfill costs duly considering illegal dumping; Financial and regulatory incentivisation to encourage the incorporation of salvaged materials in new construction; and, Risk mitigation guidelines for promoting deconstruction.

2.12 Transport in the Construction Domain

2.12.1 A Short Discussion on (Freight) Transport

The following are two fundamental definitions of transport from the literature: *"The element of economic activity which accomplishes the movement of persons and goods from one place to another"* (Rose, 1979, as cited in Shakantu, 2005); extended by Coyle *et al.* (2003) as *"the transportation system is the physical link connecting a company's customers, raw material suppliers, plants, warehouses and channels members in a logistics supply chain"*. Transportation is the largest component of logistics (Bowersox *et al.*, 2002; Madadi *et al.*, 2009). Compared to most other logistics processes (except warehousing), transportation is a ‘real’ process, while others are business, regulatory or non-physical processes (Szymonik, 2012). Transport forms the physical coupling between a company’s geographically dispersed operations and creates time/place utility to add value (Bowersox *et al*., 2002; Coyle *et al*., 2003, 2009). A key logistics activity, it moves materials through various production stages before final delivery to the customer. Within the logistics domain, it represents a major cost component. Before transport in the construction context is discussed, nuances of the domain will be discussed through an overview of freight transport with specific focus on Urban Freight Transport (UFT), which operates in a systemic framework formed by three components *viz* (Kin *et al*., 2017): -

- **Demand** for goods from places other than the place of production, requiring transportation.
- **Supply** by supplying logistics (i.e., facilities and transport) for fulfilling the demand.
- **Context** originates from the demand-supply interaction in the form of logistics operations and actual vehicle movements. The physical environment surrounding the demand-supply aggregation defines the contexts and domains of operation of various SCs.

Each of these components is associated with one or more stakeholders in the UFT environment *viz Receivers* (generate goods demand, hence, for demand side transportation; *Shippers* (fulfil demand by sending goods); *Logistics Service Providers* (LSPs) (the interaction of Receivers and Shippers results in actual deliveries by *LSPs*); *Local Authorities* (regulate contextual movements); and, *Citizens* (are inhabitants of the physical demand-supply-shipping-delivery occurs) (Kin *et al.*, 2017). Besides being the most direct link to the customer, transportation is important for four reasons which benchmark the importance of logistics in construction. These are: demand required at the point of consumption; distance from manufacture/purchase to the point of consumption; activities at the point of consumption; and diversity of products required at the point of consumption.

Figure 2.20 illustrates the attributes of freight transport in the urban context.

Figure 2.20

The Urban Freight Transport framework and key stakeholders

Note. (Kin *et al*., 2017; Taylor, 2005)

Demand dictates the volume of vehicle movements and associates it with the product type. Therefore, there is a direct relationship between demand and vehicle movements. Short-term perspective and financial models may impact transport planning, leading to lower efficiencies. The concept of cost centres can be effectively used to improve financial and operational efficiencies while maintaining customer satisfaction.

The distance from the source of supply to the location of use is a major factor that impacts the employability of transport. The longer the distance, the more variable the round-trip time and availability for multiple trips. Similarly, a combination of distances and the number of drop-off points can impact capacity utilisation. Closely related to distance and demand are site activities associated with delivery.

A concept closely associated with freight transport (specifically in the construction domain) is the 'diversity' of loads. It refers to the range of products being supplied or delivered to a consumer. In the case of a varied range of products, consolidation of loads is an ideal method to achieve transportation efficiencies. Consolidation, however, needs to be viewed from the consumer perspective as well as from the supplier perspective. At the boundary conditions, in the case of a consumer perspective, consolidation is from multiple suppliers, whereas in the case of a supplier perspective, it is for multiple consumers. In actual implementation, consolidation works in the space between the two boundaries.

When the supplier also happens to be the manufacturer, the potential to optimise the transportation function of delivery logistics increases manifold due to the range of products being typically limited and the associated potential to customise transport for effective and efficient loading.

2.12.2 Factors Impacting Transport Performance

Four primary factors govern the performance of the transportation function: cost, infrastructure-related issues, management, and externalities.

Costs

As a rough estimate, transport costs are in the neighbourhood of half the costs of logistics. Considering that construction materials are low-cost/high-volume (Balm & Ploos van Amstel, 2017; Lovell *et al.*, 2006; Shakantu *et al.*, 2003; Ying & Roberti, 2013) and that transportation is one of the two physical logistics processes (the other being warehousing) (Szymonik, 2012) transport actually contributes to more than half the logistics costs.

Materials typically comprise 30%-50% of a construction project cost (Agapiou *et al*., 1998; Ibn-Homaid, 2002; Vidalakis & Tookey, 2005; Ying *et al*., 2014). Transportation contributes between 39%-58% to the total logistics costs and 4%-10% to a building's selling price (Shakantu *et al*., 2003). BRE (2003) estimates transportation costs to be between 10% and 20% of construction costs.

A UK report by the Standing Advisory Committee on Trunk Road Assessment (SACTRA) Report (1999) that *"…transport costs accounted for 2.6% of motor vehicle part production, 7.7% for pharmaceuticals and 12% for wholesale distribution. In other sectors, such as construction, the figures can be significantly higher"* (SACTRA, 1999, p. 31). The 'Cost Staircase' in Figure 2.21 illustrates the contribution of transportation to the cost of materials.

Figure 2.21

The cost staircase illustrating construction material costs

Note. (Bertelsen & Nielsen, 1997)

In addition to direct costs, transport has certain associated externalities (discussed subsequently), which have their own costs. Figure 2.22 brings out a broad categorisation of the costs of transport externalities.

Figure 2.22

Cost externalities of transport

Note. (Director General for Transport European Union [DG Transport EU], 1995)

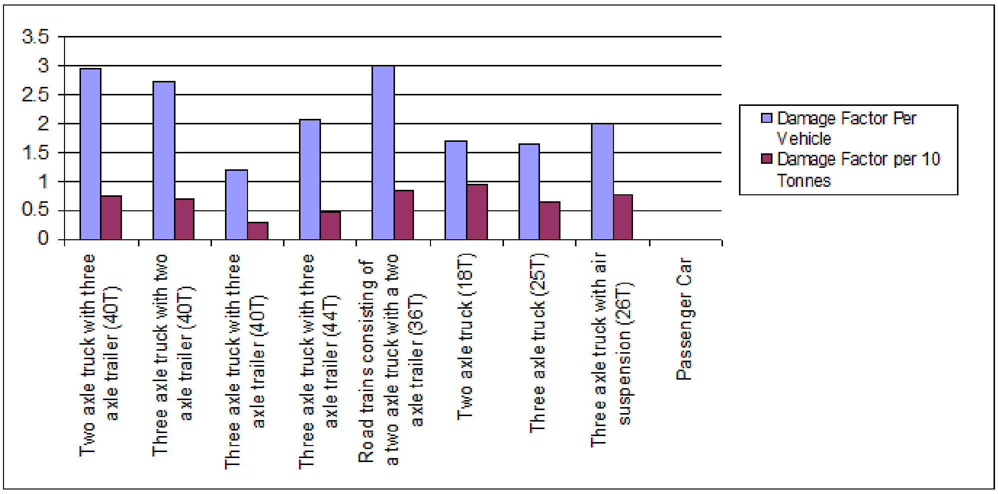
Infrastructure

Transport requirement of the construction industry creates traffic flows that compete with other traffic for the use of transport infrastructure that makes up the transport network. As a result, an infrastructural deficit is created through overloading of the existing road network.

Since road infrastructure development (supply) invariably lags behind the demand, congestion and difficult accessibility result (DG MOVE European Commission, 2012; Kin *et al*., 2017). This is over and above the damage to transport infrastructure caused by all forms of transport (the relative damage factors are illustrated in Figure 2.23).

Figure 2.23

Relative infrastructure damage factors of various types of transport



Note. (Based on DG Transport EU, 1995)

Management

Construction materials delivery and waste removal are usually different businesses. They are divergent in terms of the associated SCs and their orientations and are not integrated. A dedicated fleet with most construction material suppliers implies a lack of coordination between these activities (Balm & Ploos van Amstel, 2017; McKinnon & Ge, 2006; Shakantu *et al*., 2008).

This results in a very high level of empty trips between inbound and outbound construction transport traffic in urban areas (Crainic *et al*., 2004; DG MOVE, European Commission, 2012). Material delivery vehicles move (nearly) full along the onward trip segment to construction sites and empty on the return segment. The opposite is true of waste removal vehicles (Berden, 2017; Shakantu & Emuze, 2012).

Both businesses independently manage their own transport function, which is typically not globally optimised, ignoring the impact of localised efficiencies on the transportation system at large, and the increased negative impacts within the area of operations (Crainic *et al*., 2004).

Non-synchronisation of activities and coordination between neighbouring construction sites leads to congestion in the road network and the associated underutilisation (availability) of transport. C&DW removal vehicles being over and above those undertaking material deliveries accentuates the problem through increased traffic. Un-co-ordinated transport to a single construction site (or more than one neighbouring site), with separate deliveries from different SCs, results in a high possibility of congestion at the entrance to the construction site and areas for unloading.

The current operating scenario exhibits a paradox, with fully loaded delivery vehicles likely to cause congestion on the site with associated material wastages and productivity losses, while most vehicles actually travelling to the site are not fully loaded and return empty, leading to very high per-unit carbon emissions vis-à-vis the tonnage handled (Lundesjo, 2011).

These typical manifestations of construction industry fragmentation cause increased transport and production costs as well as an increase in unwanted impacts and externalities. Transport efficiency is measured in terms of capacity utilisation across the onward and return trips. Within the existing environment, finding backloads for returning delivery vehicles is a major logistical challenge (McKinnon & Ge, 2006).

Empty running of vehicles has graduated from merely being a wasted resource to being an environmental liability. This calls for urgent focus on reducing this anomaly through sustainable distribution strategies at both the government and individual business levels (McKinnon & Ge, 2006).

Externalities

There are clear and distinct differences between construction site delivery and consumer goods distribution.

Construction sites are material intensive, irrespective of size, and need supplies aligned to their requirements, which may be irregular (Kim & Nguyen, 2018). This leads to numerous, small, and ad-hoc deliveries to a construction site during the course of the day since material requirements are precise and are needed on time (The Bellona Foundation, 2020).

The service orientation of carriers tends to ignore the negative social and environmental impacts this method of working can have on other system users. Congestion in urban areas is caused by the need for delivery transport to deliver at the construction site when work commences during the early part of the day, i.e., rush hours.

Construction sites in areas considered sensitive, such as pedestrian zones, residential areas, and historical city centres, make residents feel less safe and constrain the liveability of the surroundings (Balm & Ploos van Amstel, 2017). In addition, congestion leads to increased traffic, inventories, distribution costs, transportation time, reduced labour productivity and asset utilisation, and delays in material delivery, amongst other effects (Sankaran *et al*., 2005).

Furthermore, the size and loads carried by heavy construction transport (as compared to other lighter freight vehicles) and their entry into residential and other urban areas cause considerable damage to transport infrastructure (Balm & Ploos van Amstel, 2017; DG Transport EU, 1995). Transport externalities are illustrated in Figure 2.24.

Figure 2.24

Transport externalities in various sustainability domains

Note. (Chatziioannou *et al*., 2020)

Transport externalities may be defined as:

> Transport externalities refer to a situation in which a transport user either does not pay for the full costs (e.g., including the environmental, congestion or accident costs) of his/her transport activity or does not receive the full benefits from it; The crucial importance of transport externalities arises from the fact that, in a market economy, (economic) decisions are heavily dependent on market prices. However, when market prices fail to reflect existing scarcities (clean air, absorptive capacity of the environment, infrastructure etc.), the individual decisions of consumers and producers no longer add up to an outcome that provides maximum benefits to society as a whole. Thus, pricing on the basis of full social costs is a key element of an efficient and sustainable transport system (DG Transport EU, 1995, pp. 4-5).

Table 2.2 illustrates the interdependence between transport externalities.

Table 2.2

Association between transport externalities

Externality	Association with other negative externalities
Water pollution	Change in land value, greenhouse gases, ecological impact, loss of amenity
Road accidents	Water quality, congestion, air pollution, visual blight, loss of amenity, ecological impact, noise, road infrastructure damage
Congestion	Water pollution, local air pollution, noise, greenhouse gases, ecological impact, road accidents, loss of amenity, change in land value
Oil dependence	Local air pollution, loss of amenity, water pollution, visual blight, greenhouse gases, ecological impact, barrier effect
Transportation invasion of public space	Water pollution, congestion, local air pollution, noise, vibration, greenhouse gases, ecological impact, barrier effect, visual blight, change in land/property value, loss of amenity
Local air pollution	Water pollution, loss of amenity, change in land value, ecological impact, visual blight, road accidents
Greenhouse gases	Water pollution, local air pollution, ecological impact, barrier effect, change in land value, loss of amenity
Road infrastructure damage	Change in land value, road accidents, congestion, visual blight, loss of amenity
Vibration	Change in land value, local air pollution, road infrastructure damage, ecological impact, noise, loss of amenity
Ecological impact	Water pollution, local air pollution, barrier effect, loss of amenity
Visual blight	Change in land value, road accidents, ecological impact, loss of amenity
Barrier effect	Change in land v]alue, ecological impact, loss of amenity
Noise	Water pollution, change in land value, local air pollution, ecological impact, loss of amenity
Loss of amenity	Change in land value

Note. (Chatziioannou *et al*., 2020)

2.13 Construction Transport

The low-cost/high-volume nature of construction materials leads to substantial transport requirement, even for small projects. Consequently, transport forms a major component of construction logistics. The volume of construction material required for a project, site requirement aligned and typically small deliveries, planning and communication voids, and transport externalities (Balm & Ploos van Amstel, 2017; Lovell *et al.*, 2006; The Bellona Foundation, 2020; Ying & Roberti, 2013) present significant challenges in the construction domain.

Figure 2.25 presents the complete gamut of transport over the construction project life cycle showing the boundaries of various phases and between participants.

Figure 2.25

The role of transport in construction

Note. (Fredriksson *et al.*, 2020)

Construction transportation is road-dominant and primarily fossil-fuel-driven. The sheer volume of materials requiring transportation implies large amounts of emissions from high energy consumption and the associated substantial negative environmental impacts. Forming 20%-30% of road traffic, freight transport consumes 40% of urban oil, and emits 80%-90% of logistics-related carbon and 16%-50% of overall air pollutants (Khaled & Alam, 2016; McKinnon, 2010b; Lindholm & Behrends, 2012). It contributes a fifth of sectoral energy consumption and nearly a tenth of its greenhouse gas (GHG) emissions (Morana *et al.*, 2014; Shakantu & Emuze, 2012; Smith *et al.*, 2003).

Transport and the environment exhibit a paradoxical relationship; while it supports mobility, transport is inextricably associated with environmental and other interlinked social and economic externalities (Figure 2.24 and Table 2.2). These include emissions, non-renewability of resources, waste, loss of biodiversity, congestion, noise, accident risk, gridlock, pollution, health, infrastructure damage, and Reduction in Quality of Life, to name a few (Balm & Ploos van Amstel, 2017; Behrends, 2015; Bretzke, 2013; Browne & Allen, 2011; Janné & Fredriksson, 2019; Kin *et al*., 2017; Kohn & Brodin, 2008; Morana *et al*., 2014; Vrijhoef, 2015).

Commercial road vehicles represent one of the least sustainable transport modes, responsible for externalities and negative impacts far out of proportion to their numbers. An illustration of the annual negative impacts (monetised) of various modes of goods transport and a similar comparison of Heavy Delivery Vehicles (HDVs) with other modes of transport in the EU is in Figure 2.26.

Figure 2.26

Monetised costs of transport externalities (European Union 2008)

Note. (Van Essen *et al*., 2011)

There has been an increasing focus on reducing the negative impacts of vehicle operation within urban and suburban areas. In addition to maximising profits with minimisation of costs and lead times, logistics systems have evolved from the environmental perspective (minimising the Total Environmental Impact) (Kohn & Brodin, 2008) to the sustainability perspective (minimising the Total Impact). These include safety and security-induced direct and short-term impacts, e.g., accidents, medium- and long-term environmental impacts, system characteristics impacting operational management, infrastructural support, SCs, upstream and downstream processes that impact environment and society, and unsustainable use of resources (Rohács & Rohács, 2020).

Systemic improvements that reduce logistics' environmental effects have potential benefits in all sustainability dimensions. Since sustainability of logistics is being discussed, and a major unsustainable component is transport, a definition of sustainable transportation is pertinent at this point *viz*: -

> A sustainable transport system is one that throughout its full life-cycle operation, allows generally accepted objectives for health and environmental quality to be met, for example, those concerning air pollutants and noise proposed by the World Health Organisation (WHO); is consistent with ecosystem integrity, for example, it does not contribute to exceedance of critical loads and levels as defined by WHO for acidification, eutrophication and ground level ozone; and does not result in worsening of adverse global phenomena such as climate change and stratospheric ozone depletion" (OECD, 2002b, p. 16)

2.14 Sustainability of Construction Transport

Four frameworks look at the sustainability or 'greening' of freight transport (of which construction transport is a subset) *viz* The Green Logistics, the A-S-I/A-S-I-F, the TIMBER, and the IF-TOLD frameworks. The first two are internal to the BU; TIMBER is outward-looking, while IF-TOLD is a generalisation.

2.14.1 Green Logistics Framework

This framework was developed for specifically greening freight transport operations. The model (Figure 2.27) consists of the following key parameters (McKinnon, 2018; Tamulis et al., 2012): -

- **Modal split** Freight proportion carried by different modes of transport.
- **Handling factor** Ratio of the weight of the goods to the freight tonnes (weight) lifted, representing a measure of the number of SC links.
- **Length of Haul** The mean length of each SC link, which converts tonnes lifted into tonne-km.
- **Empty running** Total number of km run empty by a vehicle.
- **Load factor** Despatch weight as a percentage of the truck payload capacity.

- **Energy efficiency** Ratio of the distance travelled to the energy consumed dependent on vehicle attributes, driving behaviour, and traffic conditions.
- **GHG emissions per unit of energy** Carbon content of fuel burned in the vehicle. This needs to be measured 'well-to-wheel' to cater for alternate fuels.

The 'handling factor' and 'length of haul' parameters can be combined into 'freight transport intensity', and 'empty running' and 'load factor' into 'asset utilisation'.

Figure 2.27

The Green Logistics framework

Note. (McKinnon, 2018)

2.14.2 The A-S-I/A-S-I-F Framework

The early 1990s saw the development of Avoid-Shift-Improve (A-S-I) in Germany as "*vermeiden, verbessern, verlagern"*. This framework has three principal components (Transport Policy Advisory Services (Germany), 2019): -

- **Avoid/Reduce** Reduction in the need for transport or avoiding it entirely to improve the efficiency of the transport system as a whole (e.g., through integrated land-use and transport demand management).

- **Shift/Maintain** This component focuses on improving the efficiency of individual trips. Shifting the transport mode from the most energy-consuming and polluting to those more environmentally friendly substantially addresses transport system challenges.

- **Improve** seeks optimisation of the fuel and operational efficiencies of transport. Additionally, improvement in the sources of energy, especially renewable energy sources, over the long term is the key.

The A-S-I-F framework, presenting an additional *Fuel* parameter, is also frequently referred to in the literature. The *Fuel* parameter differentiates energy efficiency from emissions per unit of energy (Schipper & Marie-Lilliu, 1999; Schipper *et al*., 2009).

The A-S-I-F framework sees its origins in the A-S-I-F equation. Freight transport emissions (G) depend on the quantum of travel activity (A) in tonne-km across all transport modes, the modal structure (S), each mode's fuel intensity (I) in litres per tonne-km, and a fuel's carbon content yield an emission factor (F) (in grams of carbon per litre of fuel consumed). A mathematical representation of the relation between these parameters is in Figure 2.28. The A-S-I-F equation may be mapped onto the A-S-I-F framework as follows: **Avoid** (reducing the level of transport *Activity*), **Shift** (altering the modal *Structure* of the transport system), **Improve** (reducing the energy *Intensity* of transport operation), and **Fuel** (cutting the carbon content of the *Fuel*). Between the A-S-I-F and the A-S-I frameworks, A-S-I subsumes the *Fuel* attribute into its *Intensity* parameter.

Figure 2.28

The A-S-I-F equation

Note. (Schipper *et al*., 2009)

2.14.3 The TIMBER Framework

Freight transport decarbonisation through logistics operations needs to consider factors external to the organisation. Aligning these to internal factors can provide positive accentuation; however, if they are counteracting, it may call for the intensification of internal efforts or a downward revision of decarbonisation targets.

The TIMBER framework is comprised of the following factors (McKinnon, 2018): -

- **Technology** Advances in transport, warehousing and materials handling technology.
- **Infrastructure** Transportation infrastructure comprising networks, terminals, and modes. It may also include infrastructure pertaining to communication and energy.
- **Market** Structural changes in the market for logistics services, the manner of their trading, and the nature of demand.
- **Behaviour** at both industry and individual or employee levels. The latter may include training and certification.
- **Energy** Pertains to the carbon intensity of the fuels used. Includes the availability of alternative fuels and the nature of electricity generation.
- **Regulation** Considered at the multi-national, national and local levels. E.g., regulation on construction and use of freight vehicles, controls on road haulage, and restrictions of access. It can also extend to fiscal policy measures.

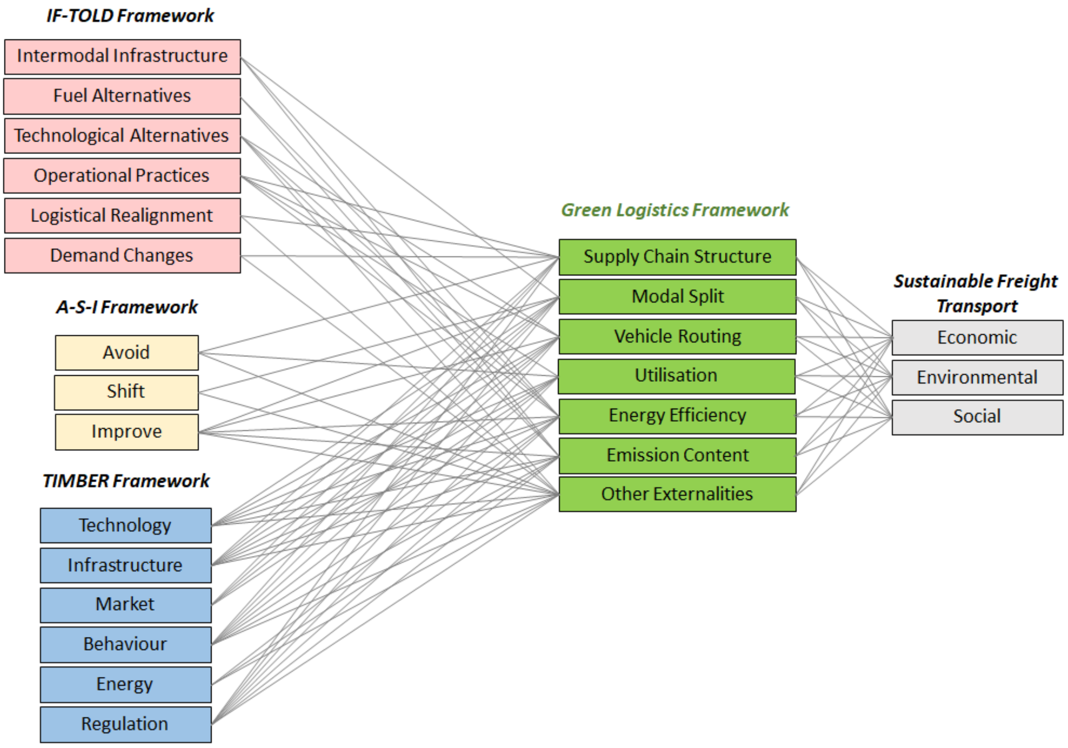
2.14.4 The IF-TOLD framework

Similar to ‘Green Logistics’, it seeks to reconfigure technologies, operations and infrastructure pertaining to freight transport. IF-TOLD dimensions are Inter-modality of Infrastructure (I), Alternate Fuels (F), Technological Alternatives (T), Operational Practices (O), Realigning Logistics, and Changes in Demand for goods and packaging (D) (United Nations Conference on Trade and Development [UNCTAD], 2017).

Figure 2.29 maps the four frameworks onto sustainable transport attributes.

Figure 2.29

Mapping between the four sustainable transport frameworks



Note. (Based on McKinnon, 2018; UNCTAD, 2017)

2.14.5 The Solution Space

Mapping between the four frameworks and their association with sustainable transport presents a solution space consisting of five focus areas *viz* freight demand management, combining and smart use of modes, maximising asset utilisation, energy efficiency, and use of lowest energy source. These are discussed as follows (McKinnon, 2018; Punte *et al*., 2019): -

- **Freight demand** Reducing the intensity of freight transport for economic activity by restructuring SCs, localisation, nearshoring, decentralised production and stocking, dematerialisation, and modified consumer.

- **Transport modes** Shifting freight to low energy intensive modes (e.g., rail, waterways, and low emission modes), optimisation of networks across modes, and synchro-modality.

- **Asset utilisation** Maximising asset utilisation through optimised loads, consolidation, asset sharing, backloads, modular packaging, open warehouses and transportation networks.

- **Energy efficient assets** Reducing per-unit energy consumption relative to every tonne-km travelled by freight through cleaner and more efficient technologies (fuels and fleet), operational methodologies, telematics, and low-energy infrastructure.

- **Low energy intensity** Reducing the carbon content of energy used in logistics (Optimising diesel systems, CNG/ LNG, biofuels, hydrogen, and electric/hybrid vehicles).

From the transport perspective, sustainable logistics are characterised by reduced movements, handling, and distances, and improved vehicle capacity utilisation and energy efficiency (International Energy Agency [IEA], 2018; McKinnon, 2010b).

2.14.6 Consolidation as a Transport Solution

Continuing with the discussion from section 2.6.3, consolidation of goods from more than one supplier into one shipment as a means of reducing delivery transport is a potent alternative for reducing the negative impacts of urban goods transportation (Allen *et al*., 2007, 2012, 2014; Björklund *et al*., 2017; Janné & Fredriksson, 2019; Kohn & Brodin, 2008).

Consolidation effectively uses the load and/or volumetric capacity of freight vehicles to consolidate urban freight flows, reducing the number of vehicles entering urban areas (Verlinde *et al*., 2012).

The literature is rich with a discussion of consolidation from the construction site perspective. The reverse perspective for consolidation at the supplier’s end also holds good; however, it does not appear very often in the literature. Potential consolidation at the supplier’s end provides innovative SC configuration, especially in the case of the construction sector, where the BM is a pivot around which the CSC revolves.

The potential for effective and implementable consolidation at the supplier’s end is also visible in cases where VI in the SC integrates the distribution function as an extension of manufacture.

Consolidation at the supplier’s end effectively tackles lateral fragmentation (between projects), a blind spot for site-centric management.

2.15 Construction Transport as a Subset of Freight Transport in New Zealand

NZ’s freight logistics are driven by certain peculiar spatial, market, regulatory, and economic attributes (*inter alia* geographical isolation, import dependency, small regional extent, long transits, small market/economy, and lack of regulatory controls, amongst others) (Chapman & Howden-Chapman, 2020; Khan & Lockhart, 2019; Ying *et al.*, 2014).

Road transport substantially contributes to moving exports and imports, the end of one logistics chain, marking the beginning of another one (for exports, the international chain commences at ports, where the internal logistics chain ends, and vice-versa for imports). Road transport also carries freight over a multitude of routes and is also an essential component of inter-modality for other significant freight transportation modes *viz* coastal shipping and railways.

Heavy trucks dominate the road freight industry. These have a long service life (an average of 24 years for a new truck). Low-emission options in NZ are limited since the transport market is entirely dependent on imports. The NZ road transport system has a 99% dependency on fossil fuels, producing approximately 17% of its total GHG emissions, which are steadily increasing (Climate Change Commission [CCC], 2021; Ministry for the Environment, New Zealand Government [MfE], 2021b, 2022b).

The ‘New Zealand Energy Strategy to 2050’ (Ministry of Economic Development, 2007) proposes a reduction in distances travelled by large trucks, increasing average truck loading, and improved distribution practices as freight transport sustainability strategies. In addition, the Intergovernmental Panel on Climate Change (IPCC) report titled ‘Mitigation of Climate Change’ (2014) states restructuring of freight logistics, shift to lower carbon modes, and increased load factors to lower transport energy intensity as key focus areas for emissions reduction (Kontovas & Psaraftis, 2016).

Within NZ, the transport sector contributes to half the overall energy-related emissions. GHG emissions in NZ have a very high contribution from the transport sector, primarily road transport. 24.8% of all road transport GHG emissions in 2015 came from the heavy vehicle fleet, comprising only 6%-7% of the VKT. By tonnage, 93% of all freight movement is via road transport, presenting the advantages of fast and reliable door-to-door service and proving more efficient for shorter trips. Emissions from road transportation have almost doubled during the period 1990-2019, and those from commercial transport have grown from circa 16% in 1990 to approximately 25% in 2015 (Concept Consulting Group Limited, 2019; MfE, 2021a, 2022b).

Figure 2.30 illustrates NZ's emissions profile, and Figure 2.31 shows the freight movement profile.

Figure 2.30

NZ emissions profile

Note. (MfE, 2022b; MoT, 2020a)

Figure 2.31

NZ freight movement profile

Note. (MoT, 2020a)

Almost a third of the freight transport in NZ serves construction (Ministry of Transport, New Zealand Government [MoT], 2020a) (Figure 2.32).

Figure 2.32

NZ road freight by commodity

Note. (MoT, 2020a)

The Avoid (Reduce), Shift/Maintain, and Improve (ASI) approach (Figure 2.33) has been adopted by the NZ Government as an overarching strategy for mitigating transport externalities (MoT, 2021).

Figure 2.33

The Avoid-Shift-Improve framework

Note. (Litman, 2021)

NZ's First Emissions Reduction Plan (MfE, 2022c) specifies decarbonisation of freight transport in the transport domain and reduction of road transport requirement in the construction sector as key emissions reduction actions. The strategy, however, does not specify any specific methodologies to achieve, stating 'commencement of work' as the aim. If proven, the research hypothesis will provide evidence-based means to achieve optimisation and decarbonisation.

2.16 Inferences from the Literature Review and Relevance to the study

The literature review was undertaken with the primary aim of extracting the space at the intersection of SCs, logistics, the construction context, and transport and its sustainability with an NZ focus.

2.16.1 Supply Chain and Logistics Inferences for the Study

Based on the preceding literature review, the following aspects of the CSC emerge: -

- The SC pertains to upstream and downstream flows of products, services, finances, and/or information from a source to a customer.

- SC complexity stems from consideration of the linkages between the actors, immediate, neighbouring or ultimate. A CSC may consider all these simultaneously, depending upon the resource being focussed upon.

- The SC has a distinct lifecycle, with emergence, growth, maturity, and decline as the lifecycle stages.

- SCM primarily involves business process integration from end-users through suppliers to provide products, services, and information, adding value for the customer.

- As a management philosophy, SCM considers the SC as a single entity for managing the entire flow of goods from the supplier to the ultimate consumer. It uses a systems approach instead of distinct functions performed by fragmented elements, extending partnerships into the multi-organisational domain. The performance of each SC component influences the performance of all others.

- To implement the management philosophy, SCM needs to adopt certain fundamental management practices *viz* integrated behaviour, information sharing, risk sharing/mitigation, cooperation, joint planning, control, and action, common goals and focus, process integration, and partnerships for long-term relationships.

- As a set of management practices, SCM needs a process approach to be adopted by all SC members external to their internal verticals, reorganising all SC functions as key processes. BUs participating in the SC need to be organised around these processes (e.g., relationship management, customer service, demand, order fulfilment, manufacturing flow, and procurement), each focussed on the customer's requirements.

- SCM may be undertaken at four different levels *viz* integration of a firm's activities, managing the dyadic relationship between two immediately connected suppliers, managing a chain of businesses outside the firm's contractual relations, and managing an interconnected businesses network providing products to customers.

- The CSC exhibits certain typical characteristics *viz* Convergence of the SC directing all materials to the construction site, where the product is assembled; A singular product (the built asset) around which the 'manufacturing plant' is set up; A temporary and situationally evolving SC involving repetitive reconfiguration of project organisations; and, A one-off and unique product, therefore, an MTO SC.

- The concept of the SC life cycle is significant in the construction industry as a result of fragmentation and the temporary nature of organisations surrounding a construction project. A CSC may undergo the complete lifecycle through just one stage or phase of a construction project, primarily driven by diverse and disjointed operational and sourcing methodologies, compounded by the diversity of stakeholders, delineated design and construction, insularity of professions, and competitive tendering.

- CSCs are impacted by: Substantial customer influence on the project and logistics; Fragmentation of the SC in terms of actors, business purposes, and methods; Multiplicity of stakeholders leading to multiple organisations and relationships (material, information, service, product, and fund flows); Transactional buyer-supplier relationship leading to conflict, mistrust, and a singular focus on margins; Temporary multiple organisations; Inertia in construction organisations to change due to conservative risk-driven perspectives; and, An MTO SC with the client commencing and terminating the process.

- Three types of CSCs participate in the execution phase of a construction project *viz* the Primary SC, for delivery of material; the Support SC focussing on equipment, expertise, and materials facilitating construction; and the Human Resources SC, concerned with labour.

- SCM in the construction domain may focus on the SC; Impacts of the SC on site activities; Transferring activities from the site to earlier stages of the SC; Integrated management for improving site production and the SC; Construction site logistics; Coordinating logistics between the construction project and the local community; and, Coordination between multiple projects.

- CSCM may be implemented through either an equitable relation-based collaboration resulting in operational efficiency and effectiveness (a simplistic perspective) or a power regime-based collaboration for SCM-based strategic efficiency and effectiveness.

- Integration in the SC, as opposed to the demand side, may also take place on the supply side through project-independent collaboration with other parties in the SC and the internalisation of neighbouring activities. E.g., a general contractor, an architect, or a materials supplier could be the system integrator.

- Logistics primarily pertains to the flow of materials and associated information, while SCM pertains to the flow of information, materials, money, workforce, and capital equipment. The relationship between logistics and SCM is ambiguous, with the most commonly accepted approach considering logistics as a part of SCM. SCM is more complicated than logistics as it involves a larger range of variables and manages different parties.

- Logistics are comprised of logistics processes, which may be taken to be orderly temporal sequences of successive conditions and changes, a set of logically associated tasks and activities, or change driven through a transformation of input data into output. The comprising logistics processes are material flow processes, information and decision-making processes, and inventory processes.

- Logistics perform three distinct functions in the SC *viz* Order processing (concerned with information flows in the logistics system); Inventory management (for determining stock levels for minimising total operating costs while satisfying customer service requirements); and, Freight transportation (contributing to a substantial part of the cost of logistics, significantly impacting the customer service level, and permitting dispersed production and consumption, leading to wider markets).

- Logistics strategy focuses on capital reduction, cost reduction, and service level improvement. It may be implemented informally (within the organisational structure), semi-formally (by an expert outside the areas of activity), or formally (a separate vertical) in a BU. Construction logistics encompass all measures for getting the right equipment, materials and workers with the right level of quality to the right construction site at the right moment and at minimum cost to meet the customer's requirements.

- Construction logistics comprises Whole-project logistics, Supply logistics, and On-site logistics. They are distinctively influenced by construction characteristics *viz* A unique logistics set-up for each site, being unique and temporary; Material intensity of construction sites, typically with requirement-driven supply; Sequential nature of construction activities, with delays transmitting through all activities, demanding timely deliveries in right quantities; and, Fragmentation-based different operational and management philosophies, and inefficient resource utilisation in temporary construction consortia.

- A construction project may see the implementation of logistics through four possible systems: Independent SCs for individual contractors; A centralised supply system managed by the general contractor or other party managing the whole project; A centralised supply system managed by an external logistics company; and/or, A combination. Logistics on a construction site may be grouped into three domains: planning and organisation, transportation, and site activities corresponding to whole-project logistics, supply logistics, and site logistics.

- Reverse logistics attempts to extract value by managing the reverse flow of goods in channels that may be the same or different from forward logistics channels. Reverse logistics for the construction industry provides a means to reduce energy consumption and the associated emissions through all activities associated with the collection, movement, storage, disassembly, and processing of used or outdated products (or product parts), and packaging and materials to ensure sustainable recovery.

- It takes place between two parties, a returning party, who had the product, and a receiving party trying to recover value.

2.16.2 Transport Inferences for the Study

Based on the literature review on transport, the following inferences may be drawn pertaining to (freight) transport in general and construction transport in particular, and its NZ context: -

- Freight transport is driven by the **Demand** for goods, **Supply** for meeting the demand, and **Context** comprised of logistics operations and vehicle movements resulting from the demand-supply interaction.
- The physical environment surrounding the demand-supply aggregation defines the contexts and domains of operation of various SCs.
- The low-cost/high-volume nature of construction materials leads to substantial transport requirement, even for small projects. Consequently, transport forms a substantial component of construction logistics.
- The volume of construction material required for a project, its site requirement-aligned delivery, minimal associated planning and communication, typically small deliveries, and externalities associated with transport present significant challenges in the construction domain.
- The performance of the transportation function is governed by its cost, infrastructure-related issues, management, and externalities.
- Four frameworks look at the sustainability of freight transport (including construction transport) *viz* Green Logistics, A-S-I/A-S-I-F, TIMBER, and IF-TOLD frameworks. While the first two are more internal to the BU, TIMBER is outward-looking, while IF-TOLD is a generalisation.

- Based on these frameworks, transport may be made more sustainable through demand management, mode combination, maximising asset utilisation, energy efficiency, and use of the lowest energy sources.

- Freight transport in NZ produces almost a quarter of the GHG emissions of the sector, with merely 6%-7% of the vehicle kilometres travelled (VKT).

- A third of NZ’s freight transport is construction related.

- The NZ Government has adopted the ASI approach as an overarching strategy to mitigate logistics (transport) externalities.

- NZ’s First Emissions Reduction Plan specifies decarbonisation of freight transport in the transport domain and reducing road transport requirement in the construction sector as key emissions reduction actions.

2.17 Chapter Summary - Relevance to the Study

As is evidenced in the literature, one of the biggest challenges to undertaking quantitative studies in the domain of construction logistics is the overall need for more data available for research. Most of the operational data collected by companies is considered ‘commercially sensitive’ and, therefore, not available to researchers. The situation in NZ is confounded by the overall void in construction logistics knowledge and its peculiar attributes, where-in it adopts philosophies and concepts behind other developed economies. Yet, the operational logistics domain does present the implementation of certain innovative SC models, which demand analysis and quantification to support or refute SC theories. E.g., forward VI of distribution with the manufacturer’s operations is one such innovation that the largest plasterboard manufacturer in NZ has implemented.

Though the particular SC segment is very narrow, it is potentially fertile for research since it encompasses elements from SCs and their management, logistics, freight transport, goods distribution, reverse logistics, and their construction context in the NZ setting.

All these domains have, therefore, been addressed in the literature review. However, certain aspects like SC integration have been discussed only from how they were perceived as implemented in the SC being studied. The intersection of multiple domains in the focus area also points to the potential for generalising the research outputs, providing further research directions for future work.

A clear description to attribute specificity to the research problem and its linkages with all these domains will be undertaken in the opening of Chapter 4 (Analysis) to revisit the problem as a preamble before the actual mechanics of data analysis are discussed.

Chapter 3 Research Methodology

3.1 Methodological Framework

This chapter presents the methodological framework for the conduct of this study. First, the research problem is discussed, followed by a philosophical positioning of research and research strategy. Next, the research being undertaken is posited within this framework. The end of the chapter presents a brief on data collection, sampling, and data analysis methods, followed by assumptions and limitations.

3.2 Research

Research is,

> A “disciplined inquiry" which . . . must be conducted and reported so that its logical argument can be carefully examined; it does not depend on surface plausibility or the eloquence, status, or authority of its author; error is avoided; evidential test and verification are valued; the dispassionate search for truth is valued over ideology. Every piece of research or evaluation, whether naturalistic, experimental, survey, or historical must meet these standards to be considered disciplined (Smith, 1981, p. 585)

This comprehensive definition illustrates that research is systematic (in the manner it is to be undertaken), it needs to be disseminated to enable others to examine it and make use of it, its dissemination must include a detailed explanation of the methods used and should be independent of the researcher’s status and research rhetoric, standing on its own merit (Morgan *et al.*, 1999).

Research has the following characteristics (Coryn, 2006; Hammersley, 2005; Naidoo, 2011): -

- **Relevance** Research must be founded on relevant material and context; otherwise, it is purposeless and wasteful in its pursuit and resource consumption and unethical in subjecting participants to procedures.

- **Conceptions** When conceptualised, research may have certain goals in mind. Possible outcomes may be creating a model or theory, recommending interventions, policy guidelines, documentation, or regulatory recommendations.

- **Orthodoxies** Parochial demarcations that emphasise method and objectivity should be avoided. Researchers practising very different approaches is not a situation that requires remedy; rather, it should be encouraged (as will be clearer in the discussion pertaining to research paradigms). Research design captures the inquiry/study blueprint, holding predetermined process-bound accountability of the researcher.

- **Theoretical orientations** provide a scoping framework for the research, while anchoring it firmly in the literature. Some examples of theoretical orientations of research are grand, substantive, or critical theories, and trends of the research eco-system. The theoretical framework is essential for positing the study in the context of the research domain it pertains to.

- **Ethical framework** Research must be beneficent and non-maleficent. It must respect autonomy of the participants, with due consideration to prevent harm to groups.

OECD’s Frascati Manual (2002) classifies research as: -

> ….basic research, applied research and experimental development. *Basic research* is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts without any particular application or use in view. *Applied research* is also an original investigation undertaken to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. *Experimental development* is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed (OECD, 2002, p. 30)

3.3 Methodology and Methods

From the middle ages French definition of research as a process of closely seeking, rational thinking has been onboarded over its evolution, introducing inquiry or investigation as a scientific quest (Harper, 2020). Research is contemporarily defined as a systematic scientific quest that produces new knowledge or creatively applies existing knowledge to answer inquiries of interest (OECD, 2013).

There is a tendency to use ‘research methodology’ and ‘research methods’ interchangeably. They are, however, to be considered distinct from each other. Research methodology is *“the combination of techniques used to enquire into a specific situation”,* defining the overarching approach to research from theoretical underpinnings to actual enactment of the research process (Easterby-Smith *et al*., 2012).

The methodology concerns the ‘why’, ‘what’, ‘when’ and ‘how’ research. The current definition introduces the doctrinal concept into this simple definition (Harper, 2020). The scientific version proposes a structured framework for solving the problem by applying suitable methods (Goundar, 2012).

A methodology is an investigation undertaken for efficient data collection, examination, and validation (OECD, 2004). The researcher's key question centres around obtaining pertinent data, knowledge, and understanding to contribute to knowledge by answering their research question(s) (Kivunja & Kuyini, 2017). Methodology ensconces within itself research approaches, designs, methods, and procedures employed in a well-planned investigation to discover something (Keeves, 1997, as cited in Kivunja & Kuyini, 2017). Research methodology broadly comprises data acquisition, participation, instruments, and analysis.

Three types of research methods exist, *viz* quantitative, qualitative, and mixed methods (Creswell, 2003, 2014), each being uniquely posited in terms of research designs and methods. Research methods refer to data collection, analysis, and interpretation as individual techniques (Easterby-Smith *et al*., 2012; Hussey & Hussey, 1997). A research method is essentially a tool that forms a component of the research methodology adopted.

A research methodology offers more than one method for data collection and analysis, producing the findings (Igwenagu, 2016). Methodologies, like theories, can be more or less useful and not ‘right’ or ‘wrong’ (Silverman, 1998), in the investigation of certain problems, compared to others.

The selection of the methodology and methods needs to be dictated by the attributes of the problem being investigated and the study's objectives (Babbie, 2009; Easterby-Smith *et al*., 2012; Hussey & Hussey, 1997; Punch, 2001; Zelditch, 1962).

3.4 A Description of the Research Problem

The problem addressed by this study pertains to the transport optimisation achieved, and further optimisation potential for the transport function in a specific and narrow segment of the NZ CSC as a result of implemented SC structures. This is directly associated with an existent void of construction logistics understanding in general and specific to the region. Sections 3.4.1 to 3.4.3 describe the research problem in terms of scope, nature, and complexity.

To address the problem, it is necessary to understand the logistics operations and processes associated with delivering construction materials from both an SC perspective as well as from an operational perspective.

The study's overall objective is to establish the SC model governing transport movements for the delivery of construction materials to assess impacts and potential for optimisation. Any selected problem presents three distinct attributes, i.e., generalisability, description, and complexity.

3.4.1 Generalisability

Logistics demonstrate a localised (specific) as well as generalisable problem in the construction domain. The problem of logistics in construction is both specific and generalisable. The specificity emanates from a lack of quantification due to a dearth of data and the existent focus on individual trips rather than the SC perspective. At the same time, the generalisability emerges from transport extending into multiple domains, not only construction. Therefore, parallels may be drawn from outcomes in the construction industry for transport operations in other industries. This points to the selection of the methodological approach as well as the adoption of methods for delivering a specific result as an analysis of the problem at hand while producing generalisable results for freight transport and SCs.

3.4.2 Describing the Problem

Problem description points primarily to qualitative and quantitative methods that may be adopted in its investigation, i.e., first addressing the ‘what’ (is happening) and then the ‘why’ (is it happening). Assessment of logistics performance, specifically that of transportation operations, is primarily associated with resource optimisation. It lends itself to effective quantitative assessment (Mohajan, 2020) and, therefore, an explanation of practices and strategies and the means for further improvement. On the other hand, a qualitative description can provide a detailed description and, therefore, an understanding of processes and issues not readily quantifiable (Guba & Lincoln, 1994). The study's objectives align with this sequential approach, to first find out ‘what’ is happening, then address ‘why’ it is happening, the former using numerical methods, and next substantiating or validating the outputs of data analysis through interactive means with the concerned actors. While quantitative methods may form a substantial part of the research being undertaken, qualitative methods provide balance in expressing a managerial perspective.

3.4.3 Complexity

The complexity of the problem being addressed is a fundamental question that points to the effectiveness of the adopted methods and, more importantly, the specificity of the likely results. SC complexity is proportional to the demand, supply, and manufacturing uncertainty that may arise in the order-fulfilment process. One method of describing logistics systems is through their ‘nodes’ and ‘links’ configuration. System complexity is a function of the number of the comprising elements, while its effectiveness depends on the inter-relationships between them (Coyle *et al.*, 2009). Further, considering construction logistics from the site perspective increases the uncertainty since the involved entities (from the supply side) may be associated with other construction sites and, therefore, form part of other SCs.

In the instant case, considering that the construction SC is extensive, extending from raw material extraction through processing, manufacture, and application in a construction project, the overall gamut of transportation operations presents a very complex domain, with the scope of work not justifying the potential outcomes. However, if the scope of the investigation is narrowed to one of the segments of the CSC, the potential for the results to be quick and reasonably accurate increases, the modelling requirements become simpler, and the overall governing ‘equation’, so to say, has limited variables.

Therefore, analysis of complex (non-stationary and/or non-linear) technical systems is usually simplified through the selection of a simplified sub-system which carries most of the information required for the inquiry being undertaken. Variables or degrees of freedom not included in the selected sub-system may be considered refining factors that have minimal impact on the solution for the simplified sub-system selected (Belardo & Pazer, 1985). Therefore, a very narrow NZ CSC segment has been selected for investigation in the instant case.

Effectively, the considerations guiding the research (material delivery-to-site from the manufacturer's premises) reduce a potentially complex problem to a relatively simple one, both from the perspective of uncertainty (since the scope of the operations is well defined, the stochasticity is minimal, making operations substantially deterministic in terms of assessment parameters), as also from the viewpoint of the links and nodes involved (the source (manufacturer's warehouse) and the consumer (the construction site) nodes joined by one link). The parameters requiring measurement for assessing efficiencies and potential for improvement are distances, loads, and costs, which are quantifiable. Materials delivery to multiple sites may fragment the consumer node into more than one. However, the potential complexity is offset by the standardisation of materials and the nature of delivery (one product 'direct to site' delivery by the manufacturer). The problem being investigated is, in terms of the Scope-Complexity (S-C) classification (Belardo & Pazer, 1985), generic (since it pertains to transport operations), quantifiable, and simple.

3.5 A Philosophical Background

The philosophical stance of research forms a cornerstone of research methodology, enabling researchers to establish, control, and enhance the approach to knowledge generation (Creswell & Creswell, 2018). Research philosophy also confirms scientific findings from the perspective of existing theories based on multiple philosophical underpinnings (Sapkota, 2019). Finally, the research paradigm describes a worldview informed by beliefs and assumptions about knowledge development.

Thomas Kuhn's (1962) seminal work, 'The Structure of Scientific Revolution', introduced the term 'paradigm' into research, defining it as a philosophical thought process (Kuhn, 1962, as cited in Kivunja & Kuyini, 2017). Other pertinent definitions of paradigm in the context of research are *"A basic system or worldview that guides the investigator"* (Guba & Lincoln, 1994, p.105); and, *"A set of assumptions, concepts, values, and practices that* *constitutes a way of viewing reality"* (McGregor & Murnane, 2010, p.419). From another viewpoint, paradigm also assumes the onus of philosophy in the literature, defined as *"the researcher's world view or assumptions guiding the research"* (Saunders *et al*., 2009, pp. 108-109).

The significance of research paradigm or philosophy stems from profound perspectives: *"Paradigm issues are crucial; no inquirer, we maintain, ought to go about the business of inquiry without being clear about just what paradigm informs and guides his or her approach"* (Guba & Lincoln, 1994, p. 116); *"It is the choice of the paradigm that sets down the intent, motivation and expectations for the research"* (Mackenzie & Knipe, 2006, p. 2). In effect, the research paradigm states the researcher's philosophical perspective, orientation, thinking, or set of shared beliefs, the 'what' and 'how' of the research subject, and the manner of interpreting the results (Okesina, 2020).

Each stage of research is, therefore, founded on assumptions pertaining to human knowledge (epistemology), social realities (ontology), and the impact (extent and manner) of the researcher's ethics and value systems on the research process (axiology). A paradigm thus points to the questions and systematic approaches for inquiry (methodology). A research paradigm, therefore, defines the nature of the inquiry being conducted through the inter-relation of practice and thinking (Chilisia & Kawulich, 2012; Saunders *et al*., 2009).

3.5.1 Epistemology

Epistemology emphasises the origin and nature of knowing and the construction of knowledge (Maykut & Morehouse, 2005; Rashid *et al*., 2019). It is the study of knowing, i.e., the 'how' and 'what', that discovers the association between the researcher and the object of study. Epistemology derives its importance from the value of knowledge to the researcher. It makes broad assumptions regarding the ways best suited to the inquiry. The epistemological investigation reflects on standards and methods of producing reliable and verifiable knowledge. Therefore, it is a study of verification of knowledge (Babbie, 2009; Chia, 2002; Easterby-Smith *et al*., 2012; Neuman, 2014).

Debates over epistemology have centred around what: (i) Knowledge consists of (what); e.g., justified true belief; (ii) Knowledge is based on how (e.g., pure reason, sensory experience etc.); and (iii) Is the extent of knowledge (how much) (Longworth, 2012;

Moser, 2010). The types of inquiry logics comprising epistemology are (Burney & Saleem, 2008; Ormston *et al*., 2014): -

- **Inductive logic** Involves bottom-up knowledge building through observation, which underpins the development of laws or theories.
- **Deductive logic** An approach that derives a hypothesis from a theory, applying it to observations for its confirmation or rejection. Hence, it strengthens or weakens the theory.
- **Retroductive logic** Identifies mechanisms or structures behind data patterns and explains them by 'fitting' different models.
- **Abductive logic** Involves 'abducting' a technical account, using the researchers' categories, from participants' accounts of everyday activities, ideas or beliefs.

Epistemological views may be characterised as objective (if knowledge is viewed by the researcher as governed by nature's laws) or subjective (if the researcher considers knowledge based on the interpretation of individuals) (Rashid *et al*., 2019). There exist four epistemological positions within the boundaries of objectivity and subjectivity *viz* objective, subjective, transactional/subjective, and relational (Creswell, 2014; Fard, 2012; Kivunja & Kuyini, 2017; Rashid *et al*., 2019; Saunders *et al*., 2009; Scotland, 2012):-

- **Objective** epistemology considers participant-independent reasoning for gaining knowledge. Objective knowledge is based entirely on the laws of nature.
- **Subjective** epistemology assumes collective knowledge generation-based researcher-participant interaction and the researcher's own experiences.
- **Transactional** epistemology demands that the researcher dwell deeper into participants' opinions to gain knowledge through cognitive interaction primarily for addressing social issues.
- **Relational** epistemology propounds the relative nature of the researcher-participant association/interaction to the researcher, who determines their appropriateness for the study depending on the research question(s).

Epistemology demonstrates a dichotomous bifurcation, i.e., studying a phenomenon, object, or idea from the outside without being part of it (etic study) or from within by being a part of it (emic study) (Markee, 2012).

3.5.2 Ontology

Ontology is comprised of assumptions surrounding the nature of reality or the study of 'being'. It may be defined as formally and explicitly specifying a shared conceptualisation (Borst, 1997; Gruber, 1993), an abstract model of a phenomenon generated through identification of its concepts.

It is a system of beliefs that reflects an individual's interpretation of representation of fact, implying whether social entities need an objective or subjective perception, i.e., the nature of social entities (their objectivity independent of social actors, or their perception, action, and interpretation-based social constructs) (Al-Saadi, 2014; Bryman, 2008; Don-Solomon & Eke, 2018).

Research may be founded on two opposing ontological backgrounds, the Paramenidian and Heraclitean. The Heraclitean view propounds a continuum of change (fluxing, changeable and emerging), therefore, 'becoming', while the Parmenidean perspective suggests permanence (unchangeable nature) of reality, effectively, 'being'.

The opposing viewpoints fundamentally impact the understanding of contemporary social science philosophy debates and implications for management research (Chia, 2002). The Parmenidean-inspired view prevails in the west, and the rest of the world, by transference (Rudestam & Newton, 2001). It considers reality as composed of clearly formed entities with identifiable attributes, while in the Heraclitean view, it is inclusively processual (Babbie, 2009; Neuman, 2014).

Two overarching ontological positions shape research: (i) Does social reality exist independent of human conception/interpretation – Realism; and, (ii) Does reality exist independent of the mind and socially constructed meanings, i.e., is reality a shared social construct or are there multiple, context-specific realities – Idealism or Relativism (Alharahsheh & Pius, 2020; Guba & Lincoln, 2005; Ormston *et al*., 2014; Rashid *et al*., 2019).

3.5.3 Axiology

The role of ethics and values within the process of research is referred to as Axiology. It implies a researcher dealing with their own value set and the value set of participants (Saunders *et al*., 2009). It prompts what values should guide the research and determines what values or outcomes will emerge from the research.

It needs definition, evaluation, and an understanding of behaviour (right and wrong) in relation to research, requiring attribution of value to research contexts, participants, data, and the audience whom the inquiry is to be reported to (Kivunja & Kuyini, 2017).

It fundamentally addresses issues regarding the nature of ethics and ethical behaviour in research.

As a response, research needs to consider regard for human values of participants, enabled by asking questions associated with values guiding the researcher around the research, respect for participants' rights, consideration of moral issues and characteristics, addressing cultural and inter-cultural issues, securing participants' goodwill, and conducting respectful, socially just, and peaceful research avoiding or minimising risk or harm (physical, psychological, legal, social, economic or other) (Australian Research Council, 2015).

Research axiology may be categorised as follows (Fard, 2012; Kivunja & Kuyini, 2017; Okesina, 2020; Saunders *et al*., 2009): -

- **Value-neutral** axiology separates research findings from the researcher's values/bias, enabled by their objective and data-independent stance.

- **Value-laden and balanced** axiology assumes accounting for biases (researcher's and participants') by the researcher during reporting. In addition, it assumes the value-bound subjective individual-dependent nature of research and the need for due consideration to the resulting subjectivities in research.

- **Value-laden, biased and culture-sensitive** axiology seeks recognition and respect for cultural norms by the researcher and the related inherent bias, implying orientation and cultural experiences will potentially impact the research.

- **Value-driven** axiology implies the researcher’s values as having a major impact on the research, i.e., the influence exerted by the research problem(s) and question(s) on the researcher.

3.5.4 Rhetoric

Rhetoric is the art of effective speaking or writing, referring to the use of language, later adding the manipulative use of words, also including the arts of persuasion and elaboration (Frye, 1957, as cited in Firestone, 2007). In research, it refers to the characteristics of the language used in the research and its reporting (Creswell, 1994).

Scientific writing is stripped-down, avoiding ornamentation and stating conclusions in cryptic forms, with interchangeable forms of data presentation. It also follows a typical ‘theory-methods-findings-conclusion’ to limit rhetorical excess (Eisner, 1981).

Conversely, elaboration also has an important role in research. The multiplicity of meanings makes everyday language rich in meaning within the same or different settings. Like other symbols, they draw power from the combination of meanings in the context of a particular setting (Cohen, 2011; Firestone, 2007).

Quantitative methods (Mohajan, 2020) typically express positivist assumptions, explaining behaviour through objective facts supported by design and instrumentation, demonstrating the elimination of bias and error. On the other hand, qualitative methods express relativistic assumptions, presupposing socially defined multiple realities. Rich description demonstrates the researcher's immersion in the setting, sufficiently detailed to enable the reader to understand the situation (Firestone, 2007). Mixed methods enable interchangeability within the same context, making the description richer than either.

3.6 A Framework for Research Paradigms

A research paradigm may be considered to be a set of methods having a common pattern or element in the background. The means to classify, however, may vary, e.g., data gathering technique (model, literature, survey, observation, interview, experiment, laboratory, etc.), data analysis (statistics, protocol analysis, taxonomy), research purpose (exploration, description, evaluation, hypothesis generation/testing), analysis units (individuals, groups, processes), or, the duration/time points of data collection, etc. One of the reliable frameworks for research in operations has been developed along two dimensions: the rational/existential dimension, which deals with the nature of truth, its logic, and man's independence from it, or it can be defined in terms of personal experience, and the natural/artificial dimension, which deals with the sources and types of data employed for the study (Meredith *et al.*, 1989).

The rational/existential dimension maps onto the research epistemology, involving the benefits and limitations of the adopted philosophical approach. While rationalism, at one end, formally structures and uses pure logic to measure truth, existentialism, at the other, propounds knowledge acquisition through interaction with the environment, considering individual capabilities as the basis of knowledge. The descriptive parameters are typically deductive in nature, structure, objectivity, methodological prescription, and based on assumptions at the rational end; while at the existential end, these are typically inductive, less structured, subjective, and more dependent on interaction with the environment. This dimension demonstrates four viewpoints that use varying formality of the research structure, *viz* (Meredith *et al.*, 1989): -

- **Axiomatic** perspective assumes high levels of organisational knowledge, theorem proofing research. Formality of procedures, consensus building, goal consistency, and the use of scientific principles for management characterise it.
- **Logical positivist/empiricist** perspective assumes separability of the inquiry from its context and independence of facts from explanatory laws/theories.
- **Interpretive** perspective considers the context of the phenomenon in the inquiry. It studies meanings and interpretations, and not people’s behaviour to understand construal, conceptualisation, and understanding.
- **Critical theory** considers positivism and interpretivism as logically related, synthesising them to overcome the dichotomy through the social evolutionary context of knowledge.

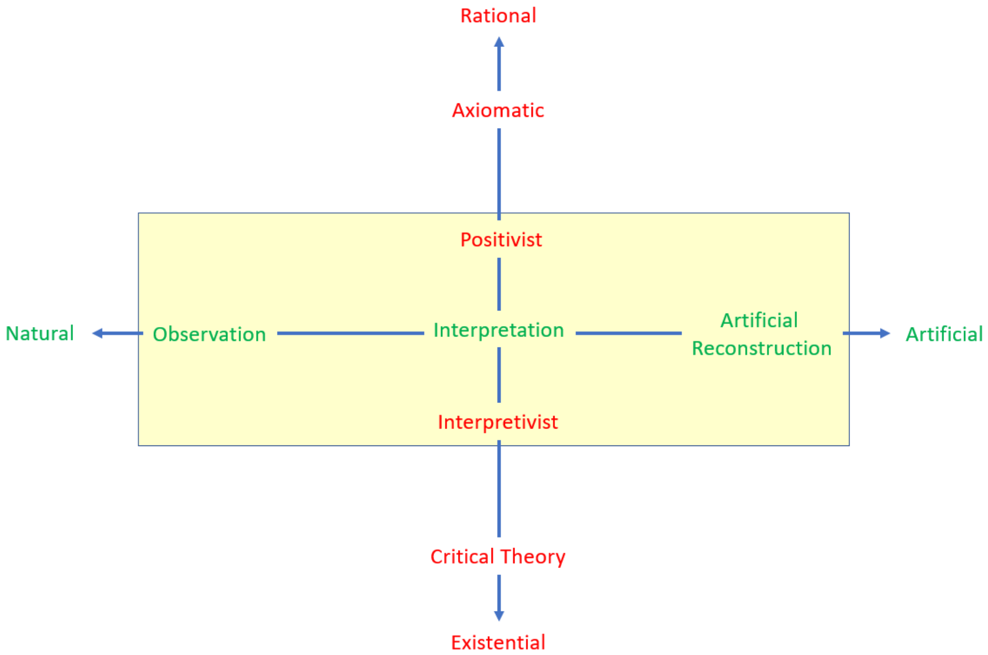
The natural/artificial dimension has empiricism (explanation of phenomena from factual and objective data) at one end and subjectivism (interpreting and artificially reconstructing reality to derive an explanation) at the other. This dimension is typically described through abstraction and simplification, consistency, a separation between the phenomenon and the researcher, the control exerted, and the dating of the phenomenon at the artificial pole. At the natural pole research is described through real phenomena, lower concern for reliability, higher consideration for externally generalisable validity, proximity to reality, less control, lesser efficiency, and higher currency.

Within these, the perception of reality is based upon the adopted inquiry mechanisms, which may be classified as object reality, people's perceptions of it, and its artificial reconstruction. ***Object reality*** refers to formal and structured analysis through observing the research object directly; ***People's perceptions of object reality*** relate to research through the lens of others' perspectives (surveys, interviews, or experiments); ***Artificial reconstruction of object reality*** is a component of modelling and systems analysis (Meredith *et al*., 1989).

Figure 3.1 illustrates the framework for research paradigms. This study narrows the rational/existential dimension to Positivism and Interpretivism, introducing Pragmatism as a balancing mechanism between them, while considering the complete continuum along the natural/artificial dimension. The axiomatic viewpoint has been excluded for its assumption of high knowledge and the critical theory viewpoint has been excluded for its primary application to social topics.

Figure 3.1

A framework for research paradigms for operations-related inquiry



Note. (Based on Meredith *et al*., 1989); The framework for this study is represented in yellow colour

Figure 3.2 illustrates methods based on the adopted framework.

Figure 3.2

A framework for research methods

Note. (Meredith *et al*., 1989)

3.7 A Discussion of Research Paradigms within the Adopted Scope

The philosophy of science examines the theories available to researchers that support the development or enable the creation of knowledge (Gray, 2018; Sarantakos, 2005).

Perspectives differ in ways of perceiving reality and knowledge creation, extending to the researcher's role in research methods (Gray, 2018).

Research demands awareness of the basic frameworks and their principles developed over time. Research paradigms, therefore, may be posited as being at the confluence of epistemology, ontology, axiology, and methodology (Hatch, 2002).

A paradigm may be defined as a common or shared framework for understanding and resolving problems. As such, the paradigm frames the evidence vs theory relationship of research within it (Kuhn & Phelps, 1979).

From this overarching definition, four perspectives or views of a paradigm emerge: -

- The widest perspective considers paradigms as *"worldviews or all-encompassing ways of experiencing and thinking about the world, including beliefs about morals, values and aesthetics"* (Morgan, 2007, p. 50). The extent of this version makes the identification of the content of the worldview possible in terms of topics and research methods.

- The second perspective views paradigms as belief systems or epistemological standpoints that influence the manner of asking and answering research questions (Guba & Lincoln, 1994).

- The third version regards paradigms as shared beliefs between members belonging to a specialised domain. Propounded by Kuhn (1962), this version is more common to the science domain vis-à-vis the social science domain.

- The fourth perspective, which is the narrowest, regards paradigms as exemplars indicating the manner of conducting an inquiry in a specific context.

One of the fundamental issues for a study is considering whether the theory is part of a long-established paradigm (above criticism) or a still-developing paradigm. While these issues may be a subject of philosophical debate, academic researchers must understand paradigms as vehicles to substantiate the selected research approach. Various theorists have proposed various research paradigms, and the classification continues to be fluid.

However, over their evolution, the following important ones have emerged: Positivist/Post-positivist, Interpretivist/Constructionist, and Pragmatist (Guba & Lincoln, 2005; Lincoln *et al.*, 2018; Morgan, 2014; Ugwu *et al.*, 2021).

3.7.1 Positivism/Post-positivism

Description

Proposed by the French philosopher Auguste Comte (Lenzer, 2017), the Positivist paradigm typifies a research perspective grounded in scientific investigation, which postulates understanding phenomena through observation, experimentation, and experience-based reasoning as the permissible means for extending knowledge (Kivunja & Kuyini, 2017).

Positivism is a system that collects data through scientific investigation while excluding metaphysical speculation (Bhattacherjee, 2012).

The positivist approach propounds that knowledge generation can only be based on the five senses, implying that it follows realistic foundationalism, i.e., suggesting the existence of the world-independent observation, therefore, possessing an objective nature (Greener, 2008, as cited in Rashid *et al*., 2019; McKerchar, 2008).

Positivism assures unambiguous and accurate knowledge of the world. It refers to an idea that has been put forth (i.e., given). Positivism views comprehensive research development by applying scientific methods for studying phenomena (Ormston *et al*., 2014).

Knowledge in this domain creates close links between empirical science and contemporary positivism, based on direct experience, not speculative (Crotty, 1998). The results of positivism lead to law-like generalisations (Saunders *et al*., 2009) driven through scientific discovery and technology. Positivists construct knowledge through the application of natural sciences to the study of social reality (Dananjoyo, 2017; Easterby-Smith *et al*., 2012).

The Comtean, Durkheimian, Logical, and Instrumental approaches can be historically recognised as shaping the positivism framework (Wacquant, 1994). The common bottom line of these philosophies is that reality is perceived as external and objective and, therefore, to be objectively measured rather than subjectively inferred through reflection, intuition, or sensation.

It also sees the construction of reliable knowledge from observing phenomena as a means to substantiate hypotheses, test theories, or provide material for the development of laws (Bryman & Bell, 2011; Easterby-Smith *et al*., 2012).

From a positivist perspective, things have meaning before and apart from any consciousness of them. Therefore, researchers address issues objectively without altering or impacting the problem being investigated in any manner.

Therefore, this paradigm demands a well-structured methodology, quantifiable observations, and statistical analysis (Remenyi *et al*., 2005, as cited in Al-Ababneh, 2020), leading to objective analysis and data interpretation by researchers (Saunders *et al.*, 2009).

Positivist research relies on deductive logic and hypothesis formulation and testing to offer quantifiable outcome-based explanation and prediction through operational definition and mathematical treatment-based conclusions. The quantifiable outcomes are underpinned by four assumptions (Cohen *et al.*, 2007) *viz* determinism, empiricism, parsimony and generalisability: -

- **Determinism** presumes a cause-and-effect cycle. Making predictions and exerting control over the impact of explanatory factors on dependent factors are necessary for understanding causal linkages among factors.

- **Empiricism** means collecting verifiable data for investigating a research problem, supporting the theoretical research framework selected and testing any hypotheses.

- **Parsimony** implies explaining phenomena studied in the most economical way possible.

- **Generalisability** is applying results from one context to other situations by inductive inference.

Characteristics

The positivist paradigm demonstrates the following characteristics: -

- The belief in the universal nature of theory cross-context generalisations.
- Non-significance of context.
- Availability of truth to be discovered through observation of knowledge.
- Distinguishability and analytical separability of cause and effect.
- Quantifiability of the results of an inquiry.
- The capability of theory to predict and control outcomes.
- Compulsorily following the scientific investigation method.
- Empirical and analytical approaches for hypotheses formulation and testing.
- Pursuit of an objective search for facts.
- Establishes a universal theory to account for human and social behaviour.

Philosophical Constructs

At the ontological level, positivism assumes realism; at the epistemological level, it disaggregates the knower and the object of study as distinct entities who do not influence one another (Fard, 2012; Guba & Lincoln, 1994), making objective knowledge possible; at the axiological level positivism focusses on facts and propounds value-free research (Fard, 2012) and beneficence; and, at the methodological level, positivism is experimental.

Realist ontology is based on perception-independent existence and retention of properties of material objects and the veracity of their truth being through sense experiences (Kivunja & Kuyini, 2017).

On the other hand, objectivist epistemology proposes gaining understanding through reasoning (Fadhel, 2002, as cited in Kivunja & Kuyini, 2017), implying the acquisition of knowledge that approximates the real nature of what is being investigated.

Experimental methodology implies the manipulation of variables to assess their impact on other variables (Smith & Heshusius, 1986), enabling acceptance or rejection of hypotheses. The beneficence axiology indicates maximisation of good outcomes for the project, participants, and humanity, avoiding harm, risk, or wrong during the research (Kivunja & Kuyini, 2017).

The postpositivist variant developed with the understanding that where human contexts are concerned, the characteristics that describe positivism cannot be applied, the study of the social and the natural world has to be different, and the social world is not value-free. Causal explanations, therefore, may not be possible. Hence, postpositivism evolved as a result of the assumptions of positivism being relaxed to accommodate the social context. Even though it proposes that reality is available to be studied, unlike positivism, it maintains that reality can never be fully understood (Kivunja & Kuyini, 2017). Postpositivism proposes a deterministic philosophy, where determining outcomes or effects by causes is probabilistic. The cause-effect sequence points to an experimental process. It also aims to disaggregate ideas into small discrete ideas which may be tested, e.g., variables that form the elements of hypotheses and research questions, to support or refute a theory. Observation and measurement of objective reality guide knowledge development (Creswell, 2014).

Positivistic Inquiry

Positivistic scientific inquiry progresses through the following stages (Shakantu, 2005; Spens & Kova´cs, 2005): -

- **Observation Stage** Observing a phenomenon in its natural state to establish it's dynamic and arrive at the dependent and independent variables (Easterby-Smith *et al*., 2012). Observational rigour provides tacit quality assurance, with the completion of observation leading to the deduction of the nature and scope of the problem. Commencement of building a theory to explain the phenomenon can commence.

- **Hypothetical Construct Stage** Further inquiry is based on a tentative explanation of the phenomenon; a hypothesis is formulated from observed facts. Research then proves or disproves this hypothesis. There may be multiple hypotheses to widen the scope and depth of research.

- Hypotheses are validated through testing and provides a means of matching the researcher's claims with real-world phenomena. Positivists aim to reduce phenomena in systems to simple elements that can be easily identified and replicated later, referred to as the 'classic reductionist' approach (Guba & Lincoln, 1994).

- **Testing Stage** This involves the design of experimentation or sampling to identify relationships between variables. This invariably points to quantitative techniques, including statistical testing. Quantifying results and validating or disproving the proposed hypotheses is the outcome. But, again, control of variables is required, which may be difficult in social settings.

- **Analysis Stage** Large amounts of data are typical of positivistic research. Data integrity and density, allied with statistical significance, become the cornerstone of effective research.

- If a hypothesis is supported, then an assessment of its sufficiency to describe the phenomenon being studied needs to be undertaken. Further testing, therefore, may need to be undertaken to demonstrate validity and repeatability.

- A rejected hypothesis will invariably lead to reformulation and experimentation. Repetitive execution of this process will establish a general law based on proven hypotheses.

Validation Criteria

Four criteria are needed to validate positivist research (Burns, 2000, as cited in Kivunja & Kuyini, 2017; Collins, 2007) *viz*: -

- **Internal validity** defines which study results may be attributed to the independent variable governing their occurrence, not other factors. This enables ascertaining the effect of the independent variable on the dependent variables and the level of confidence in the cause-effect observed. Identification of causality is supported by a high degree of internal validity.

- **External validity** refers to the generalisability of the results to other contexts, indicating that sampling has been representative of the entire population (Heale & Twycross, 2015), as also the construct of the phenomenon under investigation.

- **Reliability** is the degree of stability and consistency of results produced by a research instrument, i.e., consistency and repeatability of measurement.

- **Objectivity** implies a precision of instruments, minimisation of bias and personal subjectivity, and being open to suggestions from participants (Myrdal, 1969, as cited in Kivunja & Kuyini, 2017). It points at the researcher being distanced from the phenomenon being studied.

3.7.2 Interpretivism/Constructivism/Phenomenology

Description

Interpretivism (also referred to as phenomenology) is critical of positivism from a through subjectivity. The paradigm emphasises the difference between humans and phenomena because of the capability to create meanings, which are studied by the paradigm. It insists on a distinct difference in the manner of studying human beings and their associated social worlds from natural phenomena.

Therefore, research in the social sciences needs to be different from research into natural science phenomena, rather than emulating it. Interpretivism believes that the richness of insights into human behaviour created through different meanings and different social realities from different cultural backgrounds is likely to get lost if the complexity is reduced to generalisations expressed through laws (Saunders *et al*., 2009).

The interpretive approach seeks historically situated and culturally derived interpretations of social life (Crotty, 1998). Interpretivism emphasises social context (Orlikowski & Baroudi, 1991) and human complexity regarding people's understanding of phenomena (Kaplan & Maxwell, 1994).

The related constructivism paradigm proposes the active construction of knowledge by human beings, as opposed to being received passively by them. Interpretivism and constructionism reject the notion of objective or value-neutral observation and universal principles in favour of viewing individual perspectives of 'lived experience'.

The fundamental assumptions underpinning the interpretivist paradigm are (Crotty, 1998): -

- The engagement of humans with the world they are interpreting leads to the construction of meanings.
- Humans make sense of their engagement with the world based on their historical and social perspectives and interpret their findings.
- Meaning is always socially derived from within a community and the interaction with it.

Interpretive research considers reality as consisting of people's subjective experiences of the external world (Cohen *et al*., 2007; Krauss, 2015). It proposes that there is non-singularity of a correct route or method to knowledge (Willis, 1995) and that theories need to be judged on how interesting they are rather than being classified as 'correct' or 'incorrect' (Walsham, 2006). The paradigm professes interpreted knowledge and meaning, repudiating the existence of objective, thinking and reasoning-independent knowledge. Interpretivist research views reality through social constructs (consciousness, shared meaning, and language) (Klein & Myers, 2001).

The interpretive paradigm researches people rather than objects and focuses on interpretations and meanings as opposed to behaviour. The contextual perspective of the inquiry being conducted forms a part of the study to obtain insight into conceptualisation, construal, and others' understanding of concepts and events. Interpretive researchers explain phenomena by placing behaviours in the broader context of their making sense (Meredith *et al*., 1989).

Observation and interpretation are the primary drivers for this paradigm. Observation collects information, while interpretation makes meaning by drawing inferences or comparing it to abstract patterns, attempting to understand phenomena through meanings ascribed by people (Deetz, 1996).

Interpretivism contextualises analysis by using individual experiences to formulate an understanding of the world without predefining dependent and independent variables. On the contrary, it focuses on the intricacies of human sense-making along the evolving scenario (Kaplan & Maxwell, 1994) to explain meanings and subjective reasons behind social action.

As opposed to the implied absolute nature of positivism, interpretivism is relativistic as it considers facts in conjunction with theory and the observer. The participant's lens permits multiple views of the research problem (Alharahsheh & Pius, 2020). Ontologically, interpretivism focuses on subjective or relativist associated with a research issue (McKenna *et al*., 2011), which assumes knowledge acquisition or generation from the directly involved individual's viewpoint, and that the phenomenon being studied has multiple realities.

Epistemologically, interpretivism has a subjective stance and proposes the involvement of the researcher as well as the research participants in the context-driven process of knowing and reality (Nguyen, 2019).

It recognises that the participant's subjectivity is crucial to the development of a comprehensive picture of the social issue being studied. Participants' experiences and beliefs are invariably related in their own words (Rashid *et al*., 2019).

The researcher constructs knowledge socially through their personal experiences from the natural context, making meaning through their own thought process informed by participant interaction (Ugwu *et al*., 2021). The interpretivist philosophy develops knowledge by understanding complex situations/phenomena with a preference for descriptive and subjective methods rather than objective and/or statistical methods (Remenyi *et al*., 2005, as cited in Al-Ababneh, 2020).

Characteristics

Interpretivism does not generate new theory; rather, it evaluates, judges, and refines interpretive theories. It exhibits the following characteristics (Lincoln, 1995; Morgan, 2007): -

- Acknowledging the inability to understand the social world from an individual standpoint.
- The multiplicity of reality and its social construction.
- Accepting the inevitability of researcher-research object interaction.
- Criticality of context for knowledge and knowing.
- Finding-based knowledge creation, its value-laden nature, and the need to explicitly state values.
- The mutual interdependence of causes and effects.
- The need for considering contextual factors in the systematic pursuit of understanding.

Philosophical Constructs

Interpretivism is subjectivist epistemologically, relativist ontologically, naturalist methodologically, with a balanced axiology.

Subjectivist epistemology implies the application of own thinking by the researcher and participant interaction-informed cognitive data processing. Knowledge construction by the researcher will result from real-life experiences within the natural settings of the investigation (Kivunja & Kiyini, 2017).

A relativist ontology implies the belief in multiple realities of the situation being studied, each of which can be explored/reconstructed/interpreted based on human interaction between the researcher and participants (Chalmers *et al*., 2005, as cited in Kivunja & Kiyini, 2017).

Naturalist methodology implies that the researcher is a participative observer and utilises data gathered through reflective sessions, discourses, interviews, etc. (Carr & Kemmis, 1986, as cited in Kivunja & Kiyini, 2017).

Finally, balanced axiology assumes that the researcher presents a balanced report with due consideration of their own biases and values and the value-based nature of the information gathered (Okesina, 2020).

Validation Criteria

Unlike positivism, the interpretivist paradigm is validated using trustworthiness and authenticity as criteria. The following attributes are used for validating interpretivist research (Guba, 1981; Korstjens & Moser, 2018): -

- **Credibility** refers to the extent of the data and its analysis being believable, trustworthy, or authentic. This aspect implies similar outcomes under similar circumstances. The inferences drawn from the research are a driving factor since interpretivist research deals with human behaviour, which is contextual, variable, contextual, and has multiple interpretations of reality.

- **Confirmability** implies the extent to which others can confirm research findings to minimise researcher biases.

- **Dependability** indicates the temporal stability of the research findings. It involves evaluating and interpreting the participants' findings and recommendations supported by data received from research participants.

- **Transferability** represents the effort put into the research to provide enough contextual data for findings to be relatable to the contexts of those reading the results.

3.7.3 Pragmatism

Description

This paradigm developed because of the inherent conflict between truth and the single scientific method (positivism) and truth and social reality (interpretivism), which constrained the methods to be adopted.

Ergo, the requirement of a pragmatic and pluralistic worldview that would provide methods most appropriate for studying the problem at hand. Such a paradigm would illuminate the participants' actual behaviour, the beliefs behind these behaviours, and the consequences of different behaviours.

Pragmatism embraces a plurality of methods (Parvaiz *et al*., 2016). It proposes a philosophical and/or methodological approach best suited for the inquiry (Tashakkori & Teddlie, 1998, as cited in Kaushik & Walsh, 2019). It focuses on the research and its consequences rather than the methods. Its nature dictates the employment of both formal and informal rhetoric (Creswell & Clark, 2011, as cited in Kaushik and Walsh, 2019).

Pragmatism declares the existence of reality in the world while supporting science's objective nature and acknowledging the impact of individuality on people’s perception of the world. The pragmatist view presents multiple interpretations and explanations for science (Maarouf, 2019), accepting the existence of single or multiple realities that can be empirically inquired into (Creswell & Clark, 2011, as cited in Kaushik & Walsh, 2019). It also acknowledges the existence of human experience-independent objective reality, capable of being encountered only through human experiences being grounded in the environment (Goles & Hirschheim, 2000; Morgan, 2014).

A major underpinning of this paradigm is the dependence of knowledge and reality on socially constructed beliefs and habits (Yefimov, 2004). It also propounds the matching between certain versions of social construction and individual beliefs more than others (Morgan, 2014, as cited in Kaushik & Walsh, 2019).

Pragmatism opposes the absolutism of reality (Pansiri, 2005) and considers it a normative concept while binding it to contingent beliefs, habits, and experiences (Howe, 1988). Temporally, truth proves itself good or stands the individual’s scrutiny over time (Baker & Schaltegger, 2015; Ray, 2004).

This paradigm, therefore, employs both objective as well as subjective criteria. As a result, it is posited between the positivist and interpretivist paradigms and proposes the adoption of more than one philosophy in research since there is no single appropriate philosophy (Al-Ababneh, 2020).

Pragmatism results from actions, situations, and consequences, and not antecedent conditions (as in postpositivism). It is concerned with what works (application) towards finding a solution to the problem under investigation (Patton, 2002). Researchers emphasise the problem and balance objectivity and subjectivity while employing pluralistic approaches to knowledge development. Methods are typically not focussed on (Shannon-Baker, 2016).

Facts and values, accurate and rigorous knowledge, and different contextualised experiences are the hallmarks of this paradigm. Pragmatism considers ideas, concepts, theories, hypotheses, and research findings contextualised in terms of consequences and how they guide thought and action. Reality is considered a practical effect of ideas, and the value of knowledge lies in enabling successful actions (Saunders *et al.*, 2009).

Unlike positivistic and constructivist research, pragmatism posits the acquisition of knowledge along an objectivity-subjectivity continuum (Goles & Hirschheim, 2000), situating the mode of inquiry at the centre while offering flexibility and reflection in research design by embracing the two ends of the continuum (Morgan, 2007; Pansiri, 2005; Yvonne Feilzer, 2010).

Therefore, the research design selected is best suited for addressing the inquiry at hand.

Regarding reasoning, pragmatism moves back and forth between induction and deduction, leading to the creation of data and theory (Goldkuhl, 2012; Morgan, 2007).

Characteristics

The pragmatist research paradigm exhibits the following characteristics (Cherryholmes, 1992; Kivunja & Kuyini, 2017; Morgan, 2007): -

- Acknowledges the occurrence of research in social, historical, political, and other such contexts.
- Rejects the need for positing the study in a positivist or interpretivist domain.
- Adopts research design and methodologies best suited for the inquiry at hand.
- Emphasises ‘workability’ in research to provide freedom of method(s) selection based on the purpose of the investigation.
- Absence of a perspective considering the world as an absolute unity; Not committed to any particular philosophical system and reality.
- Propounds that ‘truth is what works at the time’; it is not based on duality between reality-independence or mind-dependence.
- Looks at *what* and *how* of research from the viewpoint of intended consequences.

Philosophical Constructs

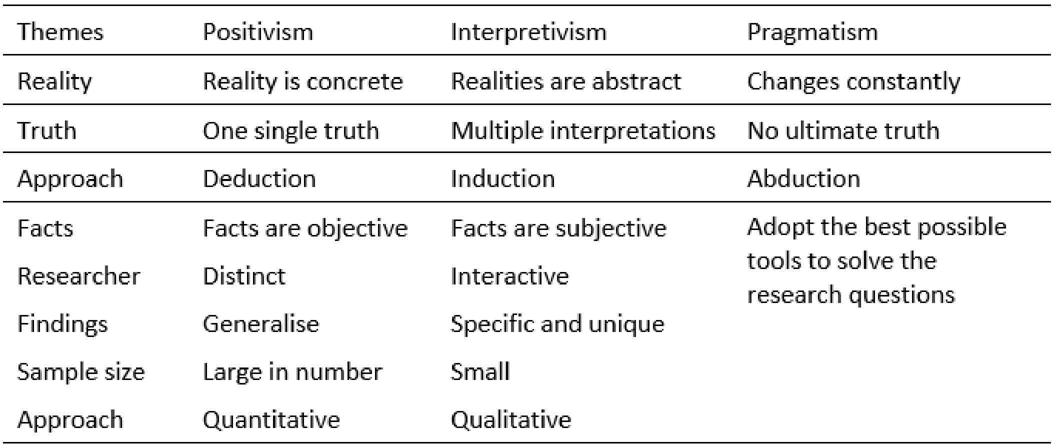
Pragmatism advocates multiple-reality ontology (non-existence of a single reality with multiple unique interpretations of reality by individuals); relational epistemology (i.e., the researcher is the best judge of research relationships appropriate to the investigation being undertaken); and value-driven axiology (research for the larger benefit of people) (Kivunja & Kuyini, 2017; Mackenzie & Knipe, 2006; Nguyen, 2019).

3.8 A Summary of Paradigms

While interpretivists actively participate in research to develop knowledge, positivists acquire knowledge objectively (Alharahsheh & Pius, 2020). A pragmatist adopts the optimal paradigm for developing knowledge (Parvaiz *et al.*, 2016). While pragmatism provides flexibility to use either or both research methods, positivism and interpretivism are the extreme ends of the knowledge generation continuum (Tran, 2017). Table 3.1 compares all three research paradigms based on different themes as a selection tool to assist selection of a research paradigm for this study.

Table 3.1

Comparison of research paradigms along various themes



Themes	Positivism	Interpretivism	Pragmatism
Reality	Reality is concrete	Realities are abstract	Changes constantly
Truth	One single truth	Multiple interpretations	No ultimate truth
Approach	Deduction	Induction	Abduction
Facts	Facts are objective	Facts are subjective	Adopt the best possible tools to solve the research questions
Researcher	Distinct	Interactive	
Findings	Generalise	Specific and unique	
Sample size	Large in number	Small	
Approach	Quantitative	Qualitative	

Note. (Al-Ababneh, 2020)

3.9 Research Approaches

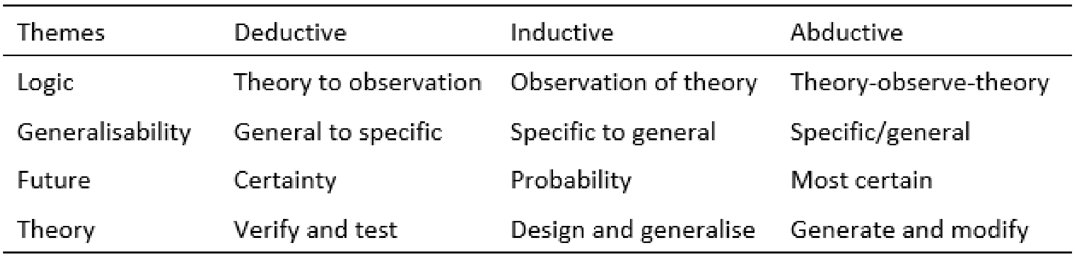
A research approach is a process that directs the gathering, processing, interpretation, and reliability evaluation of data (Gaus, 2017). These address broad aspects of research work and are viewed as a general strategy to achieve the main objective of the study (Brannen, 2005; Bryman, 2017). Before a study's research approach(es) are adopted, understanding ‘theory’ and ‘data’ is essential, these being the cornerstones of approaches. A theory is a group of deductive arguments linking various factors to explain a phenomenon; it proves the existence of a phenomenon by interpreting observations. On the other hand, 'data' is the information collected to prove a theory (Abend, 2008).

Research approaches may be deductive, inductive, or abductive. A deductive approach is characterised by developing a theory/hypothesis and then testing it using data. Conversely, the inductive approach develops a theory through data collection (Leavy, 2017). In the abductive approach (similar to the inductive approach), a theory is developed through limited data collection, providing possible answers by eliminating non-possible solutions (Awuzie & McDermott, 2017).

All three approaches have benefits based on the nature of the inquiry undertaken and the research questions asked. Table 3.2 overviews the approaches to different themes.

Table 3.2

Research Approaches



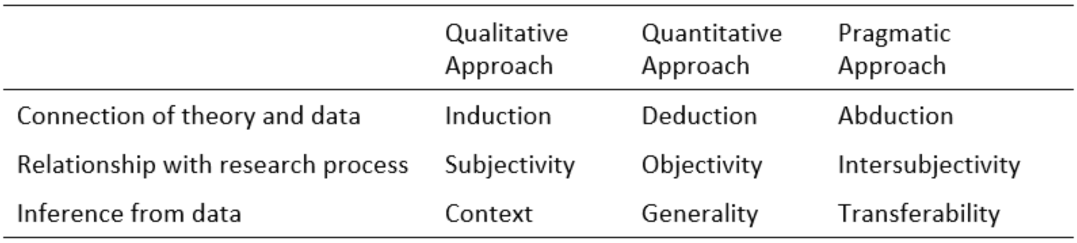
Themes	Deductive	Inductive	Abductive
Logic	Theory to observation	Observation of theory	Theory-observe-theory
Generalisability	General to specific	Specific to general	Specific/general
Future	Certainty	Probability	Most certain
Theory	Verify and test	Design and generalise	Generate and modify

Note. (Edmonds & Kennedy, 2017)

Table 3.3 summarises how pragmatism can connect induction with deduction, subjectivities and objectivity, and context and generality using abduction, intersubjectivity and transferability.

Table 3.3

Association of research approaches with methods



	Qualitative Approach	Quantitative Approach	Pragmatic Approach
Connection of theory and data	Induction	Deduction	Abduction
Relationship with research process	Subjectivity	Objectivity	Intersubjectivity
Inference from data	Context	Generality	Transferability

Note. (Tran, 2017)

While the milestones in any research are the same (Figure 3.3), the approach to be adopted is decided by the point of commencement of the research process, its aim, when are the hypotheses/propositions developed, and whether they are further applied (Spens & Kova´cs, 2005).

Figure 3.3

Paths of reasoning for the adoption of a research approach

Note. (Spens & Kova´cs, 2005)

3.10 Positing the Study

3.10.1 Preamble

Section 3.6 establishes the backdrop for methodologically positioning the research. Further, the problem at hand (assessing the performance of the selected segment of the NZ CSC through direct-to-site material deliveries from the manufacturer vis-à-vis deliveries to the site through the BM) has been categorised as a generic, quantifiable, and simple problem in section 3.4.3.

However, this requires a prior understanding of the CSC in general, the selected segment in particular, and subsequent interpretation (understanding) of phenomena detected through interaction with those responsible for operations management. The varying requirements of various components of the problem under investigation point to the pragmatist approach as best suited to address the problem.

The positivist leanings within the pragmatic approach enable quantification of transport operations in terms of parameters needed for answering the research questions and, therefore, objectively evaluating logistics practices. In contrast, the interpretive approach to understanding the NZ CSC segment under investigation can provide a rich understanding of logistical functions. The pragmatist approach substantially emerges with the potential to formulate and prove/disprove a hypothesis based on existing knowledge.

The literature supports this approach, where-in the interdisciplinary nature of the domain demands employing alternative research paradigms (Garver & Mentzer, 1999; Mentzer & Kahn, 1995; Meredith *et al*., 1989; Naslund, 2002; Solem, 2003; Wahyuni, 2012). Using one paradigm or a combination strongly supports the idea of adjusting methodology to the nature of the problem.

Aptly stated, *“a predominant research paradigm resulting in dominant methods should not exist in a complex and applied research field such as logistics”* (Naslund, 2002).

3.10.2 Research Approach

The abductive research approach was considered appropriate for the study due to its flexibility in application. Abductive research is capable of explaining, developing, or changing the theoretical framework being applied at any time during, before, or after the research process. It is characterised as oscillating between inductive and open-ended research settings to more hypothetical and deductive attempts to verify hypotheses (Dubois & Gadde, 2002a; Friedrichs & Kratochwil, 2009) (Figure 3.4).

Figure 3.4

Abductive reasoning

Note. (Dubois & Gadde, 2002a)

The following path qualifies the approach adopted for the study: -

- **The starting point** The argument of the hypothetico-deductive model follows the path from a general law to a specific case (Andreewsky & Bourcier, 2000; Taylor *et al*., 2002). Therefore, the starting point is scanning theory. In the instant case, the theory pertains to the CSC and VI in SCs.

- **Real-life observations** for the study come from operational data collected for analysis, inferences, and interpretations. The operational data in the instant case pertains to truck movements and delivery of manufactured construction products under a specific distribution model adopted by the manufacturer. The adopted model (DTS delivery by the manufacturer) is different from the standard supply chain and logistics implementation (delivery to the BM who is an intermediary providing storage and warehousing for inventory, and further distribution by the BM over the counter or to construction site depending upon the type of the customer) for this kind of product (plasterboard).

- **The theoretical framework** for the study is then formulated based on the literature review of pertinent aspects of the domains at whose intersection the study is posited. In the instant case, supply chains, logistics, the construction context, freight transport, and the NZ perspective are studied to understand the theoretical boundaries and implications that impact conduct of research on the selected topic. The loop of theory matching theoretical constructs with real-life observations then leads to the hypothesis to be proved. Based on the literature review presented in Chapter 2, a hypothesis will be proposed for the study in the next step.

- **Introduction of Hypothesis** Before a hypothesis is put forth, it is essential to understand the meaning and the broad types of hypotheses. *"Hypotheses are single tentative guesses, good hunches – assumed for use in devising theory or planning experiments intended to be given a direct experimental test when possible"* (Eric Rogers, 1966, as cited in Mourougan & Sethuraman, 2017); *"A hypothesis is a conjectural statement of the relation between two or more variables"* (Kerlinger, 1956, as cited in Mourougan & Sethuraman, 2017); and, *"Hypothesis is a formal statement that presents the expected relationship between an independent and dependent variable"* (Creswell, 1994).

- Types of hypotheses may be: Simple hypothesis (relating single independent and dependent variables); Complex hypothesis (relating two or more independent variables and variables dependent on them); Directional hypothesis (intellectual commitment of the researcher to an outcome orientates the relationship between variables; Non-directional hypothesis (insufficient past research for basing a prediction on); Associative hypothesis (relates variables without cause-effect); Causal hypothesis (cause-effect interaction between two or more variables); Inductive hypothesis (tentative explanations from inductive reasoning of specific observations); Deductive hypotheses (deductively reasoning implications of theory (Kabir, 2016).

- A null hypothesis proposes no relationship or difference between two variables. Its rejection indicates the statistical significance of the differences, while its acceptance that the differences are due to chance (Kabir, 2016).

- A simple directional hypothesis is introduced at this stage. This is based on theory and previous research suggesting that VI in an SC achieves higher efficiency. The literature points primarily in the direction of reducing costs.

- However, despite the leanings of literature towards costs, a hypothesis is put forth at this stage. The hypothesis is that ‘Vertical Integration in a Supply Chain will improve logistics efficiency’.

- Therefore, the hypothesis is ex-ante and needs to be proved or disproved. The null hypothesis will therefore be ‘Vertical Integration in a Supply Chain does not have any impact on logistics efficiency.’

- **Application/Testing** The next stage involves application/testing, which in this case, is proposed to be done by analysing operational data on truck movements. Empirical testing will corroborate or falsify the hypothesis leading to general conclusions. A substantiation/explanation of observed phenomena/patterns will be undertaken through interaction with the company's logistics manager.

- The next step will be investigating the potential for further efficiency improvement through simulation using the available dataset. The phenomena/patterns observed and the ‘artificial reconstruction of reality’ through simulation will lead to generalisations after decomposing the construction transport domain into elemental domains and applying the results achieved to these elemental domains.

- Finally, a validation exercise will be undertaken by providing strategic and operational recommendations in these elemental component domains and obtaining the opinion of the company’s functionaries on the inferences and interpretations.
- The research methods proposed are quantitative and qualitative, detailed in sections 3.10.3 to 3.10.6.

3.10.3 The Primary Research Method

The research methods associated with the interpretive approach, listed in cells (C1), (C2) and (C3) of matrix in Figure 3.2, could provide a rich description of logistics systems and functions as suggested by the methodological positioning of the research.

However, these are merely to understand the nature of the NZ CSC and the segment under consideration as a preamble and an interpretation of the phenomena detected as an epilogue. Therefore, none of these approaches is eligible to be the principal research method.

The actual quantification of transportation operations lends itself effectively to methods in cell (B1) since the metrics pertaining to transportation operations can be easily recorded in contrast to a situation where reality needs to be defined through perception.

Furthermore, the ontological and epistemological position of the study has established that the research aims to improve the understanding of logistics by offering an investigation that is as robust and objective as possible.

Therefore, methods that adopt direct observations of reality are preferred to those that incorporate people’s perceptions. Hence, the most appropriate research methods for this research are indicated in cell (B1) and include field studies and field experiments (Meredith *et al.*, 1989).

Field experiments permit control of the research situation to establish and evaluate causal relationships between variables. This presupposes the researcher’s capability to manipulate independent variables contextual to the phenomenon under investigation to evaluate the effect on dependent variables. This entails significant problems in organisational and operations research, primarily from the assumptions required for identifying variables (Easterby-Smith *et al*., 2012; Zikmund, 2003).

In the instant case, the variables governing transportation operations pertain to their management and are, therefore, considered subjective. However, the interpretation of phenomena and subsequent recommendations regarding improving operational efficiency as the research outcomes are more likely to be available as further research directions to undertake such experimentation.

Hence, a field study is considered the most appropriate research method involving direct observation of reality, i.e., direct observation of logistics (in this case, transportation) operations.

3.10.4 Introducing the Importance of Multiple Methods

Literature often proposes a combination of research methods, as opposed to adopting a single research method, to improve the quality of research. Therefore, a mix of methods best suited to the problem under consideration, and the consequent answering of the research questions needs to be selected (Benbasat *et al*., 1987; Kaplan & Duchon, 1988; McChesney, 2021; Pervan, 1994).

Having selected the primary research method in section 3.10.1, the epistemological position of the research was reviewed. Given the nature of the research, a secondary research method was considered necessary for its completeness.

The main problem to be addressed pertained to efficiencies, their existence and the potential for further improvement. Furthermore, a rich explanation of the phenomena observed was considered necessary for explaining observations, i.e., contextualising them and determining future directions for deeper investigation of the problem.

The term ‘triangulation’ as applicable to research is appropriate for introduction at this stage. Triangulation in research implies converging on a single construct through a combination of two or more theories, methods, data sources, or investigators in the same inquiry. It improves the validity and credibility of research findings.

Validity is concerned with the precision of representation of the concept being investigated by the inquiry. Credibility relates to the trustworthiness and convincing level of a study. Triangulation eliminates biases which might get introduced due to the singularity of theory, method, or observer. It may be applied to both quantitative and qualitative studies and allows for validating data (Noble & Heale, 2019).

"Triangulation of data is crucially important in naturalistic studies … No single item of information (unless coming from an elite and unimpeachable source) should ever be given serious consideration unless it can be triangulated" (Lincoln & Guba, 1985, p. 283).

Triangulation in research may be of the following types (Babbie, 2009; Denzin, 1978; Hales, 2010; Neuman, 2014; Turner & Turner, 2009): -

- **Data Triangulation** uses more than one data sources (temporal, spatial, and people) in a study. Correlation of findings and inter-source compensation of deficiencies can improve the validity and reliability of the results. This type of triangulation is typically applied in industry to reduce erroneous interpretations and reinforce findings.

- **Investigator Triangulation** employs many investigators (observers, interviewers, researchers, or analysts) in a study. Corroborating findings between and across investigators without coordination and communication between them can assist in improving the credibility and quality of results. It, however, requires reduction of bias in data collection, analysis, and reporting.

- **Theory Triangulation** is the employment of more than one theory or hypotheses when undertaking an inquiry. This enables examination of the phenomenon being studied from various perspectives, through multiple lenses, and by asking more than one research questions.

- The ideas, hypotheses, or theories need not be consistent or comparable. Their diversity fosters identification of multiple issues impacting the problem under review. Higher the diversity, higher the probability of identifying issues.

- **Methodological Triangulation** uses multiple methods in the examination of a situation or phenomenon, with the aim of reducing biases or deficiencies associated with a single method. Compensation of the weaknesses of a method is achieved through the strengths of others.

- Methodological triangulation complements, improves and clarifies the results of a method through those of others, hence, demonstrating similarity to the mixed methods approach. It emphasises data collection through different methods as opposed to data from different programmes, locations, and populations, thus, exhibiting similarity to data triangulation.

- **Multiple Triangulation** combines multiple observers, theories, data sources and methodologies in one inquiry.

In the instant case, interpreting observed phenomena and recommendations based on inferences and interpretations from data analysis for those managing operations would balance the findings, achieving, so to say, ‘triangulation by substantiation’, also providing further research directions.

3.10.5 The Secondary Research Method

The research methods associated with the interpretive approach, listed in Cells (C1), (C2), and (C3) (Figure 3.2), even though not forming the primary research method (which has been established as being field studies), can provide a rich description of logistics systems and functions as suggested by the methodological positioning of the research.

Therefore, these precede and succeed the primary research method, preceding in understanding the nature of the NZ CSC before undertaking field studies and succeeding in interpreting observations, substantiating them, or otherwise.

In addition, both these aspects lend themselves to (i) Historical Analysis (literature review) and (ii) Expert Panels (in this case, interviews/discussions with those managing operations).

3.10.6 Reconstructing Reality Artificially

The idea of reconstructing reality artificially is pertinent and applicable to the study being undertaken to find out if there is any other manner in which operations, if performed, would yield higher values of Key Performance Indicators (KPIs).

Based on the primary research method selection, those listed under category (C) need to be evaluated for their appropriateness to the study's context.

The objective of measuring the impact of variables on transport operations enables ruling out certain methods of artificial reconstruction in the context of the study, as follows: -

- **Laboratory experiments** are eliminated from the list, similarly to field experiments. No change to the system, per-se, is envisaged, neither in terms of the business model nor the overall context of operations.

- **Physical system modelling** is typically used in industrial/operations management to evaluate manufacturing strategy (Harrison & Baines, 2003). Therefore, it is inappropriate for material and/or information flows within an SC.

- **Prototyping** applies to systems but involves designing and testing a new system, usually under restricted conditions. In the instant case, the system 'as implemented' both in terms of the business model and the implementation context does not need to be modified (restricted) (Meredith *et al*., 1989) for purposes of the artificial reconstruction of reality. Probably 'the way of working' may require minor modifications.

'What-if' provides a very powerful means to make such an assessment. Rather than possibly attempting to reduce everything to mathematical expressions, which involves the identification of variables and relationships, simulation provides a powerful means of playing scenarios without controlling variables (Bryman & Bell, 2011), hence does not seek a modification of the context or application environment.

Thus, despite the similarities, it is distinctly different from field experiments. Nevertheless, its extensive application in the SC domain prevents it from being rejected. Simulation enables recasting the truth of the object under investigation into another form for further analysis (Meredith *et al*., 1989), primarily as a means of comparison/benchmarking against the 'observed truth' and, therefore, further analysis based on identified parameters. For this reason, simulation will be used as a data analysis tool.

This agrees with the definition of simulation, which categorises it as a technique for analysing quantitative data (Greasley, 2004; Law & Kelton, 1991; Robinson, 2004).

3.11 Research Design

3.11.1 Conceptual Framework

Considering that the problem centres around the distribution of a key component of urban construction directly from the manufacturer's warehouse to construction sites, in effect adopting the 'manufacturer storage with direct shipping' logistics model (Chapter 2), the nodes and links, cost centre, material management vs physical distribution, and logistics channels approaches may be valid or appropriate for different analyses. Therefore, the present study aims to quantify efficiencies achieved in transportation operations based on specific SC structures and assess the potential for further improvement in efficiencies.

The node-and-link approach is best suited for this type of analysis since the parameters which need to be investigated pertain to outputs from the warehouse (Node 1) and consumption by construction sites or consumers (Node 2), both being linked certain distances that transport needs to traverse to undertake delivery (in the system 'as executed'). A third node comes into the analysis in the form of the BM (Node 3) invoicing consignments (representing operations as 'typically would have' been undertaken).

Nodes are spatial locations where goods are stored or processed, therefore, goods stop at nodes. Links, on the other hand, represent the connection between nodes through a transportation network in the logistics system.

A node and link approach permits the two basic logistics system elements, i.e., the transportation and processing of goods, to be analysed. It also provides a convenient basis for seeking possible system improvements as it allows analysis of the supplier-site link.

In this case, three links and three nodes in two different configurations need to be analysed *viz* two nodes and one link (Node 1 and Node 2) in terms of transportation 'as executed', and three nodes (Node 1, Node 3, Node 2), and two links (Node 1 – Node 3, Node 3 – Node 2) in terms of transport 'as would have been executed'). Given the need to benchmark transport operations 'as executed' and 'as would have been executed', an appropriate research instrument was needed to harvest the required data (section 3.11.2)

3.11.2 Data Collection

The problem addressed by this study pertains to the achieved optimisation and further potential in a narrow and specific segment of the NZ CSC because of implemented SC structures. This is directly associated with an existent void of construction logistics understanding in general and specific to the region. Sections 3.4.1 to 3.4.3 describe the research problem in terms of scope, nature, and complexity.

A field study can incorporate various data collection techniques for quantitative or qualitative data. However, as discussed in section 3.10, the data collection method during the field study must satisfy the requirement for gathering quantitative data. Easterby-Smith *et al*. (2012) identify four ways of collecting quantitative data: interviews, questionnaires, tests, and observations.

To this end, the study's objectives were to establish the transportation dynamics of materials supply from the manufacturer directly to the construction site, with the invoicing and transactional aspects being performed by the BM in the SC. In addition, it required benchmarking vehicle movements as a measure of the efficiency of the transportation function.

Therefore, the instrument developed needed to be able to measure the required parameters and provide data for the establishment of a benchmark, i.e., the instrument must measure vehicle movements relating to the delivery of construction materials to site and provide a means to establish proportions of transport capacity utilised under two scenarios *viz* operations ‘as performed’ (manufacturer’s warehouse to site) and ‘as could have been performed’ (manufacturer’s warehouse to BM’s warehouse, and BM’s warehouse to construction site). The following information needed to be captured for the study: -

- Vehicles: Number, type, capacity
- Materials: Weight
- Vehicle movements: Number, runs/trips, loading
- Deliveries/collections: Number, destination, travel distance
- Builders’ Merchant invoicing consignments
- Distance of BM premises from manufacturer’s warehouse and delivery site.

3.11.3 Data Analysis Approach

The data analysis approach specifically pertained to three aspects of the transportation operations, i.e.: -

- ‘As executed’ implying loading efficiencies and capacity utilisation of transport in transporting material from the manufacturer’s warehouse to the construction site (Direct to Site or DTS delivery)
- ‘As would have been performed’ (typically) loading efficiency and capacity utilisation of transport in transporting material from the manufacturer’s warehouse to BM’s warehouse and subsequently from the BM’s warehouse to the construction site.
- Further optimisation using ‘What-if’ scenario(s) as tools for artificial reconstruction of reality without controlling any governing variable.

3.11.4 The Modelling Approach

Given the variety of problems associated with SC operations, no single approach can model all aspects of an SC. The most suitable approach is driven by the problem formulation, i.e., the scope and objectives of the study (Beamon, 1998). Models may be classified into two distinct categories: descriptive and optimisation. While optimisation models allow for predictions and better decision-making, descriptive models help understand how the SC works (Bansal, 2002; Shapiro, 2000). Optimisation models can be further categorised into deterministic analytical, stochastic analytical, economic, simulation, and heuristic models (Beamon, 1998). A short description of these is as follows: -

- **Deterministic analytical** models use mathematical programming with known and stated variables and seek to produce a closed-form analytical solution. These models are restricted to a static system representation and provide prescriptive solutions under specific assumptions (Ganapathy *et al.*, 2003). These models are incapable of addressing stochastic problems.
- **Stochastic analytical** models are predicated on a certain statistical distribution and contain at least one unknown variable. Despite the stochastic

representations making them more realistic for SCs, they are static and do not account for real-time updates and entity interactions (Ganapathy *et al.*, 2003).

- **Economic models** mainly focus on the buyer-supplier relationship in an SC from a cost perspective, e.g., direct and indirect costs (Sobotka *et al*., 2005). Economic models are useful as they consider economic decisions and decision-makers and their complete spectrum of activities. They are, however, based on assumptions which can be easily challenged due to the inherent market complexity.

- **Simulation models** model real-world interactions through computer representations, hence, are particularly useful for 'what-if' analyses. These can be built on customised or general-purpose software and address descriptive and analytical problems. The variables, however, need to be 'adjusted' according to the scenario being played.

- Simulation models are particularly useful when the system to be modelled is complex and dynamic, offering the opportunity for modelling stochastic information over time (Kleijnen, 2005; Swamidass, 1991). However, as a result, they can be data and resource-intensive and time-consuming (Robinson, 2004).

- **Heuristic models** allow for wide problem definitions while not offering any ideal answers. Instead, employing a heuristic approach makes a problem more manageable while also allowing for the exploration of potential solutions ('incremental optimisation').

The intention of the research is to develop sufficient data from the field study to be able to: (i) Benchmark the inherent efficiency in transportation introduced by the DTS model over the MD model and (ii) Use a deterministic analytical optimisation model to examine further potential for improving transport efficiency. The rest of the study's objectives are interpretive from the analysis of data proposed to be undertaken.

The second aspect is being referred to as a 'simulation' since the data from operations 'as executed' (assumed non-optimal) is now being manipulated by a mathematical model (without determining underlying variables and their interaction) over a period of time. Again, this creates a 'what-if' scenario ('what if this model were used to plan operations'). The complete modelling approach is assumed to have enough slack to absorb the stochasticities of the system in an attempt to find an incrementally better solution within the operating environment through validation over a period of time.

Consistency of results obtained from the successive application of the model to the available operational data stratified on a day-to-day basis, may be taken as the simulation approach.

3.11.5 The Sampling Strategy

Sampling implies the selection of a subset of the given dataset to estimate the population characteristics. It provides for speed in collecting and manipulating data, providing acceptable accuracy, and lower analysis/processing costs. Sampling may be of the following types (Fox *et al*., 2009; Rahi, 2017; Singh & Masuku, 2014): -

- **Probability sampling** A sampling strategy where each unit capable of being selected has an equal chance (probability) of being chosen. It is further divided into: -
    - **Simple random sampling** Each population unit has an equal probability of inclusion in the sample. A numeric list of the complete sample is drawn up, and the selection is based on a separate list of random numbers.
    - **Systematic random sampling** A method of probability sampling in which the starting sample point is chosen at random and subsequent cases are chosen at set intervals.
    - **Stratified random sampling** A probability sampling process where each subgroup (called strata) has an equal probability of selection. This provides equal proportionate representation to each sub-group.
    - **Cluster sampling** Samples are drawn out of aggregations of geographically dispersed populations.
    - **Multi-stage sampling** involves a sequence of stages: Selection of a random sample out of a cluster of regions; Random selection of a specific region; and, Random selection of observations out of the selected region.

- **Non-probability sampling** A technique where the probability of selection of each unit is unknown, and subjective judgments play an important role in selecting the sample. Non-probability sampling can be of the following types: -

    - **Convenience sampling** is data collected from a readily accessible and nearby population. It allows for cost-effective data collection; however, it has a high likelihood of biases creeping in due to the selection.
    - **Snowball sampling** involves contacting a small group relevant to the research and then approaching others through referrals.
    - **Quota sampling** defines the quota of samples from a population stratum. Findings from this type of sampling are not generalisable since probabilities are not applied to the sampling exercise.
    - **Judgment or Purposive sampling** defines a process where the sample is drawn based on the researcher's judgement. As a result, it provides biased estimates and is not statistically recognised.
    - **Independent sampling** Samples selected from the same or different populations, which do not affect one another, i.e., no correlation exists.

The sampling undertaken for the purposes of this study and the reasons thereof will be elaborated on in the data analysis chapter.

3.12 Limitations and Assumptions of the Research

A research methodology cannot be right or wrong but rather most appropriate in the context of a study (Silverman, 1998). Therefore, identifying the assumptions and limitations on which the research is based helps enhance its quality. This section identifies the limitations of this research. The assumptions are specifically brought out in the various sections in Chapter 4 (Analysis).

3.12.1 Ethics

Ethical considerations are particularly important when conducting a research study (Davis & Lachlan, 2017; National Committee for Research Ethics in the Social Sciences and the Humanities, Norway [NESH], 2016). Ethics may appear more relevant to qualitative research but are equally crucial for quantitative research. In the instant case, the following aspects of the research environment have been the enablers of promoting ethical research activity: -

- The data pertaining to vehicle trips and drops was collated at the corporate office. This precluded the need to interact directly with vehicle drivers or the contractor providing transport services. Operational data 'as executed' was available in an approximate form it was required in.
- Minimal interaction with the transport/logistics manager was undertaken, and that too only to understand the pattern of operations that emerged from data analysis.
- The possibility of hierarchical power equations questioning the methodology employed for allocating vehicles or the efficiencies achieved was precluded by the payments model in place (per tonne irrespective of distance). Both parties engaged in the contract were satisfied as long as the daily tonnages were delivered.
- An ethics approval was obtained from the Auckland University of Technology Ethics Committee to conduct research in the most ethical manner possible with respect for participants' rights, consideration of moral issues and characteristics, addressing cultural and inter-cultural issues, securing participants' goodwill, the conduct of research in a socially just, respectful and peaceful manner, and avoidance or minimisation of risk or harm (physical, psychological, legal, social, economic or other).
- Participants were fully informed of the research content, and consent for participation was obtained. The approved Ethics Application and amendments throughout this research are in Appendix A.
- At the end of the research, the research outputs and recommendations based on these have been shared with the company as a validation exercise.

3.12.2 Reliability

Reliability is related to the consistency of measures (Bryman, 2008). In this research, the issues related to reliability stem from the nature of the data collection method itself, i.e., the conduct of a field study. The selection of this method and incorporation of observations have been justified earlier in this chapter. The data collection system was designed to be as simple as possible while input required from personnel was kept to a minimum.

Reliability can have three attributes *viz* Homogeneity (or internal consistency) (how accurately a scale's elements measure a single construct); Stability (consistency of results with repetitive testing using the same instrument); and Equivalence (consistency among responses of multiple instruments, or alternate instrument forms) (Heale & Twycross, 2015).

Potential reliability problems can result from observer bias, mainly from the researcher's interpretation of the collected information (Neuman, 2014). This research intended to limit the range and scope of the study such that the findings are robust and repeatable within the context of transport operations in the CSC. Further, the data recorded were highly quantitative and analysed using established statistical methods, minimising observer bias.

The data collection and analysis phase satisfies all three attributes of reliability, i.e. homogeneity (the measured parameters being distances and loads carried, sufficient to describe the loading efficiency and capacity utilisation constructs); Stability (standard and reliable tools were used for measuring the parameters, a calibrated weighbridge for loads recorded by the company and distances measured by the researcher using Google Maps, a standard and reliable instrument used worldwide); Equivalence (the distances between fixed points on the ground, and the loads measured would be constant irrespective of the viewer, without the subjectivity of perception creeping in). The observations have been triangulated using qualitative techniques for achieving balance and further validated through a well-thought-out set of recommendations presented to the company for improved sustainability.

3.12.3 Validity

Validity refers to truthfulness and agreement between the conceptualisation of research and the measures used. The validity of research refers to the confidence that research findings are true and depends largely on the validity of information obtained during the data collection process (Shadish *et al.*, 2002; Trochim, 2000).

Validity is ascertained by interpreting data from the measuring instrument meaningfully and appropriately. Validity of an effect or test is established through demonstration or measurement of what researcher thinks or claims it does. Research errors (faulty procedures, poor sampling, and inaccurate or misleading measurements) can undermine validity. Three types of validity may be considered in quantitative studies *viz* Content validity (the extent of accurate measurement of all aspects of a construct by the selected research instrument); Construct validity (the extent of measurement of the intended construct by the selected research instrument or tool); and, Criterion validity (the extent of relationship of the selected research instrument to other instruments that measure the same variables) (Heale & Twycross, 2015).

This research collected information through a field study incorporating minimum subjective inputs from the researcher, the participants, and/or other personnel. Also, the collation of operational data by the logistics department was considered robust since transport operations were seen as impacting the company's business model directly. Further, during the data analysis phase, the aims were clearly articulated, i.e., to find efficiencies based on distance travelled by trucks and to find out the further potential for improved efficiencies by applying statistical/management techniques. With the necessary information available from the company’s database and reliability of tools in the public domain (Google Maps), the research instruments are considered highly reliable, however, with the possibility of certain errors creeping in during data recording. These were eliminated through ‘cleaning-up’ or data filtration before undertaking analysis without impacting the sample size.

Finally, outcomes of the data analysis were balanced (triangulated) through qualitative methods (discussion/interview) and further validated through a presentation of recommendations for improved sustainability. The truck operational data collected satisfied all three validities *viz* content (the instruments used were able to provide information on loads and distances accurately); construct (the instruments used provided the requisite information which was sufficient for assessing the truck operations under both operating models, i.e., Direct to Site, and BM delivery); and criterion (the research instruments measured distances and loads, which are mandatory components of metrics used for assessing transport efficiency, e.g., tonne-km, loading efficiency, and capacity utilisation).

3.12.4 Generalisability

Generalisability is the probability that the results of a study can be extrapolated to other circumstances within and outside the domain of research (Yin, 1994). Generalisability may be considered from three perspectives *viz* Statistical generalisation (extrapolating from a sample to a population); Analytical generalisation (generalisation from particulars to broader constructs or theory); and, Case to case translation (using findings from an inquiry to a completely different group of people or setting) (Firestone, 1993; Polit & Beck, 2010).

Within the domain, it implies the applicability of results from a sample to complete populations, achieved through the robustness of sampling. Outside the domain, generalisability is the applicability of results in other domains and contexts. The phenomenon under investigation in this study may have four general components to its construct, i.e., data sample, transport, freight, and the construction domain. These four components, in turn, provide a clue to the generalisability of the study.

The construct of the problem being studied makes both quantitative as well as qualitative research outputs generalisable from all three perspectives. Statistical generalisability (for the complete dataset considered) is achieved through random sampling, with sufficient data points (Krejcie & Morgan, 1970) precluding any clustering or stratification errors. Analytical generalisation is achieved by the investigated phenomenon being freight transport and, therefore, the potential applicability of results or research outputs to freight operations in other domains (industries) or contexts (long-haul, short-haul, and last-mile delivery). In addition, case-to-case transferability can be achieved by the application of results to manufacturer-to-consumer transport (manufacturer warehousing with direct shipping (DTS model) outside the context of construction) to other industries (e.g., manufacturing and urban distribution).

3.13 Chapter Summary

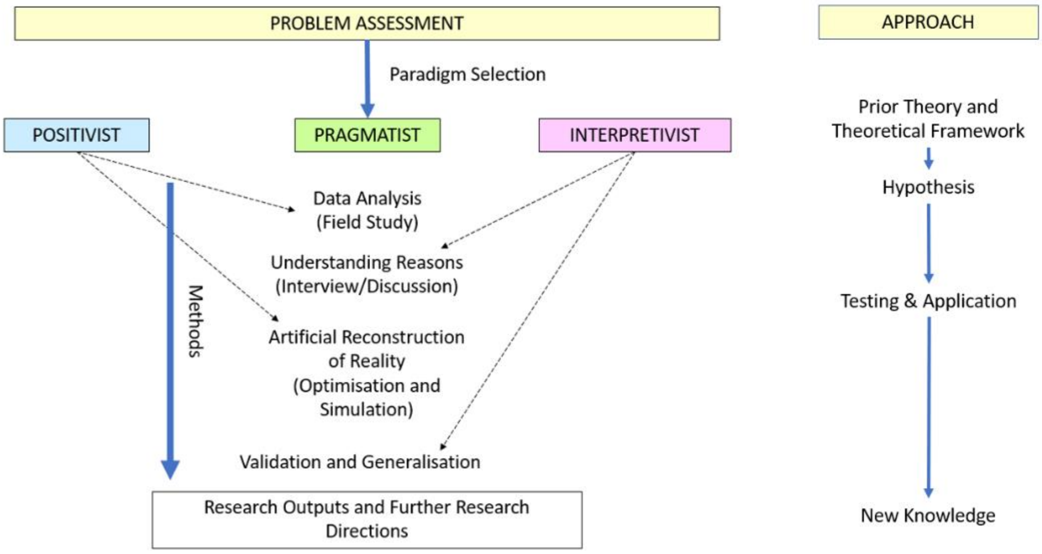
Bearing in mind that the aim of the research and the nature of the problem dictate the overall research strategy, this chapter analysed the research problem in accordance with the research objectives to establish the most appropriate research methodology. The analysis suggests that the research should adopt a primarily objectivistic approach which enables the observation and artificial reconstruction of logistics systems. Respectively, these were indicated to be most effectively facilitated by a field study incorporating observations followed by a conceptual and simulation modelling analysis.

The chapter also justifies the selection of a random sampling strategy for data collection purposes and the use of the nodes vs links approach and simulation for modelling the transport component of a very narrow segment of the NZ CSC, where in the 'Manufacturer storage with direct shipping' (Direct to Site or DTS model) has been implemented as opposed to 'Distributor storage with carrier delivery' (stocking and further distribution by the BM or the MD model).

Furthermore, the availability of data for analysis and simulation for improved efficiency and the peculiar financial or payments model ('per tonne' rather than 'per km') enables using a cost basis for optimising transport resources by applying Linear Programming. Overall, the construct of the problem presents a potent generalisability opportunity for research outputs. Figure 3.5 illustrates the research design adopted.

Figure 3.5

Research Design



Note. (Author)

Chapter 4 Analysis

This chapter presents a detailed commentary on the analyses undertaken as part of the study. Even though the problem has been classified as simple, it falls at the intersection of a large number of business/management/engineering domains. This necessitates revisiting the problem selected for investigation before giving an account of the actual data acquisition, data analysis, and inferences/interpretations.

4.1 Problem Analysis

4.1.1 Revisiting the Problem

The study stems from the overall research problem pertaining to the sustainability impacts of optimising construction logistics in NZ. Literature evidences that transport is one of the major physical processes involved in logistics (the other being warehousing and its allied functions) and, therefore, plays a substantial role in the overall efficiency of logistics.

In the construction context, construction transport can substantially contribute to improving construction logistics for improved efficiency. This highlights areas where transport is employed and the manner of its employment in the construction domain.

The efficiency of transport is reckoned from how much load it carries vis-à-vis its carrying capacity. These may be taken as static, i.e., loading efficiency (despatch load vs vehicle payload capacity in percentage), and dynamic or trip efficiency (in terms of tonne-km available and those actually used). These require certain basic parameters of vehicle movements to be captured, *viz* vehicle payload capacity, despatch load, distances travelled, and the load on the vehicle over various segments of a trip.

4.1.2 Developing the Problem

The CSC is complex and extensive, hence, presents a complex, at times non-linear problem. As evidenced in the literature, in such cases, it is attractive to single out a simplified sub-system from which important information can be extracted and then consider the contribution of other variables. In the current study, truck movements, as an indicator of logistics of CSCs, were selected as the parameter of interest. However, considering that the NZ construction sector is highly fragmented, there is a preponderance of the project delivery method in the market, and that most CSC models are site-centric, obtaining a reliable dataset on vehicle loads and movements from construction sites was considered extremely unlikely.

This was due to the following reasons: -

- Site centricity tends to optimise locally, whereas most organisations/parties associated with site delivery are invariably associated with other projects also. Hence, an optimised delivery schedule for a construction site would not directly imply wider optimisation or provide a larger picture, so to say.
- With most transport operators being small time, it was anticipated that recording of transport data would, in all likelihood, be limited to that associated with payments.
- Recording of data on a construction site would pertain to receipts of consignments, weights (pertaining to the site), timeliness of arrival, any damages etc., again primarily payments focussed. Recorded data would be unlikely to provide details such as distances travelled or the loading of vehicles.
- The fragmented market also implies that the number of data sources required would be inordinately large, assuming that the operators were recording transport movement and loading data. However, the availability, reliability, and compatibility of data from many sources were considered suspect.
- Obtaining data regarding vehicle specifications was considered a tardy exercise since the delivery vehicles, even if delivering for one sub-contractor, could change daily. Extrapolating this to the number of deliveries per sub-contractor on the site, and the number of involved sub-contractors a project implied a large and unmanageable matrix of vehicle specifications.
- The literature review also revealed that site-centric construction transport had been addressed in great detail, and granular analysis and related interpretations in the SC and CSC domains were available. At the same time, there appears to be a major void in supplier-centric transport analysis in the construction domain.

With these discoveries from the literature, the focus for analysis was shifted from the construction site to suppliers. With the adoption of this perspective, a study of the CSC in NZ was considered essential. The literature review threw up the fact that the NZ construction market consisted of very few major players. In addition: -

- Wholesale supply actors consist of a number of domestic companies who specialise in supply of one type of building material (e.g., timber or cement), and international companies that import construction material into NZ.
- Five major BMs undertake distribution of building supplies in NZ, some specialising in builder or trade customer supplies, while others operate retail outlets.
- In addition, various smaller merchants/retailers supply varying product ranges throughout NZ with a varying market presence.

Based on the NZ construction market review, the broad segment of supplier-centric transport analysis was identified. At this stage, the possibility of obtaining data from BMs in NZ (Auckland region) was considered for the following reasons: -

- Treatment of the CSC from the BM's perspective was very scarce in the literature, with only a handful of papers found. Even these spoke of management issues and the potential of applying strategies without substantiation with data.
- The number of major BMs in NZ is only five. Hence, availability, reliability, and consistency of data were expected to be higher than from individual transport operators.
- Since most data collection is undertaken for the financial model, i.e., making payments, BMs were expected to have data on loads as well as distances, or at the least destinations for the transport, from the invoiced goods.

However, the major issue that this kind of analysis was likely to throw up was the non-availability of a dedicated fleet with the BMs for delivery. The aspect of specifications of transport not being available and non-standardisation and inconsistency in the type of transport being made available for BM deliveries by the transport contractors, therefore, still needed to be clarified. The vehicle specification matrix based on daily deliveries vs the vehicles made available by the transport contractor for BM deliveries was potentially large and unmanageable. This would be especially so since the transport contractors were unlikely to provide dedicated vehicles for consignments on a day-to-day basis. Vehicles with mixed loads (i.e., pertaining to the BM and some other party whose loads the carrier accommodated on the same truck) were highly likely since the transport contractor would potentially optimise loads at his level for maximised profits. This aspect again took the data source to the individual vehicle (whose daily running details would be available with the transport contractor rather than the BM) and, therefore, outside the purview of the BM's operations.

Having put aside this option, for the time being, the focus was shifted to understanding the transport operations of one of the domestic manufacturers, assuming that their deliveries would be to stockists. The vehicle movement data from one of these was likely to provide details of loads, distances, and drops of manufactured products from the manufacturer's warehouse to one or more retailers. The focus of exploration, therefore, now shifted further backwards in the CSC from the BM to a manufacturer. Again, the assumption at this point was that all deliveries from the manufacturer would be to the stockists or retailers in a typically 'echeloned' CSC.

With this focus, the largest plasterboard manufacturer (with a plant in Auckland) was approached for research on vehicle efficiencies achieved as part of their logistics operations. Based on an interaction with the concerned functionaries, the logistics model adopted by the company was found to be two-pronged: -

- The first logistics model adopted was to supply retailers from the company's warehouse in the typical 'echeloned' CSC manifestation (Manufacturer – Retailer/BM – Construction site).
- Concurrently, the company also undertook DTS deliveries based on the requirements of the BMs. In this model, the BMs did the invoicing of products, but deliveries were undertaken by the company (manufacturer).
- The second model (DTS) appeared to provide a richer research opportunity from the viewpoint of analysing vehicle efficiencies arising from this implementation

and providing a benchmark for comparison with efficiencies with the same deliveries if undertaken through the BM (MD).

In addition, it also appeared to be a uniquely posited model, integrating manufacturing and associated distribution with the CSC. In all likelihood, this other than SCM reasons, one of the main enablers of this integrated model is the nature of manufactured products for construction, in the instant case, plasterboard. The weight/volume of the product enables bulk cartage as compared to other products, which may be far smaller in size and have a relatively lower per-unit consumption.

Further, a discussion with the logistics/operations manager confirmed availability of vehicle movement data. The model was, therefore, selected for inquiry.

4.1.3 Describing the Problem

Having selected the research problem based on its unique implementation and the availability of data, a description of the research to be undertaken was formulated.

The company was undertaking DTS plasterboard deliveries based on the BMs' invoicing. In effect, the information flow was from the customer to the BM, and the aggregated requirements flowed from the BM to the manufacturer. The physical movement of material was taking place from the manufacturer’s warehouse directly to the points of consumption (construction sites).

The flow of information and material produced a network of three nodes (manufacturer, BM, construction site) linked with two information links (customer to BM and BM to manufacturer) and one material flow link (manufacturer to the construction site). The model is a copybook implementation of the ‘manufacturer storage with direct shipping’ model from the literature (Figure 2.6). In terms of a comparison between the CSC as typically implemented (Manufacturer – BM – Construction site) and ‘as implemented’ (Manufacturer – Construction site), the DTS model points to optimisation in distances travelled by trucks by eliminating one complete link from the SC network insofar as material flow is concerned. Furthermore, the DTS model demonstrates two innovative aspects of SCM: VI of the transport and distribution function; and, Outsourcing transport operations to a third party, embodying the ‘second party logistics’ (2PL) concept.

It demonstrates forward VI by taking the transportation and distribution function as an extension of manufacturing operations. At the same time, outsourcing the transport function indicates dissociation from non-core activities (the core activity being manufacturing). Therefore, the outsourcing model is considered a 2PL model since the contractor only provides transportation services. Transport operations under this model presented certain attributes which have a fundamental impact on the overall operational efficiencies: -

- The planning of trucks was entirely left to the 2PL service provider disaggregating the planning function from operations.
- The payments model for the DTS deliveries is 'per tonne' and not 'per km' as would be normally assumed.
- Both the above attributes, viewed together, appear to delink truck efficiency, in terms of loading and distances travelled, from the quantum of material delivered.
- From the manufacturer's perspective, the system functions satisfactorily as long as the daily tonnages are lifted and delivered. The simple payments model facilitates amortisation of transportation costs across sales.
- From the 2PL service provider's perspective, the payments model appears to be generating the requisite profits within the planning framework adopted by them. However, no tools for optimising deliveries appeared to be in use.

The DTS model provides a rich research opportunity in terms of the following: -

- Evaluating the suitability of freight transport metrics for assessment of transport operations being undertaken under the DTS model.
- Assessing the loading pattern of trucks undertaking DTS deliveries of plasterboard, and therefore, commenting upon the optimal use of transport and planning.
- Assessing the capacity utilisation of trucks based on the loads and distances involved, and therefore, evaluating capacity utilisation and commenting on the means for utilising 'spare' capacity available.

- Drawing a comparison between the DTS model and the typical ‘echeloned’ delivery model in terms of optimisation of resources achieved by the DTS model, if any. In doing so, it enables quantification of benefits in terms of improved logistics as a result of forward VI of the SC.
- Using planning tools to improve operational efficiency.
- Providing strategic, operational, and tactical opportunities for ‘doing business differently’ to improve sustainability, e.g., contracting nuances, fleet management, and integration of reverse logistics.
- Commenting on the generalisability of research outputs based on disaggregation of the problem into elemental domains.

4.1.4 Ascribing Domains to the Research Problem

The research problem has been funnelled down to one involving analysis of truck movements, i.e., loads and distances. Its background discussion (development) (section 4.1.2) point to its potential disaggregation into elemental domains. This substantiates the multi-domanial character of the construction sector, is considered essential for the generalisability of results, and can point to the analysis forming a basis for further research. Table 4.1 illustrates an indicative breakdown of the problem into elemental domains based on Figure 1.23.

Table 4.1

Breakdown of the problem into elemental domains

Problem attribute	Associated domains for generalisability
Construction	Supplier perspective for analysis Consolidation Transport optimisation Resource efficiency Embodiment of resources Reverse logistics Waste management
Supply chain	Vertical integration Direct-to-customer supply chains Disaggregation of supply chain functions Impact of logistics models Outsourcing

Logistics	Freight transport Distribution models Urban distribution
Transport	Strategic fleet management Operational planning Financial models Sustainability parameters Sustainable operations
Business models	Non-price attributes in tendering Demonstrated performance-based award of contracts Mixed payment models Integrated planning and operations

4.2 Acquiring and Preparing Data

4.2.1 Data Availability

Truck Loading and Trip Data

Data pertaining to truck loading and trips for delivery of consignments was available for a period of three months (October 2020 to December 2020), containing the following: -

- Date of consignment despatch.
- Time of consignment despatch.
- Truck registration or company ID.
- Shipment ID.
- Delivery docket.
- Order number.
- Delivery District (Auckland region was divided into seven districts)
- Delivery Area.
- Delivery Address.
- Invoicing merchant.
- Item.
- Quantity.
- Weight by item.

In the above dataset, each item resulted in a datapoint.

The dataset needed to be aggregated into trip details by summating item loads by delivery address and trip details (truck ID, despatch date, and despatch time).

Each trip was allocated an ID number using the despatch date, time, and truck ID in ascending order. Travel distances across each trip were not available in the dataset.

To start with, data for 3672 trips was available in the dataset. A short discussion on the means of data capture by the company's warehouse is pertinent to understand data cleaning described later: -

- There is approximately a one-month time horizon available for planning deliveries. Actual despatch loads are, however, calculated about five days before the despatch based on the availability of trucks for that particular day. This is done by the 2PL representative integrated with the company's DTS warehouse.
- The loads are invoiced based on the finalised despatch schedule for the day, a paper-based exercise consisting only of tonnages and the trucks on which loads have been despatched. The warehouse despatch office verifies these and provides ID numbers to the invoices for payments to the transport contractor.
- Each invoice is transcribed onto a computer system as an MIS function in the headings above.
- This MIS is available to the corporate headquarters on their database. An extract of this database pertaining to the period October 2020 to December 2020 was made available for this study.
- Each truck has a trip tracker from an IT services company called 'Eroads'. The tracker tracks the route, time, distance, stops, engine switch-on and switch-off details of each truck it is mounted on.
- Eroad data is reliable as government agencies are using it for analysis.

Truck Details

Details of trucks consisting of registration number, the company allocated ID, manufacturer, model, payload capacity, special features (e.g., crane), capability to tow a trailer, and trailer payload capacity were made available.

Table 4.2 illustrates the details of trucks utilised for deliveries. The payload capacities were confirmed from the NZ Vehicles Register. All trucks were not utilised on any given day, the onus for fleet management being with the 2PL service provider.

Table 4.2

Truck details

Manufacturer	Model	Truck ID	Truck Payload (kg)	Trailer Payload
Hino	FY3248	42	23000	16000
Hino	GH	7	12800	-
Hino	GH	13	7760	17000
Isuzu	CXH	5	13860	27000
Isuzu	Elf	6	1940	750
Isuzu	FRR500F	2	6560	-
Isuzu	FSR700L	36	8930	0
Isuzu	FTR700	16	7100	0
Isuzu	FTR750	41	8630	0
Isuzu	FTR750	53	8630	0
Isuzu	FTR750M	15	6780	0
Isuzu	FTS650	30	7400	0
Isuzu	FTS650	34	7360	0
Isuzu	FTS800	3	7740	0
Isuzu	FTS800	9	5480	0
Isuzu	FVR900	1	9200	0
Isuzu	FVZ1400A	4	16240	12000
Isuzu	FVZ1400A	11	12220	0
Isuzu	FVZ1400A	44	11900	0
Isuzu	FVZ1400A	45	11900	0
Isuzu	FVZ1400FVO	10	11220	0
Isuzu	FVZ1400P	31	15700	27000
Isuzu	FVZ1400P	51	12800	20000
Isuzu	FVZ1400P	59	15700	27000
Isuzu	FYH350A	14	19820	0
Isuzu	FYH350A	21	12150	0
Isuzu	FYH350A	22	19690	0
Isuzu	FYH350A	25	12320	0
Isuzu	FYH350A	32	19210	0

Isuzu	FYH350A	37	12150	20000
Isuzu	FYH350A	47	19800	0
Isuzu	FYH350A	48	12320	0
Isuzu	FYH350A	52	19150	0
Isuzu	FYH350A	54	19150	20000
Isuzu	NQR500	17	5080	0
Isuzu	NQR500L	33	5620	0
UD Trucks	CG31470	20	13060	28000
UD Trucks	MK11250	43	6320	0
UD Trucks	PK16280	18	9290	0
UD Trucks	PK16280	40	9220	0

Note. All trucks are flatbed trucks; Zero trailer payload implies a absence of hitching capability

4.2.2 Data Cleaning

Concept

Truck specifications and trip data were the two datasets used for the purposes of this study. The dataset made available, however, was not readily usable. It needed to be cleaned up to ensure data integrity.

Attributes of data cleaning are elucidated below: -

- **Data integrity** Refers to maintaining and ensuring data accuracy and consistency over the life cycle of the data under consideration.
- The means include good data management practices, e.g., preventing alteration of data each time it is moved or copied. The concept of data integrity applies equally to paper as well as electronic (Ofni Systems, n.d.).
- **The ALCOA principle** Data integrity follows the ALCOA principle for data completeness, consistency, endurance, and availability across its life-cycle (or the period of retention) (Ofni Systems, n.d.).
- The ALCOA attributes are as follows (World Health Organisation [WHO], 2016): -
    - **Attributable** Full traceability of every piece of recorded data must exist back to the time of data entry and the individual who entered it.

- **Legible** Anyone viewing the record must find data (including metadata) traceable, permanent, readable, and understandable.
- **Contemporaneous** Summary entry of data into record when generated.
- **Original** Source data representing the medium in which data was first recorded. It also includes the first data entered and all successive entries for fully detailing the project scope.
- **Accurate** Correct, truthful, complete, valid, and reliable data with controls for implementing its accuracy on a risk-based structure.
- **Data Cleaning** Determining data inaccuracies, incompleteness, or unreasonableness, and correcting errors/omissions to improve its quality.
- The data cleaning process may include checks of format, completeness, reasonableness, limits, and its subsequent review by subject matter experts. Data cleaning typically helps in flagging, documenting, checking, and correcting suspect records.
- Therefore, data cleaning is also referred to as error checking, detection, and correction, and data validation, cleaning, cleansing, and scrubbing.
- Data cleaning improves its quality, making it 'fit for use' by reducing errors, and improved documentation and presentation (Chapman, 2005).

Cleaning of the dataset

The dataset obtained for analysis needed to be cleaned to make it accurate and remove inconsistencies. Data were cleaned as follows: -

- **Matching truck IDs between trip data and vehicle specification data** Data pertaining to certain truck IDs mentioned in the dataset provided were not available in the list of truck specifications.

- Such datapoints were far between, though they existed, and were understood as pertaining to the times when trucks were provided by the contractor as a replacement for one out of the fleet of 40 tabulated above.

- Since a means of matching these IDs with registration numbers was not available, the vehicle specifications could not be ascertained from the NZ Vehicles Register.

Consequently, complete data pertaining to such trucks were deleted from the dataset.

- **Removal of outliers** in the form of truck trips utilised for carrying pallets from the construction site or the BM back to the manufacturer's warehouse.
- Though routine, this activity was found far between in the dataset and was considered more of a periodic 'mop-up' than routine operations. Data pertaining to such movements were deleted from the dataset.
- **Dual truck IDs** Certain data trips reflected dual truck IDs with a slash as the delimiter. The specs of both the IDs were compared, and if found similar, one of the IDs was allotted to such data points. Otherwise, the datapoints were deleted.
- **Material without weight** Certain data pertained to material without weight, e.g., packing for plasterboards, which was included in the database for charging customers. All such data could be associated with actual material deliveries to the addresses to which the packing material was consigned. Such data was also, therefore, deleted from the dataset under consideration.
- **Overloading** Certain trucks showed overloading based on the specifications in the NZ Vehicles Register.
- On seeking clarification, it emerged that data of more than one trips of the truck on the same day may erroneously have been aggregated into one trip while transcribing data from invoices onto the computer. Since the payments were 'per tonne', the error was not detected as long as the invoiced tonnages matched the computer despatch tonnage. Overloaded vehicle data was removed from the dataset.
- **Data fields pertaining to delivery addresses** at certain places had instructions for the driver (e.g., 'turn in from ABC road' or 'take key from adjacent property'). Though such remarks were for efficient deliveries, their inclusion in the dataset made the delivery address fields unusable. Therefore, such remarks were removed from the addresses in the complete dataset.

- **Delivery areas/Invoicing merchants outside Auckland** Since the research pertained to distribution of plasterboard within the Auckland conurbation, and the financial models for transportation varied for different regions (per tonne, per truck), all data pertaining to regions outside Auckland were removed from the dataset.

- This data included the delivery locations and the location of the invoicing BM.

- The complete trip data was removed, not just the particular segment, to maintain trip data integrity.

- **Trucks without details in the Eroad database** The Eroad database was primarily referred to for determining the sequence in which consignments were delivered by trucks having more than one drop in a trip.

- The sequence was needed to ascertain loads along various segments of a multi-drop trip and therefore calculate the capacity utilisation of the truck over the trip as an aggregate of utilisation over each segment.

- Movement details of certain trucks on certain days were not available in the Eroad database. These were deleted as part of data cleaning, since the drop sequence could not be ascertained.

- **Modifying delivery addresses** Most deliveries in the dataset pertained to urban construction. There were many instances where different truck trips were directed at two ends of the same street.

- Since determining point-to-point distances was involved in capacity utilisation calculations, such addresses were standardised to one of them to reduce the number of point-to-point distances involved.

- Standardisation of addresses was undertaken primarily for developments on the same street, with a maximum displacement of 1 km (heuristically arrived at).

At the end of data cleaning, data pertaining to 2762 trips over 58 days was available for analysis from the original dataset pertaining to 3672 trips over 63 days.

4.2.3 Freight Transport Performance Metrics

As a preamble to data analysis and determining the efficiency of transport as part of the research, a review of the metrics in use and their applicability to company-level operations is essential.

Furthermore, governments and businesses focus on minimisation of freight transport resource costs and its environmental impacts. They, therefore, need to measure the operational efficiency of freight transport (McKinnon, 2010a).

Freight transport resource utilisation is substantially affected by the inter-functional relationship between transport and shippers' core activities. In turn, factors that impact demand of road freight are total volume of sales, characteristics of the product being transported, and logistical factors (Pahlén & Börjesson, 2012).

Of interest to this study are the following logistical factors: -

- **Logistical system structure** comprising the number of locations, factories, and warehouses between which freight moves.
- **Sourcing and distribution pattern** pertains to the supplier/customer base at which freight is directed. Freight demand is significantly impacted by changes in sourcing and distribution, e.g., outsourcing production, centralised warehousing, and distribution strategies adopted.
- **Scheduling of product flow** Order scheduling, and the size and frequency of shipments that result in vehicle movements.
- **Management of transport resources** includes modal choice, carrier and vehicle selection, and load and route planning for delivery.

The first two represent strategic factors and decisions, while the third and the fourth are usually operational and/or tactical factors.

The important factors impacting the efficiency of physical goods handling are Filling rate, Vehicle/Resource Efficiency, Freight Transport Efficiency, and System Efficiency/Effectiveness (Piecyk, 2010, as cited in Pahlén & Börjesson, 2012).

The first and second are operational/tactical, while the third and fourth are strategic. To understand vehicle utilisation, ‘Filling Rate’ is introduced here. Filling rate is defined as *“the ratio of the actual goods moved to the maximum achievable if the vehicles, whenever loaded, are loaded to their maximum loading capacity”* (McKinnon, 1999).

This may be translated to **vehicle utilisation**, the ratio of the capacity used to the capacity available.

In the case of a truck, vehicle utilisation translates to five utilisation measures (McKinnon, 2010a; Pahlén & Börjesson, 2012): -

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

The two measures selected for analysing the transport efficiency in this study are the weight-based loading factor (termed ‘loading efficiency’) at dispatch and tonne-km-based loading factor (termed ‘capacity utilisation’).

4.3 Data Analysis

Truck trip data was analysed from the viewpoint of loading at the time of dispatch (weight-based loading factor), which is considered static, and tonne-km loading factor, considered dynamic. The former did not require distances for the analysis, the latter did.

The static analysis has been undertaken on the complete dataset, since it did require data on travel distances between various destinations (which was not available in the dataset).

The dynamic analysis, on the contrary, has been undertaken using sampled data (as a true representation of the complete population or the complete dataset, in this case), with distances between various destinations over a trip and the sequence of drops being determined using standard tools.

The static analysis is referred to as **'loading efficiency'** and the dynamic analysis as **'capacity utilisation'** in this study.

4.3.1 Loading Efficiency

Loading efficiency (despatch weight as a percentage of the truck payload capacity) analysis was undertaken using the complete dataset (3672 trips across 62 days) since this did not involve distances, drops or sequence of delivery.

Assessing Normality of Consignment Despatch

Before undertaking analysis, the 'normality' of consignment transportation data was validated.

Each individual transport operation is considered dependent upon underlying random variables, e.g., delivery day and time, quantity, area, and truck availability, capacity (therefore, loading and number of drops), and allocation.

An exhaustive listing of these variables and their possible impacts on transportation operations has not been undertaken. This is considered a potentially different study altogether.

Validation of the truck loading efficiencies (the ratio of the load on a truck at the starting point to its carrying or payload capacity over all trips being considered) being normally distributed would imply that the despatch (and therefore, transportation) process was not unduly skewed, indicating no undue influence of any of the underlying variables (Howard, 2003).

Quantile-Quantile plots (Q-Q plots) offer a powerful graphical technique to assess the normal distribution of any given dataset by comparing it to a standard normally distributed dataset and evaluating the co-efficient of determination (R-squared) (Dhar *et al.*, 2010).

The coefficient of determination illustrates the correlation between the two datasets and is considered more powerful compared to statistical quantities such as Symmetric Mean Absolute Percentage Error (SMAPE), Mean Absolute Percentage Error (MAPE), Mean Absolute Error (MAE), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE) (Chicco *et al.*, 2021).

To discover the underlying distribution, first, a histogram was plotted, and then the trip loading efficiencies for all 3672 trips were modelled against various distributions using SPSS (Appendix B). The histogram showed the data to be left-skewed (Figure 4.1).

The Q-Q plots showed that the data could be closely modelled using the Beta, Normal, and Logistic distributions (Figure 4.2, Figure 4.3, and Figure 4.4).

Distributions other than those mentioned above were not considered as possibly underlying the dataset based on the deviations visible in the detrended plots (Appendix C).

Further, the Beta distribution was discarded from consideration since it is a two-parameter distribution, both of which are manipulated by SPSS to fit the curve.

In comparison, the Normal and the Logistic Distribution obtain their parameters from the dataset, with the Logistic distribution being a little more ‘fat-tailed’ than the normal distribution.

On examining the Q-Q plots for the two distributions, minimum deviations were found in the Normal Q-Q plot. Hence, it was accepted as the distribution underlying the loading efficiency dataset, even though skewed.

Figure 4.1

Histogram of loading efficiencies showing left skewness of data (SPSS)

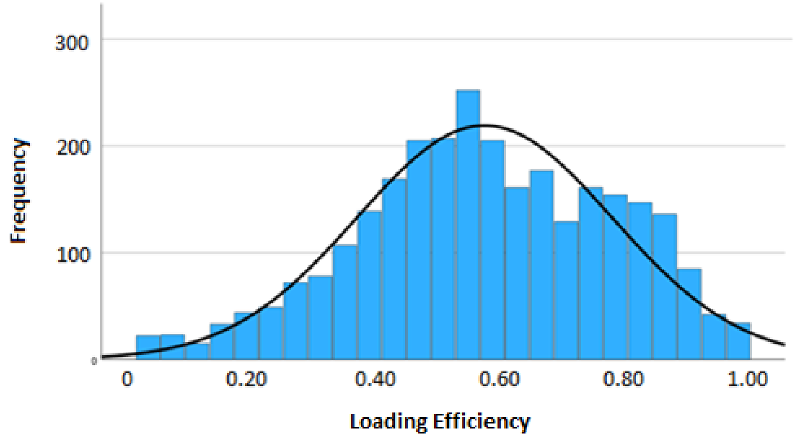


Figure 4.2

Q-Q plot of loading efficiency vs Beta distribution (SPSS)

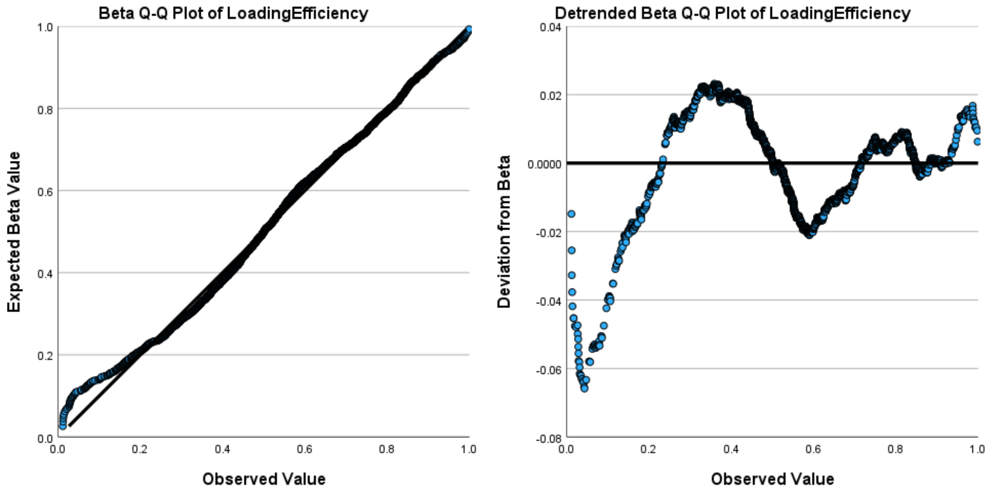


Figure 4.3

Q-Q plot of loading efficiency vs Normal distribution (SPSS)

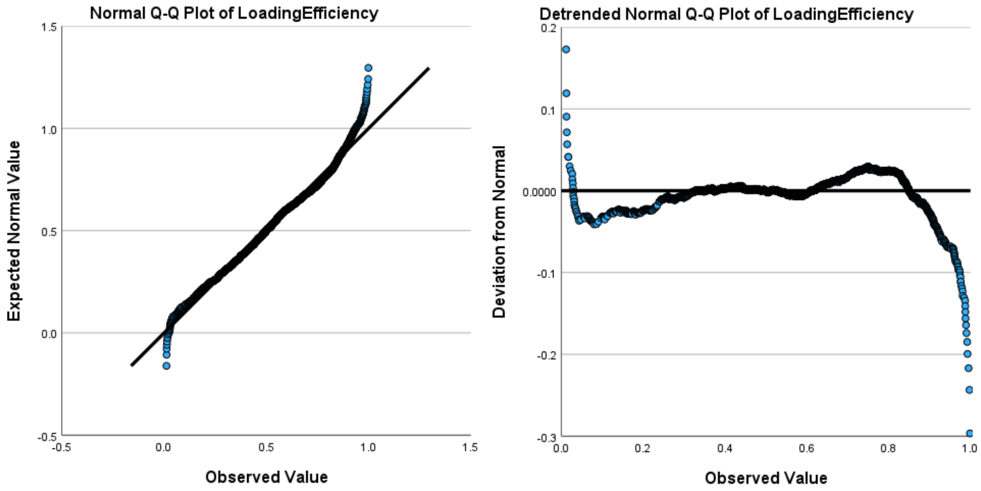
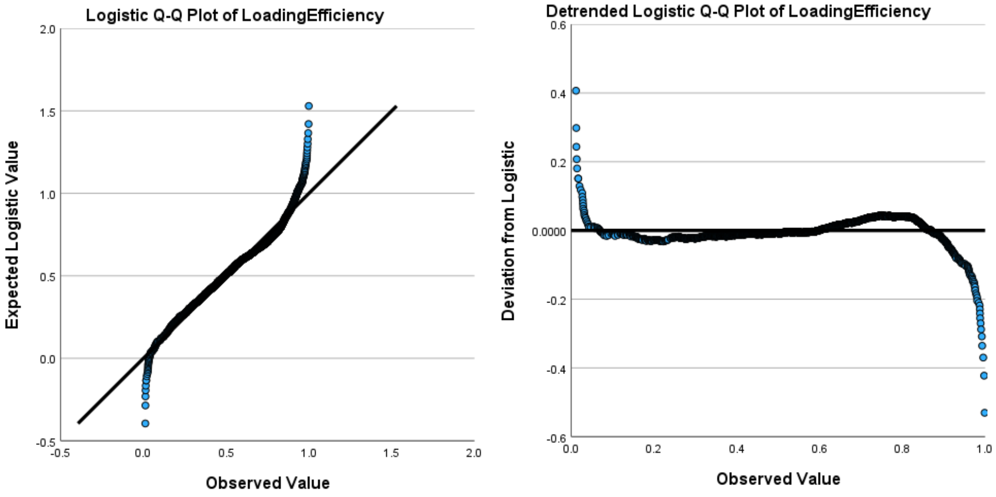


Figure 4.4

Q-Q plot of loading efficiency vs Logistic distribution (SPSS)



The co-efficient of determination was found to be 0.9882, which indicates a good fit. Appendix D shows the Q-Q plots for despatches by individual truck models, which also coincide with the despatches to various delivery zones.

In case of splitting a trip between more than one zone, the zone consignment weight vs the pro-rata distributed truck payload capacity between zones would give the same result.

Internal Consistency of the Dataset

Before the data analysis was undertaken, it was necessary to ascertain the internal consistency of the dataset and, therefore, its reliability.

Although the original dataset followed the normal distribution with a very high R-squared factor, ascertaining its reliability was essential due to the dataset having undergone cleaning, and therefore, removal of datapoints.

Internal consistency is the extent of measurement of the same concept or construct by all items in a test. It is, therefore, connected to how the items within a test are inter-related.

Internal consistency should be determined prior to using a test for research or examination, to ensure validity of data through the measurement of the correlation of the dataset with itself.

Reliability is a construct associated with consistency of measurement by an instrument. Reliability maps onto validity; an instrument must be reliable to be valid, though the converse is not true.

The reliability of an instrument is independent of validity. Cronbach's Alpha is the most widely used statistic to test an instrument's reliability, in this case, the available dataset (Tavakol & Dennick, 2011).

In the instant case, the only independent factor on which destination loads were considered dependent was the planning process, subsuming all other factors within itself.

Cronbach's alpha for the dataset was calculated by splitting the dataset into daily destination loads, as planned. However, loads to one destination were not aggregated because these had been delivered separately in actual implementation.

This resulted in a matrix with 58 rows (number of days), with varying entries for each day.

Even though the application for Cronbach's alpha is for Likert-scale type entries in a dataset, it was still used to obtain consistency without truncating the dataset (Gliem & Gliem, 2003).

The value of Cronbach's alpha obtained was 0.51230, which is considered poor. However, the non-uniformity of the loads vs days matrix is considered the substantial reason behind the low score.

Therefore, although the score is poor, it is still above the lower acceptable limit for dataset consistency (George & Mallery, 2003, as cited in Gliem & Gliem, 2003). Therefore, it validates the internal consistency of the dataset.

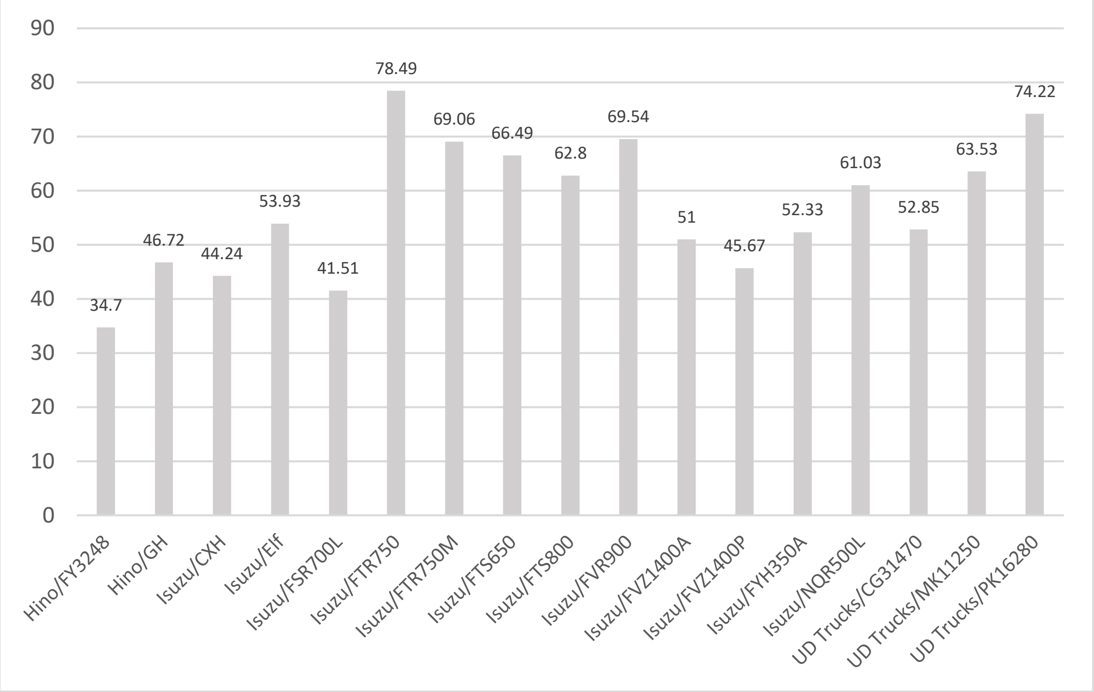
Loading efficiencies

The loading efficiencies were analysed for each truck type and zones the consignments were directed to, for identifying underlying patterns. Figure 4.5 illustrates the average loading efficiency of various truck models, Figure 4.6 the number of trips by truck model and delivery district, and Figure 4.7 illustrates an aggregate plot of the truck model loading efficiencies and the number of trips by model and district.

An average loading efficiency of 56.64% was discovered, which is considered quite low, and translates into approximately 250+ tonnes of loading capacity lost daily (based on payload capacity of the trucks employed).

Figure 4.5

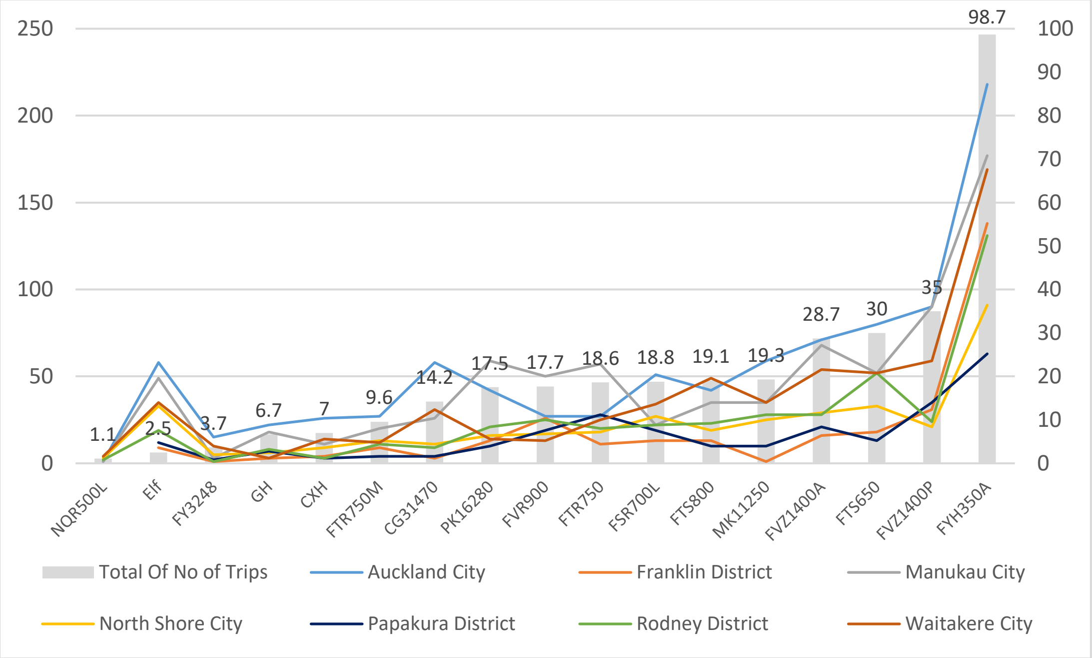
Loading efficiencies by truck model



Note. X-axis – Truck model; Y-axis – Loading efficiency (%)

Figure 4.6

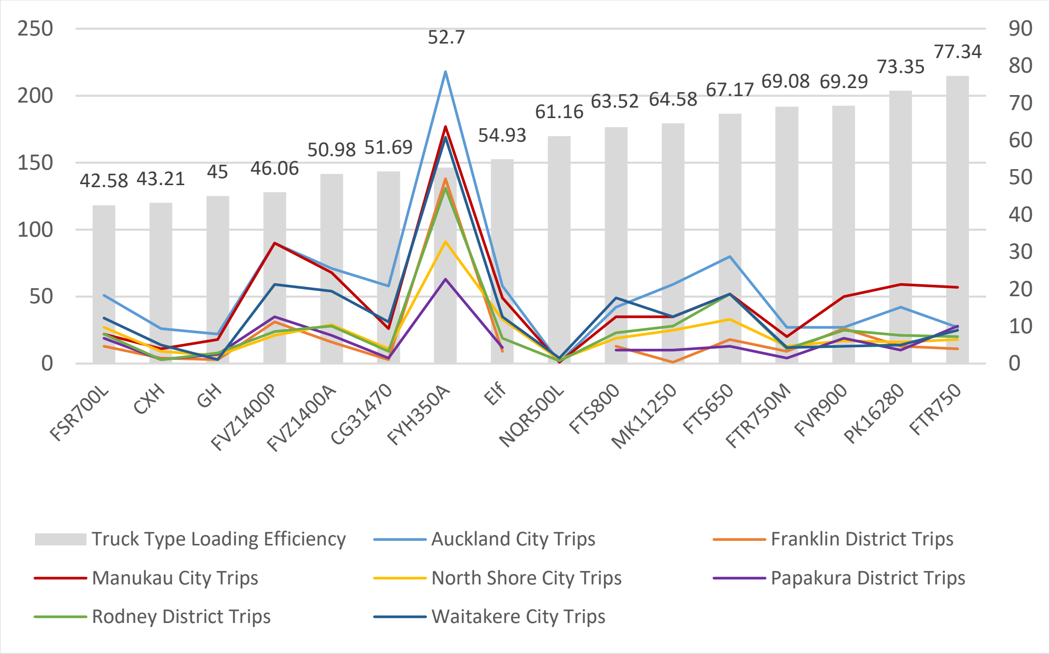
Truck trips by model and delivery district



Note. X-axis – Truck models; Y-axis (left) – Number of trips by truck models for delivery districts (line graph); Y-axis (right) – Total number of trips by truck model/10 (for better readability) (bar graph)

Figure 4.7

Aggregate plot of truck (model) loading efficiencies and the number of trips by model and district

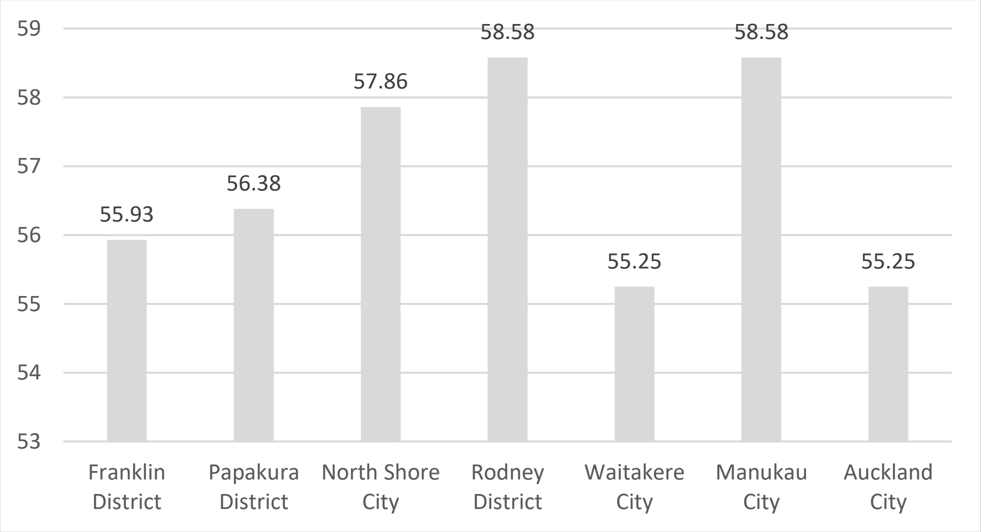


Note. X-axis – Truck models; Y-axis (left) – Number of trips by truck models for delivery districts (line graph); Y-axis (right) – Loading efficiency (%) (bar graph)

The loading efficiencies achieved for various delivery districts are in Figure 4.8.

Figure 4.8

Loading efficiencies by delivery districts as an aggregation of truck loading efficiencies and trips

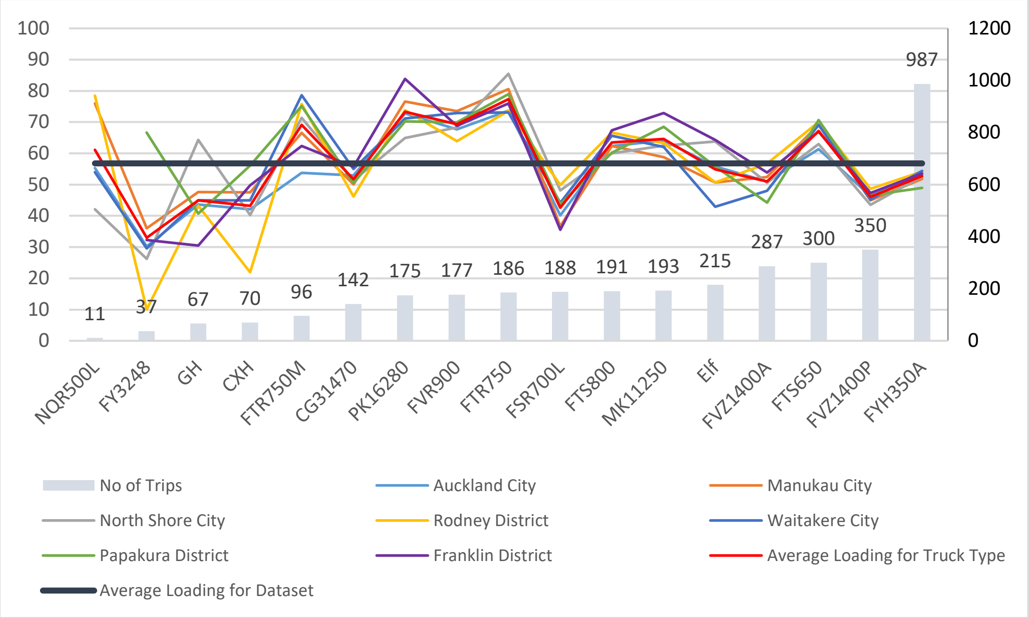


Note. X-axis – Delivery districts; Y-axis – Loading efficiency (%)

The governing variables are despatch loading efficiency and truck allocation to a district (translating to the number of trips of a type of truck to a district). The bunching of loading efficiencies for various models across deliveries to different districts substantiates this. A spread in the efficiencies is seen for those truck models whose trips are very low in number, whose payload capacities are low, where the number of trucks is small, or the truck has been used more for its material handling capabilities rather than its load carrying capacity (Figure 4.9).

Figure 4.9

Truck model trips and loading efficiencies across delivery districts



Note. X-axis – Truck models; Y-axis (left) – Loading efficiencies across delivery districts (%) (line graph); Y-axis (right) – Number of trips (bar graph)

Inferences

The following inferences are drawn from the above analysis: -

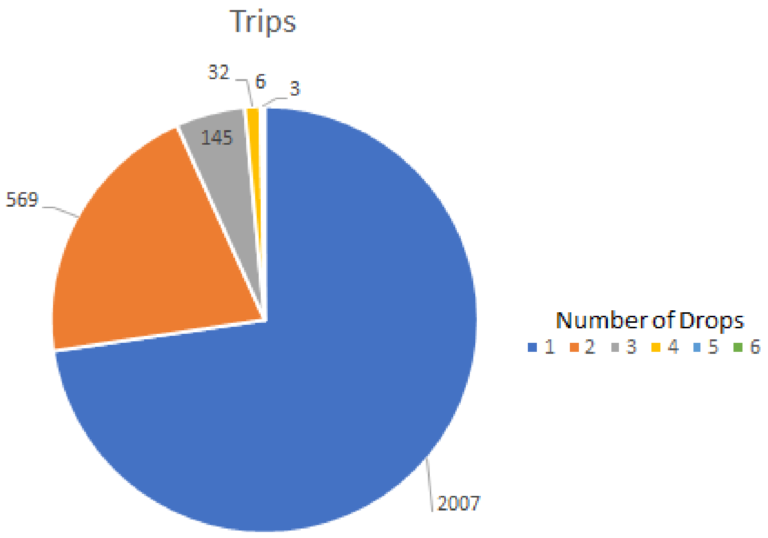
- Truck models exhibit a pattern of loading efficiency. The truck model, therefore, appears to be a governing variable.
- Each model shows a consistent loading pattern across delivery districts, implying that the truck model is an independent variable that governs the efficiency of operations.
- One truck model stands out as the ‘workhorse’. However, its loading efficiencies are in the middle order of a range (approximately 52.7%).
- The average loading efficiency achieved across the complete dataset is 56.71%. This translates to an unutilised truck payload capacity of approximately 252 tonnes daily.

- The unutilised payload capacity points to potential reduction in the number of trips by increasing the loading efficiency. However, this will likely increase the number of trips with more than one drop.

- The current distribution of drops per trip across the dataset is in Figure 4.10. The cleaned dataset has been used for this analysis since a comparison of loading efficiency with capacity utilisation based on the number of drops is proposed subsequently. Furthermore, the analysis of capacity utilisation requires data on distances and drop sequences; therefore, it can be done only on the clean dataset. Hence, the drop analysis is based on the cleaned dataset.

Figure 4.10

Trips vs number of drops (cleaned dataset)



4.3.2 Capacity Utilisation

Freight transportation has two fundamental components: the weight carried on the vehicle and the distances covered. The capacity utilisation of trucks will be calculated based on transport operations 'as executed,' i.e., DTS delivery from the manufacturer's warehouse to the construction site. The statistic is calculated based on the tonne-km available by multiplying the truck's payload capacity with the round-trip distance as the comparison datum. The actual tonne-km utilised is a summation of the tonne-km pertaining to each segment of the journey, considering the loads dropped en route.

This analysis requires distances between the warehouse and the trip's first and last delivery destination. However, the number of trips in the cleaned database precluded determining distances between the warehouse and delivery destinations and/or the inter-se distances between intermediate destinations. Therefore, undertaking the analysis on a statistically significant sample was essential.

Sampling

An appropriate sample size is critical to the design of successful study in addition to its generalisability. A sample smaller than that appropriate may lead to insufficient statistical power for detection of meaningful effects. The consequent answers to research questions may be unreliable. Excessive sample sizes, to the contrary, consume additional (processing) resources, without achieving meaningful improvement in accuracy. Appropriate sample size increases the probability of detecting an effect, ensures accuracy, and optimises resource consumption, therefore, cost-effectiveness (Guo *et al.*, 2013).

Any sampling exercise needs to specify three criteria *viz* precision level, risk or confidence level, and the degree of variability of the attributes being measured (Israel, 2013; Miaoulis & Michener, 1976, as cited in Singh & Masuku,2014): -

- **Level of Precision** Also referred to as the sampling error. It is the range of the estimate of the true value of the population. Expressed as percentage (e.g., ±5%), it broadly provides a band within which the results can be understood to be true. E.g., if a sample indicates the adoption of a practice by 60% of respondents, a sampling error of 5% would imply concluding that 55% to 65% of the respondents have adopted the practice.

- **The Confidence or Risk Level** Based on the Central Limit Theorem (which states that repeated sampling of a population leads to the average value of the parameter of interest from the samples equals the value of the parameter for the complete population. The values of these sample means exhibit normal distribution around the population mean.

- The confidence level in percentage implies that this percentage of samples will have the true population value within the range of the specified precision. The risk of values not falling within this band is 100-[Confidence Level] in percentage and represents the risk (Gupta & Kapoor, 2000; Singh & Masuku, 2014).

- **Degree of Variability** This refers to the distribution of attributes in the population. A more homogenous population implies the requirement of a smaller sample size and vice-versa. A proportion of 0.5 indicates the maximum variability as it divides the population into two halves, unlike any other proportion where one part will always be higher. Therefore, 0.5 being used as the degree of variability invariably results in a conservative sample size.

- Further, the sample sizes vary for continuous and categorical or discrete data. In the instant case, discrete data in the form of individual loading and trips are available. They are being considered on the merits of how they have been recorded, with no cause-effect relationship being explored from the underlying variables.

There are two fundamental approaches to calculating sample sizes: Yamane's (1967) and Cochran's (1977).

While Yamane's approach provides one expression for calculating the sample size, Cochran's approach provides two alternatives for calculating sample size depending upon whether the population is infinite, and by applying a correction to the infinite population expression if the population is finite.

In the case of this study, the population is finite in terms of the number of trip observations available in the cleaned dataset. Both approaches provide approximately equal sample sizes with minor variations (Adam, 2020; Uakarn *et al*., 2021).

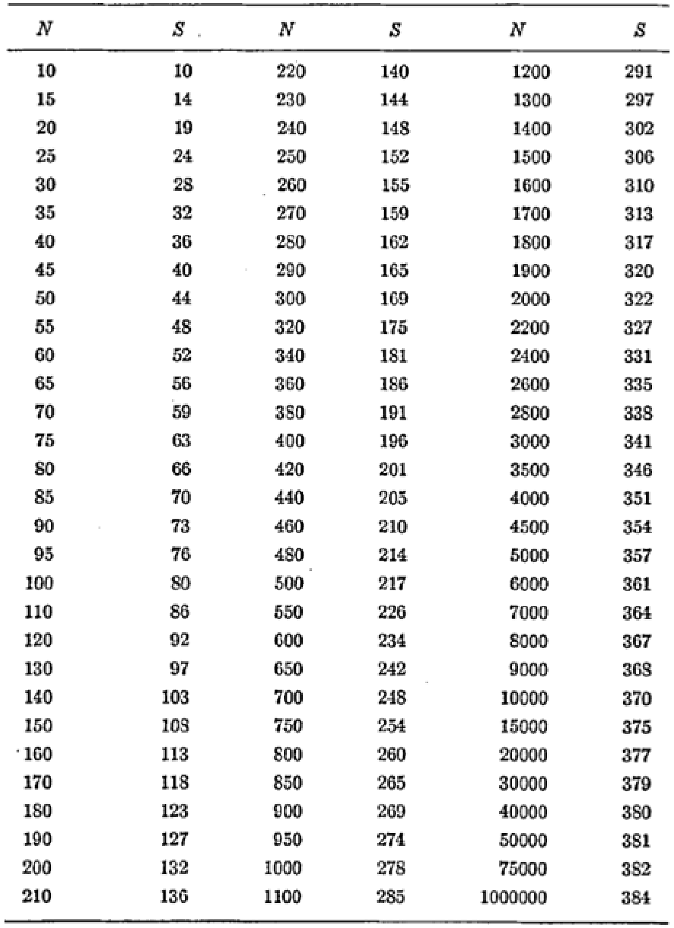
Krejcie and Morgan (1970) provide a ready reckoner and a nomogram for calculating sample sizes based on the population size. In the instant case, the clean data population is 2762 data points (Figure 4.11).

Based on the trips vs the number of drops analysis (Figure 4.10), it was found that the dataset contains nine data points pertaining to trips with more than four drops. Considering nine as insignificant in a dataset containing 2762 'observations', these were deleted from the database leaving 2753 datapoints for analysis.

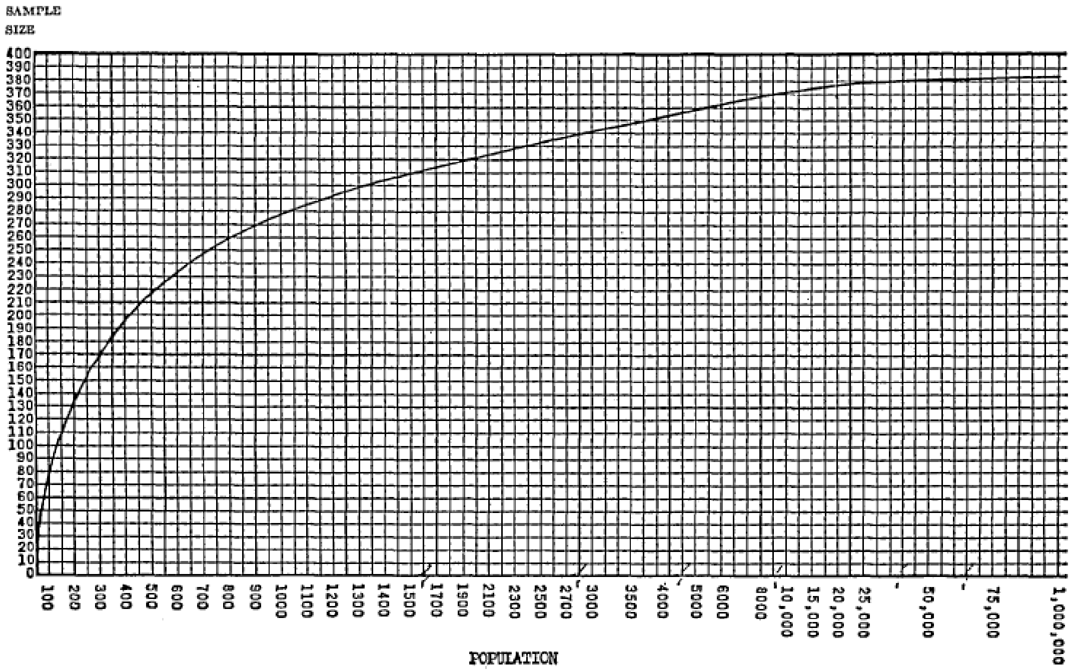
From the nomogram (Krejcie & Morgan, 1970), a sample size of 338 is statistically significant for a population of 2721.

Figure 4.11

Sample size ready reckoner



N	*S*	*N*	*S*	*N*	*S*
10	10	220	140	1200	291
15	14	230	144	1300	297
20	19	240	148	1400	302
25	24	250	152	1500	306
30	28	260	155	1600	310
35	32	270	159	1700	313
40	36	280	162	1800	317
45	40	290	165	1900	320
50	44	300	169	2000	322
55	48	320	175	2200	327
60	52	340	181	2400	331
65	56	360	186	2600	335
70	59	380	191	2800	338
75	63	400	196	3000	341
80	66	420	201	3500	346
85	70	440	205	4000	351
90	73	460	210	4500	354
95	76	480	214	5000	357
100	80	500	217	6000	361
110	86	550	226	7000	364
120	92	600	234	8000	367
130	97	650	242	9000	368
140	103	700	248	10000	370
150	108	750	254	15000	375
160	113	800	260	20000	377
170	118	850	265	30000	379
180	123	900	269	40000	380
190	127	950	274	50000	381
200	132	1000	278	75000	382
210	136	1100	285	1000000	384



Note. (Krejcie & Morgan, 1970)

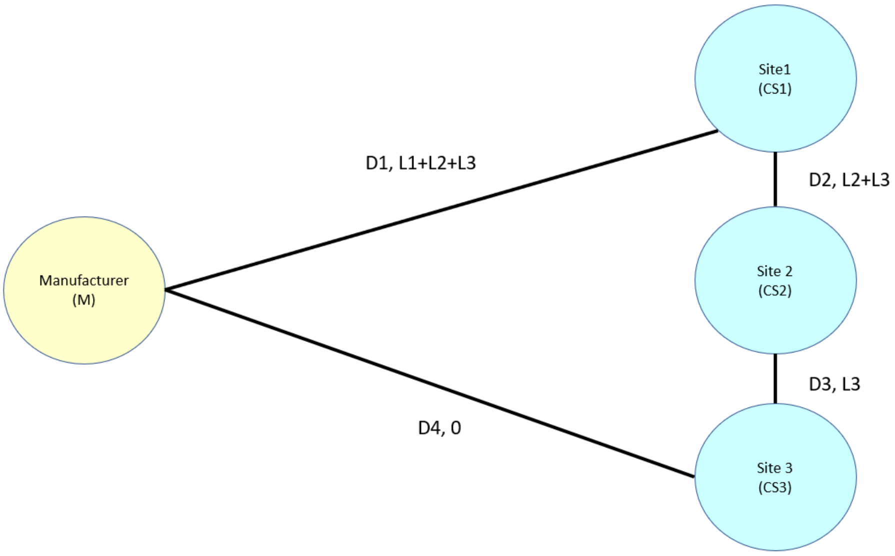
Simple random sampling (probability sampling) was considered the most appropriate since the technique best fits the dataset. For selecting the sample out of the population, the dataset was first sorted in ascending order of date of despatch, time of despatch and truck ID. After this, each data point was allotted a serial number in ascending order. Hence, the observations now were numerically marked from 1 to 2753. After this, a list of 338 random numbers between 1 and 2753 was generated using an online tool. The observations corresponding to these random numbers as their serial number were selected as the datapoints for analysis.

Capacity Utilisation vis-à-vis loading efficiencies from the Sample

Figure 4.12 illustrates the mathematical concept for calculating the capacity utilisation of a truck over a complete trip with multiple drops (Samuelsson & Tilanus, 1997).

Figure 4.12

Truck capacity utilisation model



The figure illustrates three destinations for the truck moving from the manufacturer's warehouse to these in a nominated sequence and then returning empty from the last drop destination to the manufacturer's warehouse, completing a loop or trip.

The letter 'D' represents distances in km, and the letter 'L' represents the load carried. Numeral suffixes for distances represent the distance of the particular trip segment (e.g., D1 is the distance from the manufacturer's warehouse to drop destination 1 or Site 1). Similarly, numeral suffixes for the loads represent loads for a particular drop destination. The first segment has the maximum load on the truck, which consecutively keeps decreasing as loads are dropped at various construction sites along the trip route.

The tonne-km over the trip is calculated by a summation of the products of the segment distances (km) and the segment loads (tonnes). As the comparison datum, the available capacity in tonne-km is calculated by multiplying the truck payload capacity in tonnes with the total length of the trip in km (the tonne-km possible). Capacity utilisation is calculated as a ratio of the former to the latter. Based on the sample of 338 datapoints, the loading efficiencies and corresponding capacity utilisation achieved vis-à-vis the number of drops are in Table 4.3, and their negative correlation at Figure 4.13.

Table 4.3

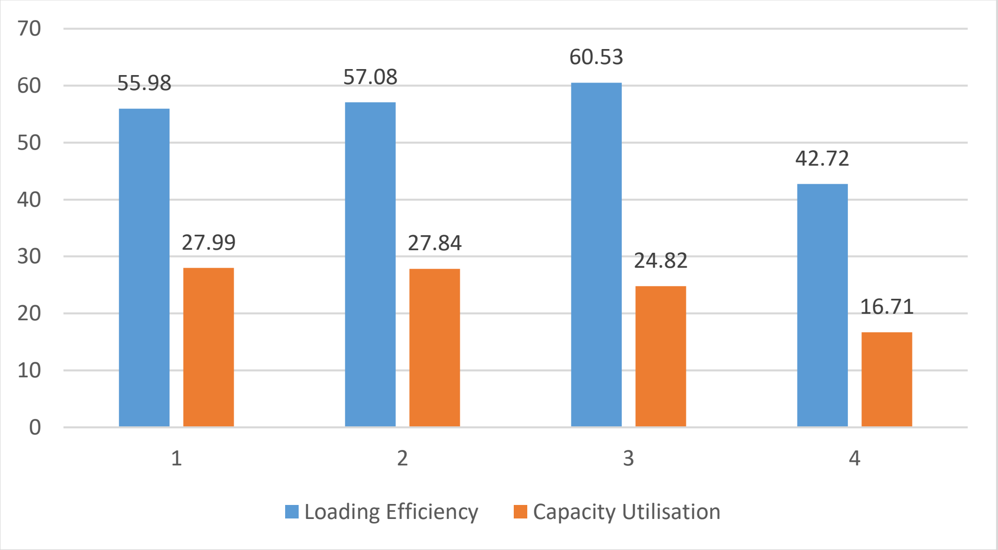
Achieved capacity utilisation vis-à-vis loading efficiencies across number of drops

Drops	Trips	Loading Efficiency (%)				Capacity Utilisation (%)			
		Avg	Max	Min	Std Devn	Avg	Max	Min	Std Devn
1	238	55.98	99.21	4.31	21.75	27.99	49.61	2.16	10.88
2	74	57.08	99.77	6.45	22.21	27.84	55.79	3.33	12.14
3	22	60.53	90.33	14.99	24.16	24.82	42.11	4.93	11.67
4	4	42.72	54.44	26.19	14.73	16.71	21.41	11	5.28
Avg		56.36				27.61			

Note. Avg – Average; Max – Maximum; Min – Minimum; Std Devn – Standard Deviation.
The high standard deviation of loading efficiencies suggests that vehicle loading may be arbitrary.
There appears to be a very sharp drop in the loading efficiency from three to four drops.

Figure 4.13

Correlation between loading efficiency and capacity utilisation vis-à-vis the number of drops



Note. X-axis – Number of Drops; Y-axis – Loading Efficiency, Capacity Utilisation (%)

Inferences

The following inferences may be drawn from the comparison of the loading efficiencies and capacity utilisation achieved vis-à-vis the number of drops: -

- There is substantial spare capacity available at the commencement of daily trips, circa 250 tonnes on average.
- Combined with dropping loads en route on a trip, this unutilised capacity results in nearly 72% of tonne-km going unutilised.
- The availability of this capacity can be gainfully utilised by higher loading of trucks at the commencement of trips, i.e., higher loading efficiency and finding loads for backhaul to compensate for loads dropped off along the route.
- When seen from the viewpoint of each truck making between two and three trips daily, the pattern of loading efficiencies and capacity utilisation points to combining destinations and reducing the number of trips.
- Though the loading efficiency, and therefore the pro-rata loading of trucks, shows an upward trend from one to three drops, it drops when a fourth drop is added to the trip.
- This appears to suggest that the fourth drop is invariably added to either make up for damaged consignments or to deliver the tail end of pending consignments, leading to poor pro-rata loading.
- From the available spare capacity on trucks (at the time of loading), such loads could be added to trucks undertaking one or two drops to keep the maximum number of drops to within three.
- The low-capacity utilisation, when seen purely as a consequence of loads being dropped sequentially for destinations in a trip, point to integrating reverse logistics (picking up waste from the drop points on the same trucks) with forward logistics (material deliveries).
- Integrated planning could assist in improving the loading efficiency and, consequently, the capacity utilisation of trucks.

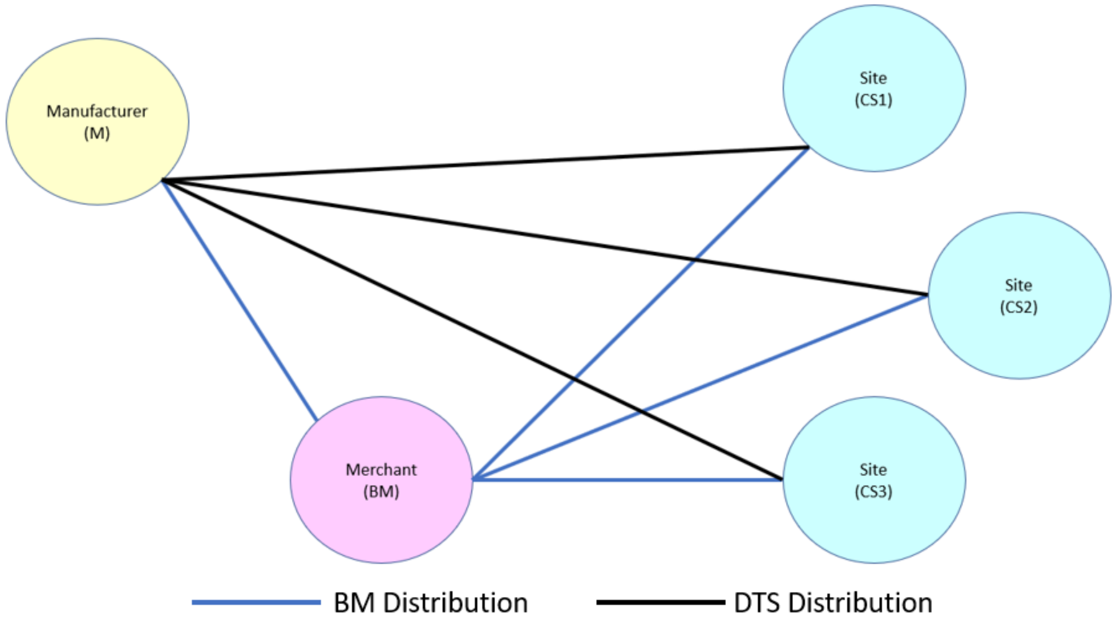
4.3.3 Comparison of 'Direct to Site' Delivery vs 'BM Delivery'

As a result of VI, and therefore, the distribution function's inclusion into the manufacturer's operations, one linkage in the network has been eliminated compared to the standard echeloned CSC. The network of nodes and linkages, therefore, consists of three nodes (for storage/handling) *viz* manufacturer's warehouse, BM's warehouse, and construction site. In an echeloned CSC, these are joined by two linkages *viz* manufacturer to BM and BM to the construction site.

The DTS model eliminates two linkages and one node and substitutes these with one linkage since the supply is directly from the manufacturer to the construction site. Figure 4.14 shows the network in both configurations.

Figure 4.14

The Builder's Merchant Delivery and Direct-to-Site Delivery configurations



Considering that the three linkages joining the three nodes form a triangle, the length of anyone will always be less than the sum of the other two unless all three nodes lie on the same line, in which case they will be equal. However, actual manifestations of road and destination networks are rarely composed of straight lines.

Therefore, an evaluation of the reduction in distances travelled in the DTS model compared to those travelled under the MD model will enable quantification of benefits VI creates for transportation operations in the CSC.

Even though these would be indicative for this segment of the SC and contextual to Auckland, they provide a benchmark for improved efficiencies. They can further be associated with other domains of which transport, and the type of operations undertaken, form a part (Table 4.1).

Reduction in Distances Travelled by Trucks

For calculating the reduction in distances travelled by trucks, the distances between the manufacturer's warehouse and the first and last nodes and the inter-se distances between the nodes based on the sequence of drops were required. For all trips within the sample having more than one drop, the sequence of drops was obtained from the Eroads database.

Once this was determined, the distances between the various nodes were obtained from Google Maps. A comparison of the distances involved in the DTS and MD models for every trip was calculated. Since the calculations are simple distances without any consideration of associated loads, the overall average figures are presented in Table 4.4.

Table 4.4

Comparison of DTS distances to MD distances from the sampled dataset

Parameter	DTS (km)	Ratio of DTS km to BM delivery (km)
Avg	27.04	0.7086
Max	119.1	2.19
Min	3.8	0.1047

Note. Instead of presenting the distances travelled in the BM delivery model, a ratio of the distances travelled in the DTS model to the distances (that would have been) travelled in the MD model has been provided as a stronger indicator of reduction of distances travelled. On an average, the distances travelled in the DTS model are 70% of the BM delivery model, thereby quantifying the average reduction in distances travelled as almost 30%.
In terms of km, the reduction = 27.04[(1/0.7086) – 1] = 11.11 km

From the results obtained from the sampled data, an average reduction of 30%, translating to about 11.11 km for every truck trip, has been determined.

Inferences

The following may be inferred from the overall reduction in truck movements: -

- A reduction in overheads in the cost element of plasterboard.

- Reduction in resident inventory at the BMs warehouse, thus reducing inventory carrying costs and the possibility of alternate use of available space.
- Implementing a ‘pseudo-JIT’ model for deliveries reduces the embodiment of resources and makes the overall SC leaner.
- Reduction in the negative impacts of transport movement associated with the delivery of construction material.
- Associated benefits in all three sustainability domains.
- DTS delivery needs to be maximised; BM delivery should be used only for contingent retail consumption.

4.3.4 Impact on Sales Pattern

To undertake this analysis, the BM locations and the construction site locations were grouped under five regions based on municipal boundaries within Auckland. The complete dataset was used for this analysis since only the tonnages attributable to merchants and construction sites were required (no distances were required).

The total material delivery in tonnes attributable to BMs located in a zone (from invoicing details in the dataset) vs that attributable to construction sites located in that zone (from the delivery details in the dataset) were then calculated (Table 4.5 and Figure 4.15).

Table 4.5

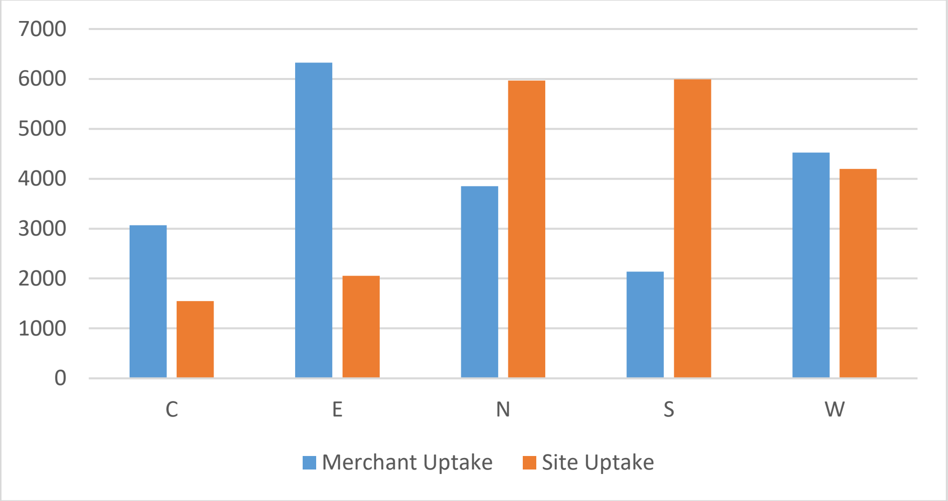
Comparison of uptake by merchants vs uptake by construction sites in various zones

Zone	Merchant Location		Delivery Location	
	Uptake (Tonnes)	Uptake (%)	Uptake (Tonnes)	Uptake (%)
C	3065.47	15.4	1549.84	7.8
E	6327.47	31.8	2054.45	10.4
N	3852.99	19.4	5967.26	30.2
S	2136.69	10.7	5995.27	30.4
W	4526.12	22.7	4195.95	21.2

Note. Merchant location uptake comes from the invoicing merchant in the dataset, while site uptake comes from the deliveries undertaken. The figures clearly indicate the dissociation of construction site uptake from the BMs invoicing materials in the same zone.

Figure 4.15

Graphical representation of merchant uptake vs site uptake by zone



Note. X-axis – Zones; Y-axis – Uptake in tonnes (over the period under review)

Inferences

Inferences drawn from this analysis pertain to the competition and competitiveness of services provided by contractors/developers. These are as follows: -

- The DTS model dissociates physical deliveries from the location of the BM invoicing the material.
- This, in effect, implies that the contractors/developers dependent on the BM are no longer constrained to operate in a particular area, region, or zone. As a result, they can move away from their 'base' location, so to say, to seek work.
- This makes the market more competitive for the customer by providing them with wider options.
- Work is no longer constrained by physical location, making the urban development playfield level.

4.3.5 Applying the Transportation Model for Quantifying Optimisation Potential

As an interdisciplinary domain, logistics does not have its own methods, and uses the principles and methods from other technical and economic sciences, the most commonly ones being (Hrablik *et al.*, 2015): -

- Logistics process and material movement analyses.
- Mathematical analysis of operations.

- Network analysis and using graph theory.
- Simulation.
- Planning and forecasting.

Since the problem pertains to the transportation of material in a logistics system, at first glance, the Transportation Model from operations research was explored as an optimisation tool. Transportation models primarily pertain to optimal transportation of the product of different plants (sources - supply) to depots or warehouses (consumers – demand) (Taha, 2008). The objective of the transportation model is to minimise the cost of satisfying the requirements of the destinations within the existing production capacity (Uzorh & Nnanna, 2014).

Formulating the Problem

The basic design of a transportation problem is represented by a network with nodes representing sources and destinations and arcs linking the nodes representing routes. The arcs are associated with quantities of the material moving and the per unit shipping cost on that arc (Taha, 2008). Though the problem under investigation has nodes and arcs, the source is only one, i.e., the manufacturer's warehouse. The transportation cost is uniform, irrespective of the distance (within Auckland) or the route. Hence, reformulation of the problem to align it with the standard transportation problem was done as follows: -

- The problem was reformulated on a date, i.e., transport operations taking place on a given day.
- Instead of the warehouse being the source, each truck trip is considered a source with a capacity equal to the truck payload capacity (supply).
- Each delivery undertaken during the day is a consumer or destination (demand).
- The per unit cost of transport being constant irrespective of destination or route can be taken as any positive number for each arc connecting sources and consumers. It has been assumed to be unity.

When put in a matrix form, the matrix will have the following elements: -

- **Rows** Each truck trip is considered an independent source with capacity equal to the payload capacity of the truck. E.g., a truck with a payload capacity of A tonnes making B trips in a day represents B sources each having a production capacity of A units.

- This is a ‘less than equal to’ constraint for the current analysis, truck capacity is not being fully utilised by the loads (from the loading efficiency analysis).

- **Columns** Each individual load pertaining to destinations serviced during the day represents the consumers or the demand. This is an ‘equal to’ constraint for transportation model since these are being fulfilled within the truck payload capacities.

- **Matrix cells** Each cell of the matrix of the above rows and columns consists of an arbitrary standard figure, since the payments model is standard across the region (uniform ‘per tonne’ transportation costs irrespective of the distances involved). In the instant analysis, this figure is taken to be unity, though any other positive can potentially be used (a negative number might produce a reverse result).

- The transportation problem fundamentally pertains to minimisation of costs. However, the unform transportation costs (‘per tonne’ irrespective of distances) converts it to a resource (transport) minimisation tool.

Solving the Transportation Problem

The ‘Solver’ add-in to MS Excel presents a convenient tool to solve transportation problems. The ‘Solver’ add-in, however, has a restriction of not more than 200 cells in the problem matrix.

The analysis aimed at proving a concept (that of improved planning and resource optimisation using LP). The basic optimisation unit was a day of operations. The data being presented to MS Excel was truncated in a manner to include as many truck trips as possible from a day to keep the matrix cells within 200. Trip integrity was maintained, i.e., no trips were split during truncation of data. Trip integrity was maintained since the trip is the basic aggregation unit for the transportation of material from where destinations, loads, and drops are reckoned. Splitting a trip would corrupt the data regarding the planning and execution of the transportation operations ‘as executed’. Two matrices on a worksheet have been used to find a solution: -

- The first matrix (M1 – problem matrix) has rows and columns as per the problem formulation. Each matrix cell will be populated with unity as the objective co-efficient. The row immediately below M1 represents the demands of each consumption node represented by columns (as a reference). The column adjacent to the matrix represents the supply from each source represented by the rows (as a reference) (Figure 4.16).

- The second matrix (M2 – solution matrix) will be the same as M1; however, the cells (decision variables) will be blank since they will be populated with the optimised solution after the problem is solved by applying the transportation model. Each cell in the row immediately below the matrix (the solution row) will be a sum of the cells in the column of the matrix above it, and each cell in the adjacent column (the solution column) equals the sum of the cells in the row adjacent to it.

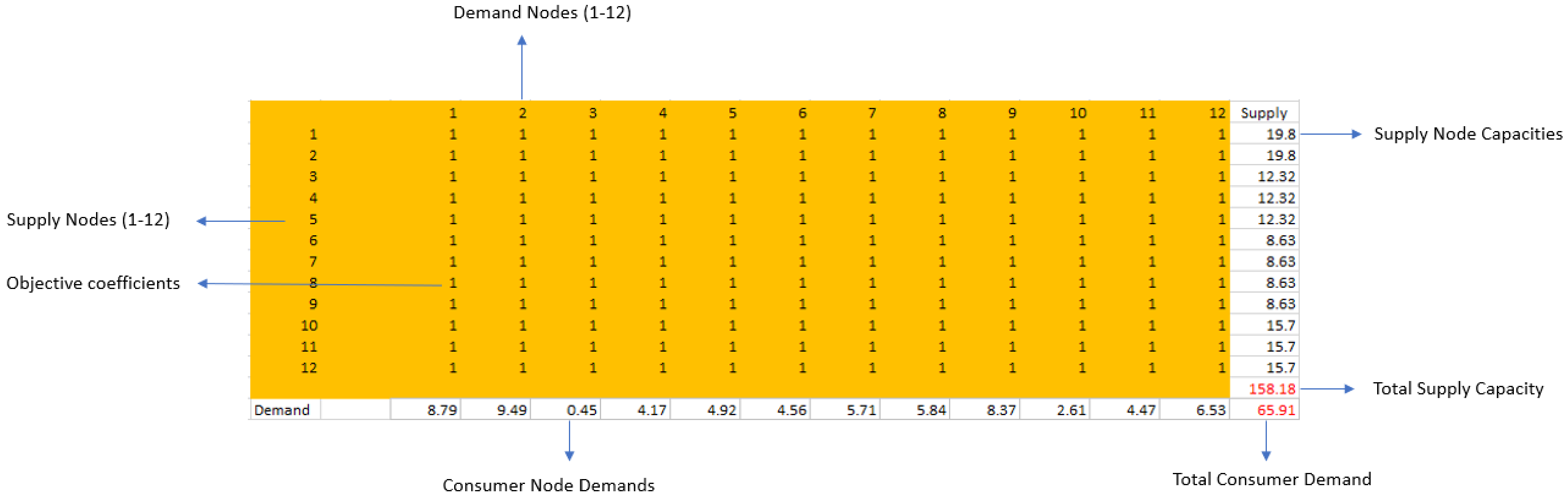
- Before solving the problem, these will appear as zero since the matrix cells are blank. The row representing demands (M1) is replicated below the row containing sums of the column cells. Similarly, the column representing the supply (M1) is replicated adjacent to the column containing sums of rows in its cells (Figure 4.17).

- The constraints for solving the problem are: Total load to be delivered is equal to the summation of the node demands (‘equal to’ constraint), and Total Load to be delivered is less than or equal to the trip capacities (‘less than equal to constraint’). The objective function is the minimisation of the cost. However, since the cost of transportation is uniform for all combinations of supply nodes and demand nodes, this will lead to a minimisation of resources. The minimisation function is the summation of the individual products of the corresponding objective coefficients and decision variables between M1 and M2.

The solution matrix based on the constraints and the objective function is in Figure 4.18.

Figure 4.16

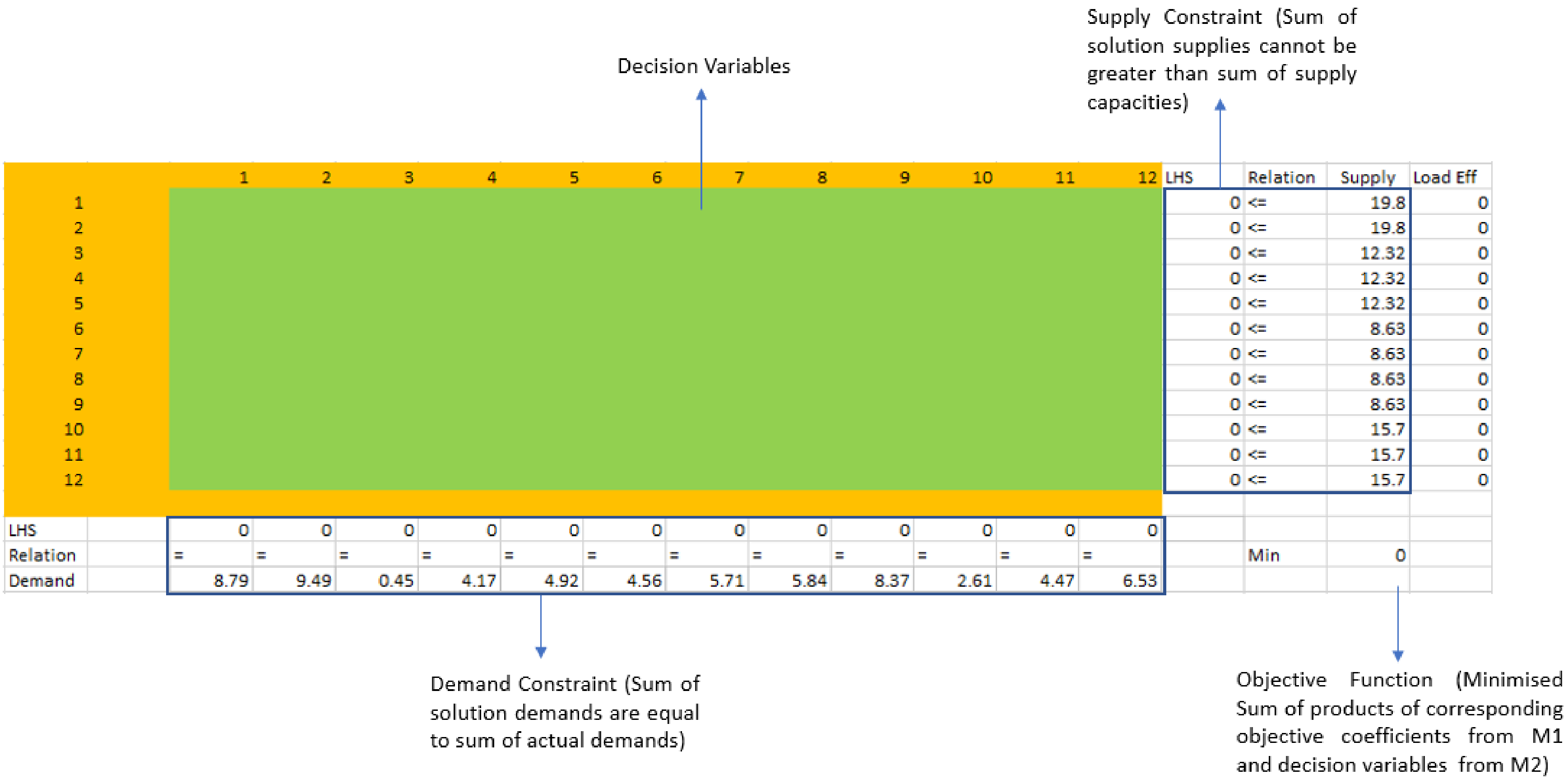
Problem matrix (M1) for transportation problem in MS Excel



		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

Figure 4.17

Solution matrix (M2) for transportation problem in MS Excel (Unsolved)



Decision Variables

Supply Constraint (Sum of solution supplies cannot be greater than sum of supply capacities)

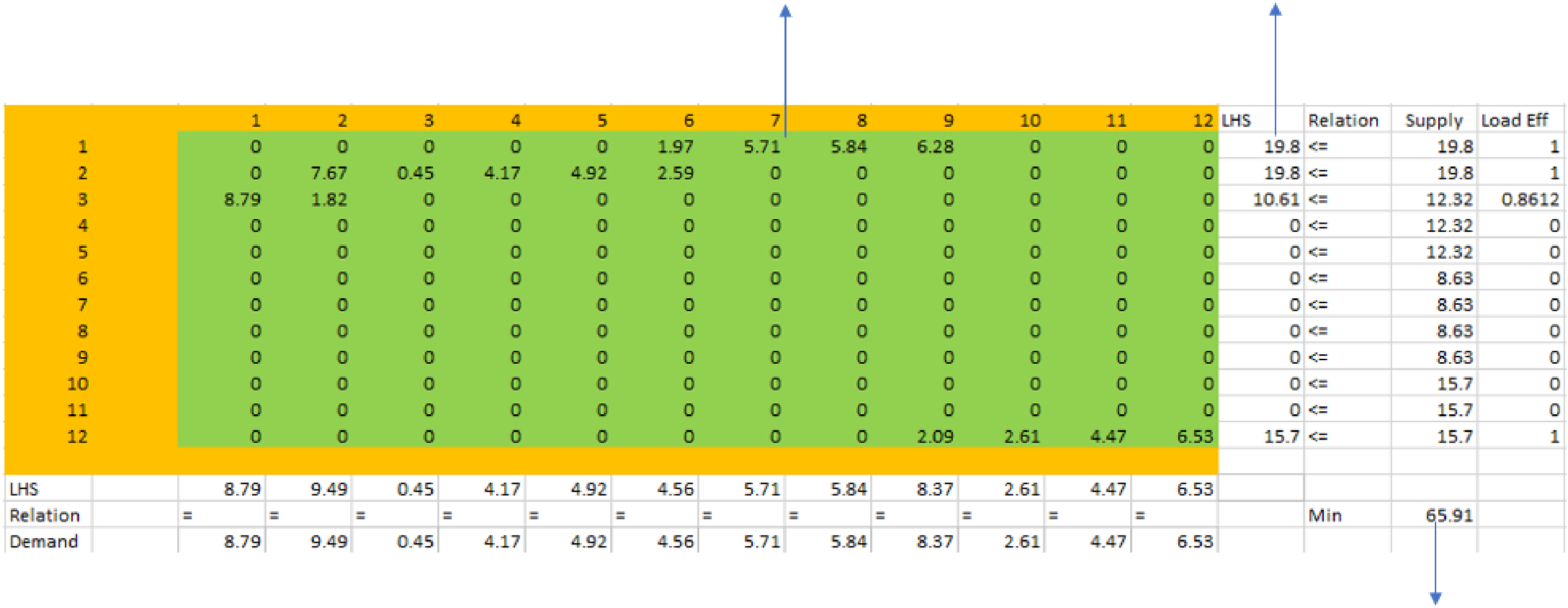
	1	2	3	4	5	6	7	8	9	10	11	12	LHS	Relation	Supply	Load Eff
1													0	<=	19.8	0
2													0	<=	19.8	0
3													0	<=	12.32	0
4													0	<=	12.32	0
5													0	<=	12.32	0
6													0	<=	8.63	0
7													0	<=	8.63	0
8													0	<=	8.63	0
9													0	<=	8.63	0
10													0	<=	15.7	0
11													0	<=	15.7	0
12													0	<=	15.7	0
LHS	0	0	0	0	0	0	0	0	0	0	0	0				
Relation	=	=	=	=	=	=	=	=	=	=	=	=		Min	0	
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				

Demand Constraint (Sum of solution demands are equal to sum of actual demands)

Objective Function (Minimised Sum of products of corresponding objective coefficients from M1 and decision variables from M2)

Figure 4.18

Solution matrix (M2) for transportation problem in MS Excel (Solved)



Solved Decision Variables (allocation of truck loads for each destination)

Optimised Supplies (truck loads) pertaining to columns as destination loads

		1	2	3	4	5	6	7	8	9	10	11	12	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	1.97	5.71	5.84	6.28	0	0	0	19.8	<=	19.8	1
2		0	7.67	0.45	4.17	4.92	2.59	0	0	0	0	0	0	19.8	<=	19.8	1
3		8.79	1.82	0	0	0	0	0	0	0	0	0	0	10.61	<=	12.32	0.8612
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	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
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	0	0	2.09	2.61	4.47	6.53	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				

Fixed cost based minimised objective function

From Figure 4.18, it may be seen that the application of the transportation model from operations research to DTS delivery of materials has resulted in the following: -

- Eight of 12 truck trips have become redundant with no designated loads (a 66.67% reduction in the requirement of transport for the same deliveries).
- Out of the balance four truck trips, three have 100% loading efficiency, while one has a loading efficiency of 86%. The overall loading efficiency achieved is 97.47%, up from 41.66% in the operations 'as executed'.
- Each destination, except three, has only one truck visiting them during the day.
- All trucks being used need to undertake only one trip during the day, connecting the destinations given by the model.

From the above solution, there is a two-pronged optimisation of resources, more effective loading of trucks, leading to a reduction in the number of truck trips (Table 4.6). However, the data is indicative due to the truncation of the daily dataset for accommodating it in MS Excel.

Table 4.6

Improved efficiencies and optimised resources (truck trips) by applying the transportation model

Parameter	Manual Planning	Transportation Model	Improvement/Optimisation
Average loading efficiency	54.01%	89.85%	35.84%
Daily truck trips	11	7	36.36%

Note. The individual solved excel sheets from which the above aggregate figures have been extracted are in Appendix E.

These statistics pertain to truncated data.

From the cleaned dataset, the average number of truck trips per day is approximately 42. Hence, the analysed data is about 25% of the overall dataset, which is considered fairly indicative.

Extrapolating the total number of trips to 42, the number of trips from the optimised model is approximately 26, indicating a saving of 16 truck trips per day.

Inferences

From the above analysis, the following may be inferred: -

- There is substantial operational 'slack' in the planning process, potentially resulting from the payments model being followed.

- Integration of the planning process with operations can improve efficiencies within the existing business model.
- The absence of sustainability concerns in transport operations points to the inclusion of non-price attributes (NPA) in the tender evaluation process and performance-based award of contracts.

4.3.6 Managing the Problem Further

Application of the transportation algorithm optimises the number of trucks that need to be used for a particular day's deliveries to approximately four trips per day. However, it tends to increase the number of drops in the case of many trucks while providing very low consignment sizes (weights) for certain drops. Here, manual intervention is needed. One of the possible interventions could be combining all small drops in one truck, maybe over a period of more than one day, which will enable achieving high loading efficiency. However, the number of drops and the associated consignment sizes may reduce the capacity utilisation of this particular truck. Still, optimisation of transport on a day-to-day basis continues to be substantial.

Once the above has been done, there is a set of loads that each truck needs to deliver during the day across only one trip. Since each truck trip can be handled as a separate entity here onwards, application of Linear Programming (LP) has, therefore, reduced a 'Vehicle Routing Problem' (VRP) (multiple vehicles across multiple routes) to a 'Travelling Salesman Problem' (TSP) (one truck visiting many vertices over a defined route) (Devendra, 2010).

The route to be followed by each truck can further be optimised by working out the 'next' vertex it needs to visit along the drops specified by the (LP) transportation model solution. A 'Hamiltonian Path' or 'Hamiltonian Loop' approach with a 'greedy' algorithm can be effectively used for this part of the problem (Bondy & Murty, 1976). The 'greedy' algorithm selects the next destination (vertex in a route) as the one closest to the present vertex. However, in the case of physical routes, the lines joining vertices on a route may not necessarily be straight, and therefore, a greedy algorithm may or may not give optimal results.

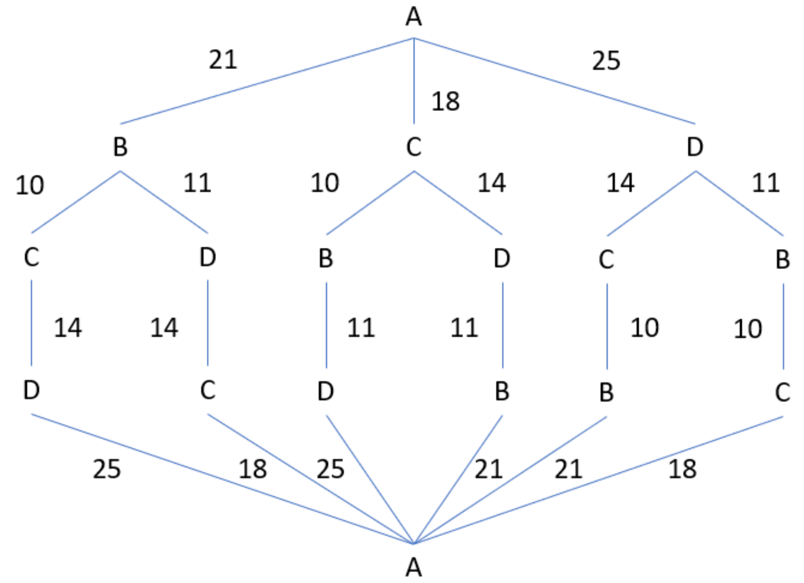
A table of distances maintained on a database can help solve the problem of sequencing vertices. The algorithm for processing distances from this table would require minimal processing resources within the capability of any computer, especially since the number of drops within most cases would not exceed three.

Figure 4.19 illustrates the solution to a problem of routing from the origin to three vertices. The 'Hamiltonian Path' and the 'Hamiltonian Loop' provide different results and options for route selection in the instant case.

Figure 4.19

The 'Hamiltonian Loop' and the 'Hamiltonian Path' solutions

	A	B	C	D
A	-	21	18	25
B		-	10	11
C			-	14
D				-



Hamiltonian Loop	70	64	64	64	70	64
Hamiltonian Path	45	46	39	43	49	46

Note. The table on top of the figure shows distances between points or vertices to be serviced for which the possible routes are illustrated in the network graph.

The Hamiltonian Loop (including return to the origin) provides four choices for routes to be followed with minimum overall distance (64 distance units), one of which comes from the greedy algorithm-based Hamiltonian Path (highlighted in yellow).

In the case of the Hamiltonian Path approach, the greedy algorithm, in this case, provides the minimum possible distance to be travelled to visit each of the vertices (39 distance units).

Both approaches have their applicability depending upon the business model adopted. In case transport is relieved and not paid for after the last vertex on the route, the Hamiltonian Path approach minimises the distances. On the other hand, if the transport is captive to the business and returns to the origin after completing deliveries, the Hamiltonian Loop approach is appropriate for application.

4.4 Assumptions for Data Analysis

The data analysis undertaken was based on certain assumptions, as follows: -

- The cleaned data represents transportation operations as planned and executed.

- The transport contractor aims to maximise his profits by lifting the maximum possible tonnages daily and seeks to minimise the time of travel and the time spent on site. However, these two parameters were not considered during the analysis since the analysis pertains to operations 'as executed'.

- Planning of transport operations is being done heuristically.

- Even though different models of trucks are being used, all trucks have an equal probability of being employed for a trip.

- The truncated data used for the application of the transportation model is a near-true representation of daily operations. The inclusion of all truck trips is likely to vary the results marginally.

- Any optimisation achieved as a result of modelling will be within the constraints of transport movement realities in the Auckland conurbation since the stochasticity of the time associated with truck movements is a common factor.

4.5 Understanding Reasons (External Validation through Substantiation)

The data analysis presented certain patterns in the manner of employment of transport. In addition, certain issues from the inferences of data analysis needed amplification (the 'what' needed substantiation by 'why'). Opinion of the functionaries managing logistics aspects in the company on these is as follows: -

- **Loading pattern** The loading pattern was attributed to arbitrary planning and a higher loading efficiency for farther destinations. In the planners' understanding, it was more efficient for a truck to make a short run and get back to the warehouse faster for another run rather than combining runs into one trip. Trucks were loaded for a long trip to achieve the maximum possible delivery along the route.

- In addition to trucks making short runs, trucks with low payload capacity, and those trucks with a small number of trips in the dataset, there were certain high payload capacity trucks making frequent and long runs which also showed a poor loading pattern. This was attributed to the high specialist character of the trucks in terms of the crane capacity and reach. Invariably, these trucks stayed on at a site after delivering their loads to perform the role of a crane for other deliveries. Hence, the actual material transported by them was low.

- **Motivation for DTS model** The company's primary motive behind the DTS model was three-fold, to consolidate deliveries at their warehouse rather than retail deliveries from the BMs warehouses and therefore exploit economies of scale in distribution to obtain a first-hand estimate of the requirement of material in the market and hence, coordinate production, and to provide higher customer satisfaction by virtue of the consolidation of delivery resources with the company. Higher customer satisfaction was achieved by customised delivery, free replacement of any damages during transit, and off-loading and storage of the material 'in the room' where it was to be used. This compares very favourably with the deliveries undertaken by BMs. Financial benefits were not discussed, being 'commercially sensitive'.

- **Further potential for shifting material from retail distribution to DTS distribution** Overall, 35%-40% of plasterboard deliveries in NZ are DTS (including Wellington, Hamilton, and Waikato). Approximately 75% delivery of plasterboard in Auckland is already under the DTS delivery model. Therefore, a substantial increase is unlikely, though an incremental increase may continue based on merchants' invoicing of material. However, DTS delivery in other major urban areas of NZ (Hamilton, Wellington, Waikato) has substantial potential to increase.

- **Financial model for hiring trucks** Within the Auckland region and the (to include bordering areas of neighbouring regions) a 'per tonne' model is being followed. For certain other regions within NZ, a 'per truck' model is being followed. From the discussion of these models, it emerged that the 'per tonne' model did not create any sustainability compulsions on the LSP since the KPI, in this case is the tonnages to be delivered daily.

- The distances travelled, or the loading efficiency of trucks is of no consequence to either the contracting party or the contracted party. However, the 'per truck' model makes it incumbent upon the LSP to achieve maximum loading efficiency since a reduced loading efficiency automatically translates to an increase in the number of trucks required to deliver the same weight. Hence, loading efficiencies for this model are likely to be far higher than the ‘per tonne’ model. No data were obtained for truck movements based on this model since this pertained to deliveries outside the Auckland region.

- The feasibility of a ‘per km’ model has not been investigated for deliveries within the Auckland conurbation. The ‘per tonne’ model appears to be working fine regarding the business and the financial model in terms of margins and expenditures.

- **Non-price Attributes (NPA) in the tendering process** Currently, the financial model for procurement of transport services is primarily based on financial considerations, i.e., minimum per unit cost of transportation of the product from the manufacturer’s warehouse to the customer’s location (construction site). Non-price attributes associated with sustainability concerns for transport, i.e., demonstrated sustainable transport practices such as fleet composition, operational planning, and fleet employment/utilisation do not form part of the tendering/tender evaluation process.

- **Sustainability concerns in fleet management** This aspect involves the employment/implementation of technology for sustainable transport fleet operations: -

    - At the vehicle level, this would potentially deal with conversion to more sustainable fuels and a transition plan. There is demonstrated evidence for this as far as the company’s material handling fleet is concerned, where LPG has been adopted as the fuel for forklift trucks, making them cleaner than diesel.

    - At the management level, this will imply using ICT tools to support operations. E.g., An app where-in the customer (construction site) can communicate with the manufacturer’s warehouse to enable more effective scheduling and intimating any damaged material which can be collected as a backhaul; Use of computer-based tools for scheduling and truck allocation, which are likely to improve the efficiency of operations and reduce slack (as demonstrated by the application of transportation model to the transport operations).

- **Integrating reverse logistics with forward logistics** As part of the data analysis, certain deliveries were observed as 'replacements'. These pertained to material damaged during transit before being delivered on-site. In addition, other waste arisings of plasterboard on-site pertained to issues like offcuts, etc. The literature provides conflicting estimates of plasterboard waste (in terms of tonnage) from urban construction in NZ *viz* 5%-20% (Jacques, 1999) and 27.5% (Gade & Seadon, 2022).
- The company estimates that plasterboard waste arisings from construction sites are approximately 20%. A figure of 20% appears to sit midway between the estimates presented by the studies quoted and is substantial. However, the plasterboard waste stream has not been integrated into manufacturing and, therefore, is not collected back by the company.
- An important reason cited for this was the limited use of waste plasterboard in new manufacture for quality reasons. The absence of a reverse logistics model was implied.

4.6 Chapter Summary

This chapter analyses the development of the research problem through an assessment of various options and their limitations. The final research problem is selected around assessing the transport operations pertaining to the 'Direct to Site' delivery of plasterboard by a manufacturer, achieving forward VI of the distribution function as an extension of manufacture. Distribution, though integrated, has been outsourced to a 2PL, disaggregating the planning function.

Next, the chapter discusses the acquisition of data, its cleaning, analysis, and drawing of inferences from the data analysis. It investigates the impact of the DTS model on loading efficiencies, capacity utilisation, and the regional sales pattern. An average loading efficiency of 56.64% was discovered, which is considered low. The DTS model was assessed as producing an improvement of approximately 30% in capacity utilisation compared to the deliveries being routed through the merchants. The sales pattern in terms of uptake by construction sites in a zone was dissociated from the pattern of invoicing by merchants in the zone, indicating that the DTS mode removes the constraints of contractors/developers operating and seeking work in the proximity of the BM they are dependent on, in effect making the Auckland urban development playfield competitive.

Application of the transportation model from operations research to the transport operations ‘as executed’ found the potential for a reduction of approximately four truck trips a day, with a corresponding improvement of approximately 36% in the average loading efficiency.

To further manage the problem, the Hamiltonian Path and the Hamiltonian Loop approaches for deciding the sequence in which vertices are to be visited (‘drops) ’have been discussed with an arbitrary example demonstrating their applicability.

The analysis finds substantial operational slack in transport operations, with major optimisation potential.

A discussion with the concerned functionary mostly substantiated the inferences drawn from various analyses, which provide a way forward towards enhanced sustainability of the transport function in plasterboard distribution under the DTS model in Auckland.

Chapter 5 Discussion

Chapter 4 discussed the problem development, data analysis, inferences, and simulating the impact of integrating the planning function. The inferences drawn were pointers, a detailed discussion of which will be undertaken in this chapter.

5.1 Generalised Model of a Trip

A substantial number of trips are single-drop trips, with most others limited to two to three drops and a small minority consisting of four drops. Overall, approximately 72% capacity of the truck fleet in terms of tonne-km appears to be going unutilised. This results from low loading efficiency factors and dropping off loads along the route, even if it is a one-drop trip (the connotation of a route here is round-trip).

Table 5.1 illustrates the availability of truck trips (reckoned from those made for delivery from the cleaned dataset) for each site and each locality or area.

Table 5.1

Trips, site, and delivery area relationship from the complete dataset

Parameter	Maximum	Minimum	Average
Delivery trips per site	37	1	3.05
Delivery trips per area	245	1	20.21

Considering approximately 93% loading efficiency of trucks, which is achieved to a very large extent by the application of the transportation model to the problem (inferred from Appendix E), the capacity utilisation of trucks is likely to be at best 50% (for a one drop trip) and less than 50% for trips with more than one drops (Vrijhoef, 2015). Besides the trucks moving back to the origin from the last drop empty, capacity for backloads also gets generated as a consequence of sequential unloading at the drop points (Berden, 2017; Shakantu & Emuze, 2012).

If this generated capacity is to be utilised, a fertile opportunity for the backhaul of plasterboard waste from construction sites exists. The potential for backhauls needs to be seen from two perspectives: the arisings of plasterboard waste on-site and the potential for picking up this waste. Based on estimates by Jacques (1999), Gade &

Seadon (2022), and an estimate based on discussion, 20% plasterboard waste arisings from each construction site is considered appropriate as a ballpark figure.

This provides an effective and potent opportunity for utilising capacities generated from the availability of waste on sites.

Approximately 11.64 tonnes of plasterboard is delivered per site on an average from the dataset. This implies arisings of approximately 2.32 tonnes of plasterboard waste from each construction site.

An aggregated model to attribute a generalised number of trips per truck, a generalised load per trip segment to trucks, and a generalised per site per truck waste arising need to be formulated for evaluating the potential to improve capacity utilisation by integrating reverse logistics for lifting plasterboard waste in the delivery vehicles.

The model is constructed as follows: -

- From the cleaned dataset, on average, 26 trucks operate for delivery daily. These 26 trucks represent a payload capacity of approximately 330 tonnes, again from the cleaned dataset (here, one trip per day per truck has been used for calculation, assuming that operations are optimised as per application of the transportation model, and therefore, nearly 100% loading capacity is achieved).
- This presents a 'worst-case' scenario of the availability of capacity for lifting waste from construction sites; In 'Business as usual', the capacity available for lifting waste would be much higher owing to low loading efficiencies).
- This translates to approximately 12.7 tonnes of capacity available per truck. Considering an even distribution of loads pertaining to different drop sites and an average of 3.16 drops per trip reckoned from the dataset, approximately four tonnes of material will be delivered to each site in one trip.
- Considering an average of 3.05 delivery trips per site, approximately 12.15 tonnes are delivered to a site. This agrees closely with the average figure from the dataset (11.64 tonnes per site), given the rounding off in the calculations.

- For simplicity of the model, we consider the average number of drops per trip as three (from the optimised delivery model), the average capacity of a truck equal to 12.9 tonnes (easily divisible by 3), and the waste arisings from a site as approximately 2.4 tonnes (easily divisible by 3, which is the average number of trips per site).

- The loads being delivered by this generalised truck are approximately 93% of 12.9 tonnes (based on estimates from Appendix E), i.e., 12.5 tonnes.

- Delivery at each drop is about 4.24 tonnes, and waste arisings approximately 0.8 tonnes per trip per site (which closely agrees with 20% of 4.24 tonnes being delivered per site per trip).

To complete the model, the distances of various segments of a generalised three-drop trip need to be reckoned (Speičys & Jensen, 2008). These may be calculated from the sampled data since sampling ensures that the sample represents the complete dataset.

Out of 338 sampled data points, only four pertained to four drops, hence, were ignored for formulating a generalised model, being statistically insignificant (these were included in the sample only for finding out the trend in loading efficiencies and capacity utilisation).

Distances pertaining to various segments of a generalised three-drop trip are calculated as a weighted average of these segments travelled by trucks in the sampled data. These are presented in Table 5.2.

Table 5.2

Distance parameters for the generalised three-drop model from sampled data

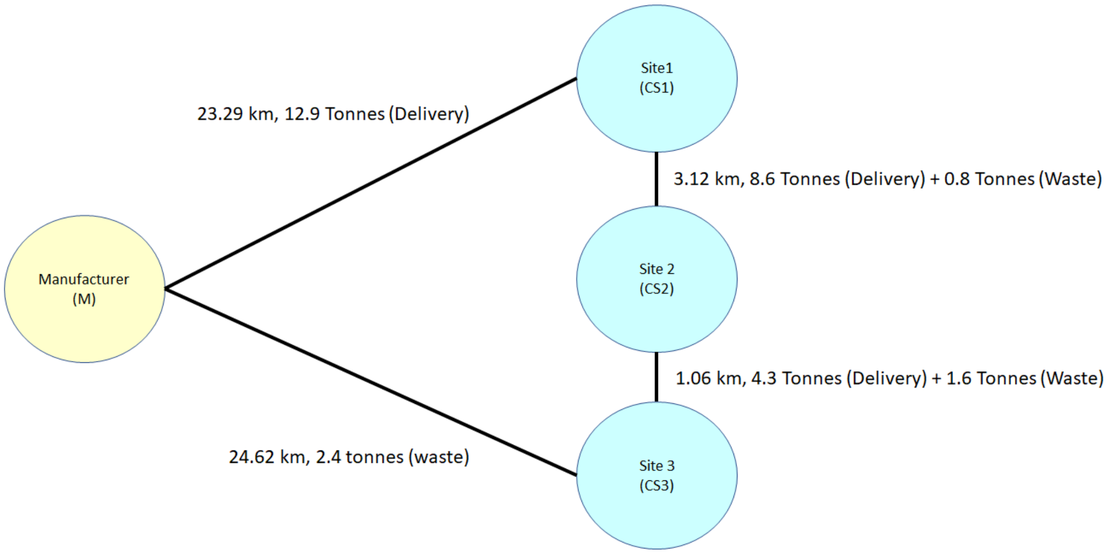
Number of Drops	Trips	WH to Drop 1	Last drop to WH	Drop 1 - 2	Drop 2 – 3
1	238	22.76	22.76	0	0
2	74	24.92	28.22	10.55	0
3	22	23.67	32.6	11.84	16.16
Weighted Average		23.29	24.62	3.12	1.06

Note. All distances are in km; WH – Warehouse; Drop 1 – The first drop applicable to all trips; Drop 2 – Second drop; Drop 3 – Third drop; Distance from drop 1 to Drop 2 applicable to two and three drop trips; Distance from Drop 2 to Drop 3 applicable to three drop trips; Distance from the last drop to warehouse applicable to all drops to maintain the balance of the model by closing the loop.

From the discussion of loads and distances, a generalised model for capacity utilisation improvement considering an already optimised delivery model (using the transportation model) (Taha, 2008) and integration of backhaul of plasterboard waste on delivery vehicles is presented in Figure 5.1.

Figure 5.1

Generalised model for deliveries and potential waste removal



Note. (Author)

From Figure 5.1, out of a total of approximately 672 tonne-km of transportation capacity available on the generalised trip, 326 tonne-km are utilised (48.61% capacity utilisation) without waste backhauls.

With waste backhauls, the figure jumps to 390 (58.04% capacity utilisation).

The optimised model results in an improvement of nearly 22% in capacity utilisation compared to operations ‘as executed’.

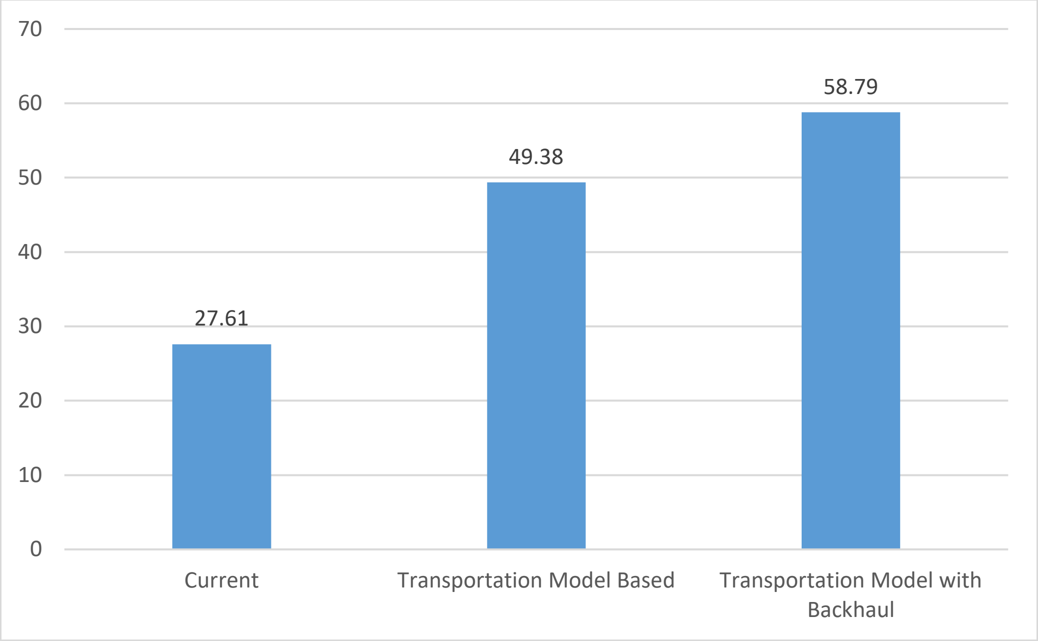
Superimposing waste backhauls on the generalised optimised model results in another 10% increase in capacity utilisation (Figure 5.2).

In addition, plasterboard waste is now available to be put to purposeful use as raw material for manufacture.

Therefore, integrated planning based on ICT tools needs to be introduced into the existing operational model.

Figure 5.2

Improvement in capacity utilisation in three vehicle employment scenarios



Note. X-axis – Operational scenario; Y-axis – Capacity Utilisation (%)

5.2 Backhaul Arrangements

The truck fleet utilised for plasterboard delivery comprises flatbed trucks, where-in plasterboard consignments are ‘strapped-on’. Since plasterboard waste would not be in defined shapes or volumes like new plasterboards, some arrangements of loading waste onto trucks without making the arrangement unwieldy needs to be found (NZTA, 2017).

This is especially so because each trip in the generalised model has more than one drop, which should not be hampered due to waste loading.

The best method is using waste ‘bags’ on-site, which can be easily loaded and strapped on the vehicles, either between or on top of the consignments.

This aspect, however, points to the requirement of a crane for every delivery truck, an issue which will be further amplified in the section discussing fleet configuration.

The next issue concerning plasterboard waste is its utilisation. A discussion with the concerned functionaries revealed that plasterboard waste could be used as raw material in the manufacture of new plasterboard (Erbs *et al.*, 2021) to the extent of approximately 10%, beyond which there may be quality issues concerning load-bearing capability.

Waste arisings need to be looked at from two perspectives *viz*: -

- Use of waste plasterboard as raw material for load-bearing applications to the extent of 10% composition and a higher composition for non-load-bearing applications.
- Considering that approximately 75% of delivery in Auckland is on the DTS model. In contrast, Auckland accounts for only about 40%-45% of the national sales, with the balance split between Hamilton, Wellington, and Christchurch.
- Establishing a backhaul model for other regions may not be practicable. Hence, the backhaul arisings from Auckland can feed manufacture.

A business model involving customers (contractors/developers), merchants, current waste management businesses, and the company may need to be worked out for waste management ex-site and management of waste overflow ex-company yard.

Re-configuring the actors responsible for waste collection, the mechanisms of waste collection, and the quantum of waste going to landfill from which location would potentially form the governing variables of the new business model.

5.3 Sustainability Aspects

Two major issues regarding transport employment have emerged from the analysis of the model being followed and simulation of daily transport operations using the transportation model, and subsequent inclusion of backhauls on delivery vehicles. These are: -

- A decrease in the number of vehicles required for the same deliveries through improved loading efficiencies.
- A further increase in the capacity utilisation factor through integration of reverse logistics (waste removal on the same trucks delivering fresh plasterboard to site).

The sustainability benefits of the above are discussed in the following sequence: -

- Improved capacity utilisation of trucks due to a reduction in numbers.

- Further improvement in capacity utilisation due to integration of reverse logistics (waste removal on the same vehicles that are delivering fresh material to site).

- Reduction in the number of km run on a day-to-day basis due to a reduction in the number of trucks as a result of applying the transportation model.

5.3.1 Estimate of Emissions Reduction due to Improved Capacity Utilisation

The capacity utilisation factor governs the per-unit emissions of trucks. In the instant case, an increase in the capacity utilisation (as a result of optimisation in the number of trucks required for delivery) will translate into an overall decreased transport carbon footprint (also having embodied energy connotations from the Life Cycle perspective).

The reduction in emissions due to improved capacity utilisation will be viewed from two perspectives as a reckoning-cum-validation exercise. The first perspective is using the average vehicle GVM capacities from the dataset vis-à-vis an approximation from the payloads in the generalised model. The figures obtained from this calculation will be validated using an experiment-based generalised fuel efficiency plot of transportation modes from literature.

Emissions Reduction due to Improved Capacity Utilisation during Material Delivery

A ballpark estimate of the reduction in emissions from the improved distribution model may be made as follows: -

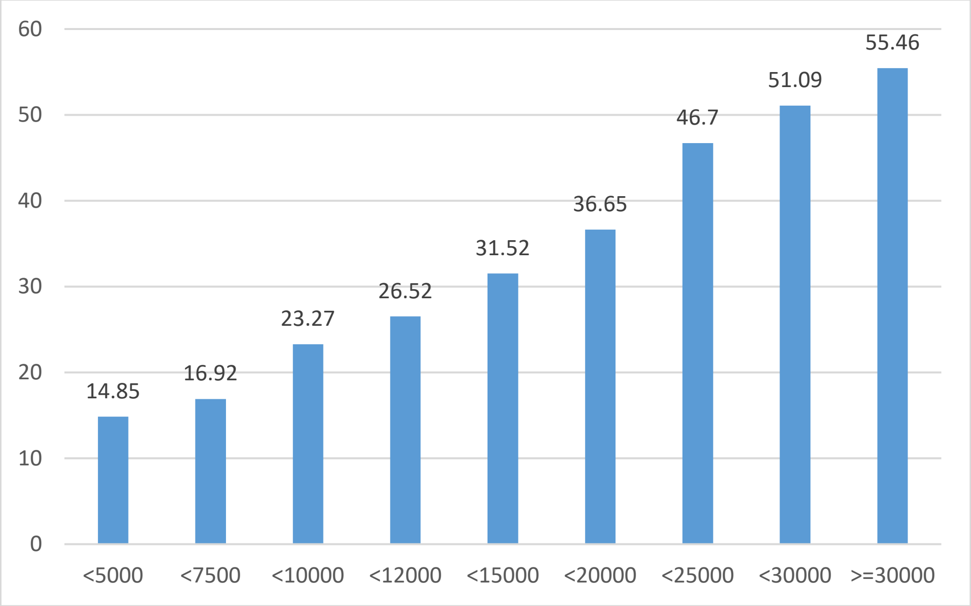
- From the truck specifications in Table 4.2, a Gross Vehicle Mass (GVM) may be attributed to each type of truck.

- Wang *et al*. (2019) have assessed the fuel consumption figures for heavy trucks based on GVM and fuel consumption associated with each GVM category irrespective of the payload, based on the results of a longitudinal study on fuel consumption from January 2015 to August 2018. These figures provide national average fuel efficiencies for various categories of trucks (based on GVM) in New Zealand.

- Figure 5.3 shows these mean fuel consumption figures along with the truck GVMs. A graphical plot illustrates a near-linear increase in fuel consumption vis-à-vis GVM.

Figure 5.3

Plot of truck fuel consumption vs GVM



Note. (Wang *et al.*, 2019)
X-axis – Truck GVM in kg; Y-axis – Fuel consumption in litres per 100 km.

- To arrive at an approximate figure for emissions reduction, we first reduce the complete fleet employed in the current configuration of operations to one representative truck GVM by finding the weighted average of the GVM of each trip.

- From the sampled dataset, this is reckoned to be 21,170 kg (which agrees with a weighted average GVM of 21052 kg from the cleaned dataset).

- This falls in the GVM category of '<25000' in Figure 5.3, demonstrating a fuel consumption of 46.7 litres per 100 km.

- The generalised optimised model works on a weighted average truck capacity of 13.1 tonnes (with approximately 93% loading efficiency from Appendix E). Considering that the trucks employed are flatbed trucks, and most are not equipped with cranes, the GVM for a payload capacity of 13.1 tonnes will be in the neighbourhood of 15000 kg. For purposes of the calculations that follow, the generalised truck is considered in the GVM category '<15000' as per Wang *et al.*'s analysis.

- Multiplying these figures with their respective loading efficiencies shows that they agree (21200 x 0.5636 = 11950; 11950/13000=0.926, about 93% loading efficiency for the generalised model, which is a fair agreement with Appendix E considering rounding off at each step).

- The optimised distribution model provides a reduction of 16 trips per day (Table 4.6), translating to a reduction of truck GVM from 21,170 kg (actual) to 13,105 kg (optimised).
- Considering these two capacities over the generalised roundtrip distance of 52.1 km, we achieve a reduction in diesel consumption of approximately eight litres per trip [(46.7-31.52)/100x52.1], which translates to about 126 litres over 16 (reduced) trips per day).
- An annual reduction of 31,122 litres of diesel consumption results.

Validation of Emissions Reduction due to Improved Capacity Utilisation during Material Delivery

For validating the annual reduction in diesel consumption, an experiment-based indicative plot of fuel efficiencies of various transport modes (Henningson, 2000) is being employed (Figure 5.4).

Figure 5.4

Per unit emissions vs capacity utilisation

Note. (Henningson, 2000; McKinnon, 2007)
X-axis – Capacity utilisation; Y-axis – Per unit emissions

The plot shows the approximate consumption of fuel in tonnes per kilo-tonne of load (y-axis) for various capacity utilisation factors (x-axis) when transported over a distance of 3,218 km by various transportation modes.

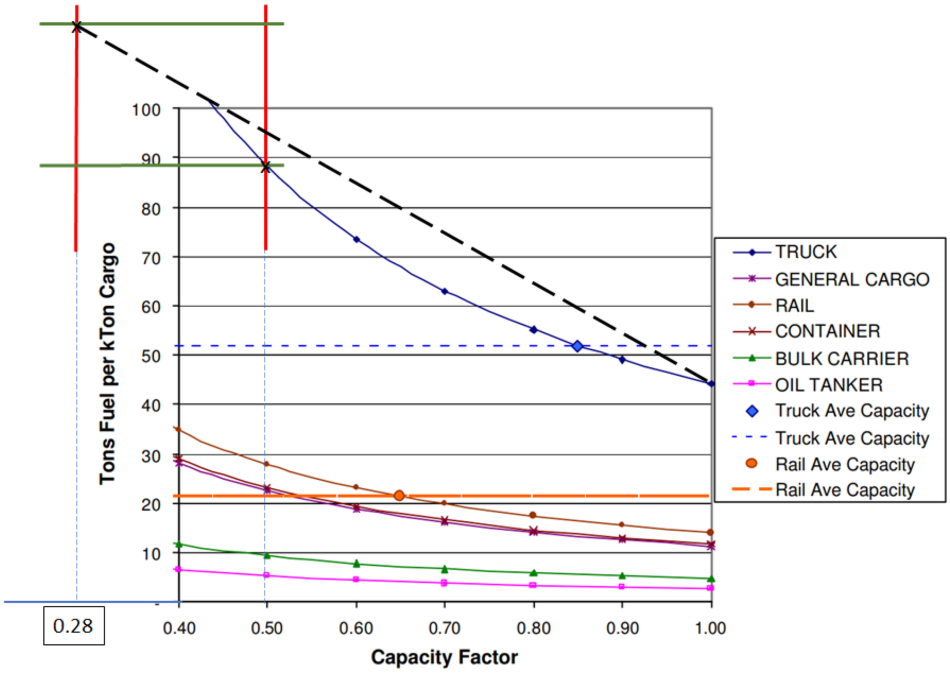
This reduction in fuel consumption may be validated by superimposing the improved capacity utilisation (from 27.61% to 49.38%) as a result of implementing the transportation model on Figure 5.4. This is illustrated in Figure 5.5. The following analysis results: -

- The assumption made for plotting the fuel consumption corresponding to 27.61% capacity utilisation is that the fuel efficiency curve for trucks follows a linear path rather than an exponential path in this region of the plot, for ease of plotting, and reasonability of the assumption (since the exponentially increasing fuel consumption tends towards being asymptotic to the y-axis at this capacity utilisation).

- The red lines have been used for marking capacity utilisation less than 40% (linear assumption instead of exponential, to take a conservative estimate) and marking the increased capacity utilisation of approximately 49+%).

Figure 5.5

Superimposition of improved capacity utilisation as a result of applying the transportation model on the generalised fuel efficiency plot



Note. (Based on Henningson, 2000)

- The green lines mark the vertical intercept between the intersection of the red lines with the truck performance curve.

- The intercept between the green lines is converts to a figure of about 0.0074 kg/tonne-km (0.0082 litres/tonne-km) of reduction in diesel consumption [(113,000 – 88,000)/(3218 x 1000) kg/tonne-km]. For a vehicle carrying 13,105 kg of load (the generalised truck), it converts to 0.1077 litres of diesel per km.

- For a generalised trip of 52.1 km, this equals 5.6 litres of diesel, making it 145 litres of diesel per day for 26 trucks (since 26 trucks deliver material daily).

- An annual reduction in annual diesel consumption of 35,815 litres results.

- The validation is considered fairly accurate considering the general nature of the plot used for calculations, and the rounding off at various stages of calculation, and the assumption of linear variation as a plotting approximation beyond the region of the plot.

- From the emissions guide issued by the Ministry for the Environment (MfE, 2022a), the CO2-e per litre of diesel is approximately 2.69 kg.

- Annually, emissions are likely to be reduced by approximately 90,000 kg CO2-e using the optimised transportation model, considering average of fuel consumption reduction figures determined from the two analyses.

5.3.2 Estimate of Emissions Reduction due to Improved Capacity Utilisation through Integration of Reverse Logistics (Waste Removal)

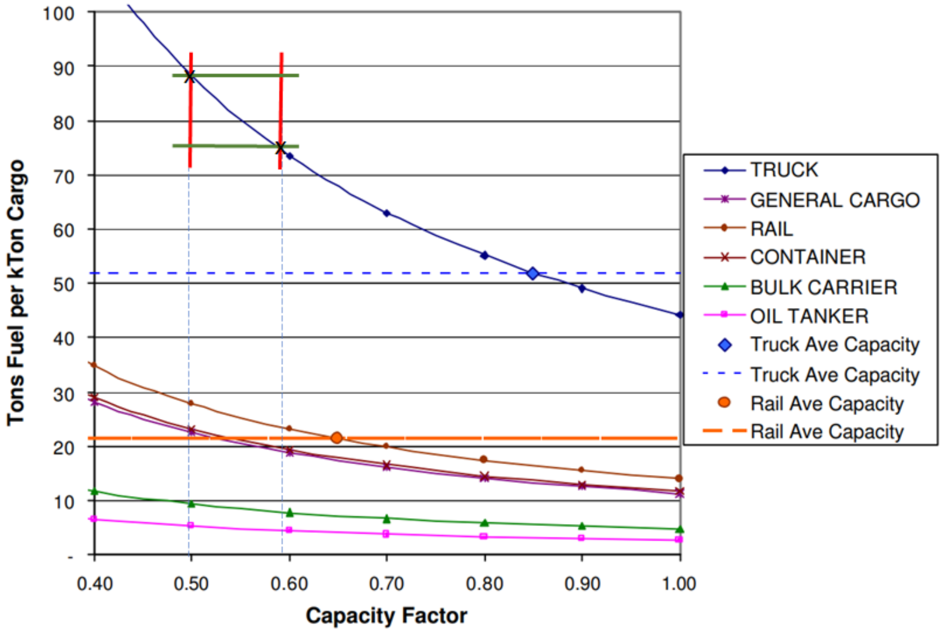
Henningson’s (2000) plot is again utilised for reckoning the decreased fuel consumption due to improved capacity utilisation as a result of including waste removal on the material delivery trips. The analysis is as follows: -

- The red lines have been used for marking capacity utilisation of approximately 49+% and approximately 59% (Figure 5.6).

- The green lines mark the vertical intercept between the intersection of the red lines with the truck performance curve. The original curve has been used in this case since the analysis is within the plot area provided in the literature.

Figure 5.6

Superimposition of improved capacity utilisation due to waste removal on the generalised fuel efficiency plot



Note. (Based on Henningson, 2000)

- The intercept between the green lines is converts to a figure of about 0.004 kg/tonne-km (0.0044 litres/tonne-km) of reduction in diesel consumption [(88,000-75000)/(3218 x 1000) kg/tonne-km]

- For a vehicle carrying 13,105 kg of load (the generalised truck), it converts to 0.06 litres of diesel per km, converting to 3 litres of diesel over 52.1 km (trip length), making it 80 litres of diesel per day for 26 trucks. A reduction of 19,674 litres of diesel consumption results annually, equalling approximately 52,923 kg CO2-e (MfE, 2022a) reduction in emissions annually.

A total annual reduction of approximately 53,000 litres in diesel consumption translating to 142,953 kg CO2-e emissions reduction from improved capacity utilisation of trucks results.

5.3.3 Monetisation of Sustainability Impacts

Viewing transport optimisation from the reduction in the number of truck trips (16 per day), it translates to a reduction of daily km travelled by approximately 833.6 km (This figure agrees with the emissions calculations above as follows: 833.6 km reduced between the actual GVM ('<25000') and the generalised truck GVM of 13,105 kg

('<15000') translates to (46.7-31.52)/100x833.6=126 litres of reduced fuel consumption per day). 833.6 km per day translates to approximately **206,000 km annually**. Table 5.3 shows the monetised externalities of freight transport costs per km in New Zealand.

Table 5.3

Approximate monetised costs of transport externalities in NZ

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

Note. (Briggs *et al.,* 2015; Climate Change Commission, 2021; Ernst & Young, 2021; MfE, 2021b; MoT, n.d.a, b, 2020b, c, 2022; New Zealand Transport Agency [NZTA], 2021a, b; Statistics New Zealand, 2019, 2021)

- @ NZ$1.736 per km, the monetised benefits of 206,000 km annually work out to approximately NZ$360,000. These may not be direct revenue generation; however, they are tangible monetary benefits based on financial/economic models. Further, @ NZ$108.9 average central shadow carbon price per tonne (2022-2035), the reduction in emissions translates to NZ$15,500 annually. The monetised impact, therefore, is NZ$375,000 per annum.

5.4 Fleet Management Connotations

From the inferences on loading efficiencies and capacity utilisation of trucks, certain aspects of long-term fleet management emerge *viz*: -

- Fleet configuration needs to be standardised to the trucks demonstrating maximum loading efficiencies so that fleet configuration-based optimisation is introduced into transport operations. This aspect also points to the phased discard of trucks to rejuvenate the fleet.

- Trucks that do not exhibit consistent loading patterns and lie at either end of the normal probability distribution functions should be the ones to be discarded earliest (Bentley & Hodge, 2020).

- From the loading pattern in Figure 4.9, models Hino GH, Hino FY3248, Hino CXH, Isuzu NQR500, and Isuzu Elf show an irregular loading pattern. Other than Elf and NQR500, the other models have high payload capacities (>13000 kg).

- The irregular loading pattern of Elf may be attributed to its low payload capacity (<2000 kg); hence it is being used for shorter trips and loads which are overflow from regular truck loading, despite the relatively large number of trips.

- The NQR500 model, on the other hand, has a very low number of trips, which has most likely skewed the statistics.

- Despite having high payload capacities, the other three models exhibit low utilisation in terms of the number of trips attributable to each. This is because these trucks also have high-reach cranes, which lead to them being used as cranes rather than load carriers.

- In addition, the number of these trucks in the fleet is very low; hence, the number of trips is not aggregated, as with other models.

- The recommendation for fleet configuration is standardisation to achieve a uniform loading pattern, as well as fleet to be comprised of all trucks with cranes so that selective employability is done away with. Those trucks with comparatively low payload capacities should be discarded first (whenever fleet rejuvenation is planned), followed by those with irregular loading patterns.

- Further, considering the government strategy for emissions reduction and the ‘First Emissions Reduction Plan’ issue, a technology transition plan for the fleet may be considered. As understood, the company has converted material handling equipment to Liquified Petroleum Gas (LPG) (Liviu *et al.*, 2018).

- Based on government encouragement, the fleet may convert fully to electric/hydrogen/biofuels in the ultimate analysis. However, hydrogen and biofuels currently have implementation challenges in NZ, notable being understanding the life cycle costs (LCC) of GHG emissions; externalities of commercial production and utilisation; costs of infrastructure, storage, transportation, and distribution; economics of vehicle modification and operation; public perception; and, technology absorption (MoT, 2019).

- Electric vehicles suffer from supply and demand challenges, especially in the freight sector. The current supply challenges are a small, therefore, a low priority market for manufacturers, non-availability of new and used vehicles in specific categories, battery costs, and an unlikely displacement of the EV sector by alternative technologies in major consumption regions of the world, hence, their constrained supply continuing to the small NZ market (Denne, 2021).

- The demand issues around electric vehicle uptake are higher purchase prices, non-consideration of the total cost of ownership (TCO) by all procuring segments, range anxiety, depreciation rates of EVs, and end-of-life management of EV batteries.

- These current issues are likely to impact the development of the EV market in NZ till about 2030 (Metcalfe *et al.*, 2015; Denne, 2021). Fleet conversion to Liquefied

Petroleum Gas (LPG) may be considered in the interim (The emission factor of LPG is 1.64 kg CO2-eq/litre as compared to 2.69 – 2.79/litre for diesel) (MfE, 2022a).

- A progressive or phased approach to fleet conversion is likely reap rich sustainability dividends for the company.

5.5 Ways of Doing Business

As a result of disaggregated planning and no sustainability perspective on transport operations, it has been demonstrated that there exists a substantial potential for improving the efficiency of operations and, therefore, improved sustainability. In addition to adding to the brand image and company reputation, sustainable operations reduce the carbon footprint of operations and the embodiment of resources, thereby optimising the life cycle costs of built assets.

Changing how business is done will improve sustainability, in addition to the company being seen as having improved sustainability as one of its Key Result Areas. Changes in ways of business, from the analysis undertaken in this study, pertain to the following facets: -

- **Non-price attributes in tendering and contracting** As has been seen from the analysis of data pertaining to truck loading, the ‘ab-initio’ loading efficiency is hovering around 56%, yet the financial model implemented leaves both the manufacturer as well as the transport contractor satisfied. The manufacturer is happy that the required tonnages are lifted, and the transport contractor earns his profits/margins with a ‘per tonne’ payment model.

- Therefore, the overall efficiency of the transport function, which has been integrated with manufacturing as a conscious decision, does not form a focus area for either.

- However, the sustainability imperative demands that the future commercial model give due consideration to non-price attributes (NPAs) as part of the tendering and tender-evaluation process (Auckland Transport, 2015; Miklautsch & Woschank, 2022; Kohli & Karun, 2023). NPAs here mean that demonstrated sustainable transport practices such as efficiency of operations, loading factors, capacity utilisation of trucks, clean technology, etc., need to be a part of the tendering and tender evaluation process.

- A suitably weighted matrix consisting of costing parameters as well as non-price attributes, based on the sustainability perspective of the company, needs to form part of the tender evaluation process.

- Overall highest sustainability indices, appropriately balanced with financial considerations, should be the guiding factor for awarding contracts.

- Appropriate checks and balances for continual benchmarking of transport operations need to be a part of the contract monitoring process.

- **Integrated planning** An effective integrated business process consists of a business-backed design, high-quality process management, including inputs and outputs, accountability and performance management, the effective use of data, analytics, and technology, and specialized organisational roles and capabilities.

- In the current configuration of transport operations, these attributes need to be introduced as performance imperatives. Currently, the planning process is entirely fragmented with no participation from the manufacturer, leading to high inefficiencies in the system.

- To achieve integrated planning of transport operations, the following are recommended: -

    - Sustainability statement of the company.
    - Design of transport operations around this sustainability statement to include planning tools (ICT-based means of improving operational philosophy and implementation), resources (sustainable transport technology and operations), and performance parameters (design of suitable performance indices).
    - Managing the transport process through planning, monitoring, and control. Processes and performance indicators need to be put in place to achieve this.

  - Accountability to be built-in within the organisation for those managing logistics/transport and on the service providers to achieve optimal performance benchmarks forming part of the contracting arrangements.
  - Putting in place a mechanism for data collection and evaluating performance indicators based on day-to-day operations.

- The potential for enhancing sustainability through the adoption of 'different ways of doing business' *viz* integrated planning (demonstrated through the use of planning tools – transportation model) and consideration of NPAs in the future commercial structure of business re-define how to compete in a sustainability-driven environment.

- **Shifting more deliveries to the DTS model** The DTS model has inherent efficiency as compared to the BM delivery model in terms of reducing physical movement, making the transport function more efficient, reducing 'inventory in transit' (between the manufacturer and the customer), hence optimising inventory carrying costs, reducing the potential for damage, and making the overall system more responsive and leaner.

- It also provides direct forecasting inputs to the manufacturer enabling a more agile product mix based on market demand.

- The system has also demonstrated the 'unshackling' of developers/contractors from their 'home' zone, making the whole gamut of urban development in Auckland more competitive across a level playing field without bias of zone/region.

- The complete SC structure has been redefined without impacting business adversely.

- The company also takes pride in its delivery efficiency and robustness by delivering 'in the room' and not 'on-site', as well as making up for any damages that might occur in transit or during handling on-site.

- Overall, the model pitches customer satisfaction at the level of customer delight.

- Auckland sees approximately 75% of its plasterboard supply under the DTS delivery model. However, the overall deliveries of plasterboard in NZ under the DTS model are approximately 40%.

- This implies substantial potential to shift supply to the DTS model in regions other than Auckland while incrementally increasing this quantum in Auckland.

- **Financial model** Currently, a 'per tonne' model has been adopted, which appears to be working fine. However, based on the discussion, it is understood that no other financial model for transport services has been considered. The 'norm' in the freight industry is 'per km' payments, though 'per truck' payment models also exist (as are implemented for certain regions outside Auckland by the company).

- The 'per tonne' model does not consider the kilometres travelled for delivery of those tonnes, therefore, does not consider operational efficiency. However, the 'per km' model tends to get minimised with maximised efficiencies, hence is a sustainable model.

- A decision-making tool for selecting between the 'per km' or a 'per tonne' model needs to be available to finalise contracts at the beginning of each year or modify contracts periodically.

- The two basic parameters available as far as deliveries are concerned are the average aggregate km travelled daily and the average aggregate tonnages delivered daily.

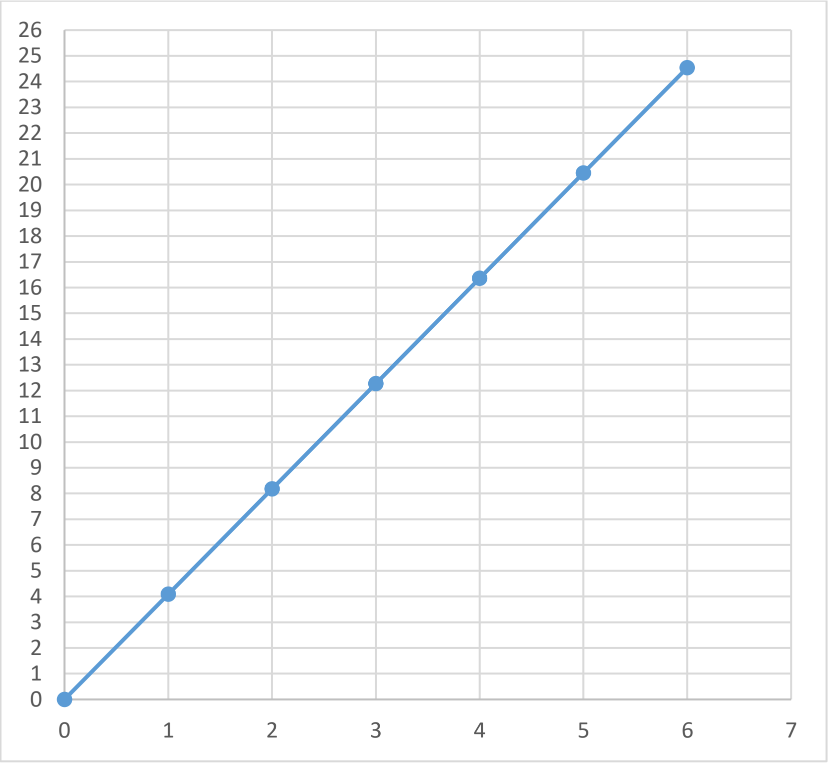
- Considering the generalised optimised model, in terms of km, about 26 trips of a generalised length of 52.011 km are made daily. This translates to approximately 1,352 km travelled every day. Regarding tonnages delivered, 26 trips with an initial load of 12.7 tonnes are undertaken daily, implying approximately 330 despatched (chargeable) tonnes.

- The ratio between the daily km and the daily tonnages is 4.09. E.g., if NZ$1/km is charged, the daily cost would be about NZ$1,352. At 330 tonnes of deliveries within this cost, the rate per tonne works out to NZ$4.09/tonne.

- Therefore, NZ$1/km balances NZ$/tonne for 1,352 km or 330 tonnes daily. This implies that in terms of NZ$/km, any per tonne cost less than NZ$4.09/tonne is beneficial within the daily delivery parameters. As in Figure 5.10, a graphical solution may be developed from this short analysis.

Figure 5.7

Graphical solution for payment model selection ('per km' vs 'per tonne')



Note. X-axis - NZ$/km; Y-axis - NZ$/Tonne
Slope = Daily Average Km/Daily Average Tonnage (in this case 1352/330=4.09)

- The graph can take either axis as the datum and fix a value on it. Any value on the other axis less than the value of the corresponding intercept is more economical in terms of the other axis unit compared to the datum value in its units. E.g., NZ$1/km on the x-axis corresponds to an intercept of 4.09 on the y-axis. Hence if a choice is made between NZ$/km and NZ$/Tonne for an offer of NZ$1/km, any value just less than NZ$4.09/Tonne will be more economical. Similarly, if NZ$5/tonne is selected on the y-axis, the corresponding intercept on the x-axis is NZ$1.22/km. Therefore, any cost of transportation up to a value of just less than NZ$1.22/km will be more economical than NZ$5/tonne.

- The graph can be revised periodically (based on the periodicity of the transport contract) after considering the average daily km and the average daily tonnages during the period. The parameter values in the graph would be based on the achieved parameters during the period under review.

- Optimised model values have been considered only as an illustration. The graph, therefore, provides the best value for money within the efficiencies achieved, whatever these may be.

5.6 Impacts of Sustainability Outcomes on Quality of Life

Quality of Life can be understood as a complex and multi-dimensional construct, representing the degree to which individuals' essential values and needs are met.

It encompasses well-being and can be viewed as either the objective circumstances in which a person lives, their subjective perception and lived experience, or a combination of both. (Steg & Gifford, 2005). E.g., vehicle emissions are objective indicators of quality of life, while the extent to which individuals are concerned with these emissions are subjective indicators of quality of life (Steg & de Groot, 2008).

Although quality of life can be a subjective concept to everyone, there are certain common aspects to most of the population, such as health, social relations, social justice, freedom, security, education, privacy, environmental quality, work, comfort, remuneration, physical beauty, and leisure (Steg & Groot, 2008). The importance given to each factor varies with the individual characteristics and is, in turn, affected by several factors.

Many aspects need to be considered in the quality of life *viz* health, friends and family, social justice, freedom, security, education, identity, privacy, environmental quality, social relations, work, biodiversity, leisure time, money, comfort, beauty, external challenges, status, religion/spirituality and material goods. However, the importance given to each of these aspects during assessment can be more or less significant (Aguiar, & Macário, 2017).

A variety of negative social, environmental, and economic impacts of urban freight transport exist, and require mitigation to achieve an improvement in the Quality of Life (Browne *et al.*, 2012). Figure 5.8 illustrates the features of UFT and their negative impacts, in the context of quality of life pertaining to this study.

Figure 5.8

Features and negative impacts of UFT operations

Note. (Browne *et al.*, 2005)

Based on the above concept of quality of life and the negative impacts of UFT, Table 5.4 brings out the implications of sustainability outcomes of the study on quality of life.

Table 5.4

Quality of life impacts of sustainability outcomes

Research Outcome/Inference	Quality of Life Implication (s)
Reduction in transport requirement	Reduced noise, pollution, and accidents; Enhanced health and safety of citizens; Improved liveability of the city; Impact on visual blight; Improved travel times; Reduction in transport-related deaths and injuries
Reduction in distances travelled by trucks	Reduced pollution; Improved health of residents; Reduced ecological damage; Impact on visual blight
Improved capacity utilisation of transport	Reduced pollution; Improved health outcomes; Reduced damage to infrastructure; Reduced severity of accidents; Reduction in transport-related deaths and injuries
Reduced inventory in transit	Improved land-use planning; Reduced inventory holding costs; Reduced construction costs
Increased market competitiveness	Reduced costs of construction; Improved quality of construction
Inclusion of NPAs in tendering/contracting	Reduction in emissions, pollution, number of trucks; Enhanced health and safety of citizens; Improved liveability of the city; Impact on visual blight
Integration of forward and reverse logistics	Reduced waste burden; Reduced costs of construction; Reduced noise, pollution, and accidents; Enhanced health and safety of citizens; Improved liveability of the city; Impact on visual blight; Reduced congestion

Fleet management	Reduced emissions and pollution; Enhanced health outcomes; Improved liveability; Reduced visual blight

5.7 Challenges in Implementation of Recommendations

5.7.1 General Challenges in Implementation

The general challenges in implementation of the recommendations revolve around improved loading of vehicles to reduce the per unit costs and per unit emissions.

Broadly, these are as follows: -

- Data availability for problem analysis and solution synthesis (almost quarter of the dataset lost in the current exercise).
- Changing the BAU mindset.
- Service delivery is a part of aggregate costing in the construction industry.
- The distinct difference between construction logistics (onus on the construction industry) and city logistics (onus on city planners and managers) restricts generalised implementation of outcomes.
- Measures for behavioural change need gradual and firm introduction for commercial importance and competitive advantage.
- NPAs need to be mandatory in public procurement as a trendsetter.
- Load consolidation arrangements.
- Congestion pricing trough technology implementation.
- Public intervention in procurement of transport resources and their sustenance.
- Technology maturing challenges (electric freight, hydrogen vehicles).
- Waste management policy implementation.

5.7.2 Fleet Configuration and Composition

New Zealand is geographically isolated from the world markets that supply vehicles, and the vehicle market (including freight vehicles) is substantially a second-hand vehicle market.

Changing the fleet composition, therefore, is a long-term solution. Discard and replacement need to be deliberately thought out and planned.

The transport contractor may not have any motivation or incentive to undertake the exercise because their business model is working fine, considering that someone is paying for the inefficiencies of the system (Shakantu *et al*., 2003).

Considering the financial implications of upgrading fleet composition, the company may need to work out an incentive model, as well as financial support to the transport contractor to change the fleet composition (vehicle models) as well as fleet configuration (every vehicle having a crane) over time.

Similarly, a transition plan for converting the fleet from diesel to electric needs deliberation. Interim possibilities (LPG, CNG) need to be explored and assessed for implementation. Again, an incentive and financial support scheme may need to be worked out between the company and the transport contractor.

Freight transport ownership models may also be examined by the company. In New Zealand, both extremes of transport ownership models exist in the construction industry – fully company owned (Fulton Hogan) and fully outsourced (Fletchers).

5.7.3 Integrated Planning

As brought out earlier in the thesis, there is no existing incentive for either the company or the transport contractor to improve transport operations, since the cost of transportation is getting included in the cost of the material, a typical characteristic of construction material pricing (Shakantu *et al.*, 2003).

The company has a sustainability statement and has identified carbon hotspots in its supply chain, of which transport is one (Thinkstep ANZ, n.d.).

However, the consideration of transport is only pertaining to waste component of the plasterboard transported to site. The solution being thought of is ‘pre-cut’ plasterboard according to the needs of the consumer (Thinkstep ANZ, n.d.).

The loading of vehicles and integration of reverse flow of plasterboard waste from site is not within the consideration focus currently. Creating a compulsion for improving the efficiency of transportation, changing the manufacturer’s operational model to include a part of the planning function, and a suitably skilled team for undertaking delivery planning are the current challenges.

Including plasterboard waste as a raw material for new plasterboard is currently constrained by: -

- The extent to which plasterboard waste can be utilised as raw material (percentage) without the new product losing its quality parameters.
- Establishing a reverse logistics model within the company’s SC as opposed to third party waste management as is being done currently.
- The requirement of plasterboard waste to be dry for utilisation as a raw material.
- The availability of a consolidation facility for optimising loads for transportation to the manufacturing plant, which is likely to shift outside of Auckland.

5.7.4 Shifting More Material Delivery to the DTS Model

Approximately 75% plasterboard in Auckland was being supplied on a DTS basis during the period to which the operational dataset pertains. Subsequently (during the external validation of the findings), it was revealed that currently 80% plasterboard requirement in Auckland is being supplied using the DTS model.

The scope of any further increase in Auckland is considered marginal, and is, therefore, a challenge for the overall distribution philosophy of the company. The possibility of increasing DTS deliveries in regions neighbouring Auckland (e.g., Waikato) is possible.

However, the uptake vis-à-vis the quantum of transportation will need to be considered. Similar issues presently are challenges in Wellington and Christchurch, which need detailed operational analysis for implementation.

5.7.5 Non-price Attributes in Tendering and Pricing Mechanisms

The current state of freight transport fleet in New Zealand is highly fragmented. The road freight industry consists of 4,700 firms. Most operators in the industry are small family-owned businesses, with over 75% operating five trucks or less (Clark, 2021). In this scenario, inclusion of NPAs in the tendering process as a selection criterion may lead to a market shock, if implemented suddenly.

The challenge exists in first attempting to formulate the NPAs, then working with the transport contractor to improve efficiency of operations gradually to align with these

NPAs, and then convert these into substantive tender evaluation and contract awarding criteria.

The complete process, it is anticipated, will lead to higher downstream (forward) vertical integration of not only the distribution function, but also the operating methodologies. Once benchmark performance has been achieved, data-driven pricing mechanisms for best sustainability outcomes may be implemented.

The challenges here are availability of data and tools for data analysis to be undertaken annually for tender evaluation. The graphical tool (Figure 5.7) may be used as an elementary tool.

5.8 A Distributed DTS System

5.8.1 Distributed Delivery Models

In the current configuration of the manufacturing plant and the warehouses for distribution, DTS delivery takes place directly from the warehouse to the construction sites. Two different patterns emerge based on the zoning of Auckland into five zones *viz* Central, North, South, East, and West.

The uptake pattern of merchants differs from that of construction sites within the same zone.

Though zones have been demarcated hypothetically, the different uptake patterns demonstrate levelling the urban development playing field for contractors/developers across the Auckland region, being set free of physical locations.

The centre of gravity, as far as plasterboard consumption is concerned, now sees a shift to the actual physical consumption in the zone without being impacted by the location of the invoicing merchant. In effect, the DTS model has encouraged cross-zonal invoicing, so to speak.

In a scenario where the manufacturing plant and the warehouse shift outside Auckland for compulsions outside the scope of this work, there may be two possibilities for the SC configuration.

- In the first instance, a central warehouse in or around the current location of the company's existing warehouses may be set up. From there, the distribution operations (both DTS and to the merchants) could continue as at present (Model I).

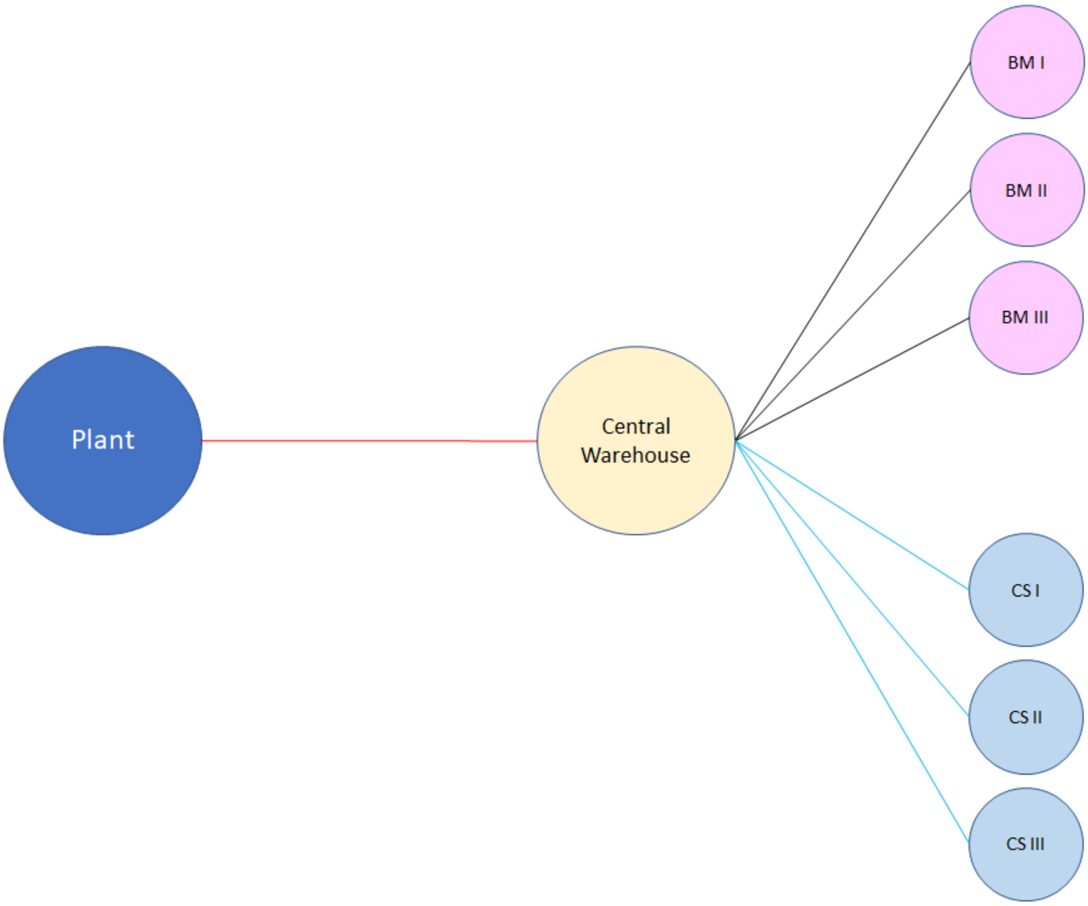
- If setting up a central warehouse as in Model-I is not feasible, the distribution function is likely to become distributed, with 'zonal' warehouses for undertaking DTS as well as merchant delivery within the zones.

- This model creates mini-warehouses that currently perform the same function as the central warehouses, supplied directly from the plant outside Auckland (Model-II).

Figure 5.9 illustrates Model I and Figure 5.10 illustrates Model II.

Figure 5.9

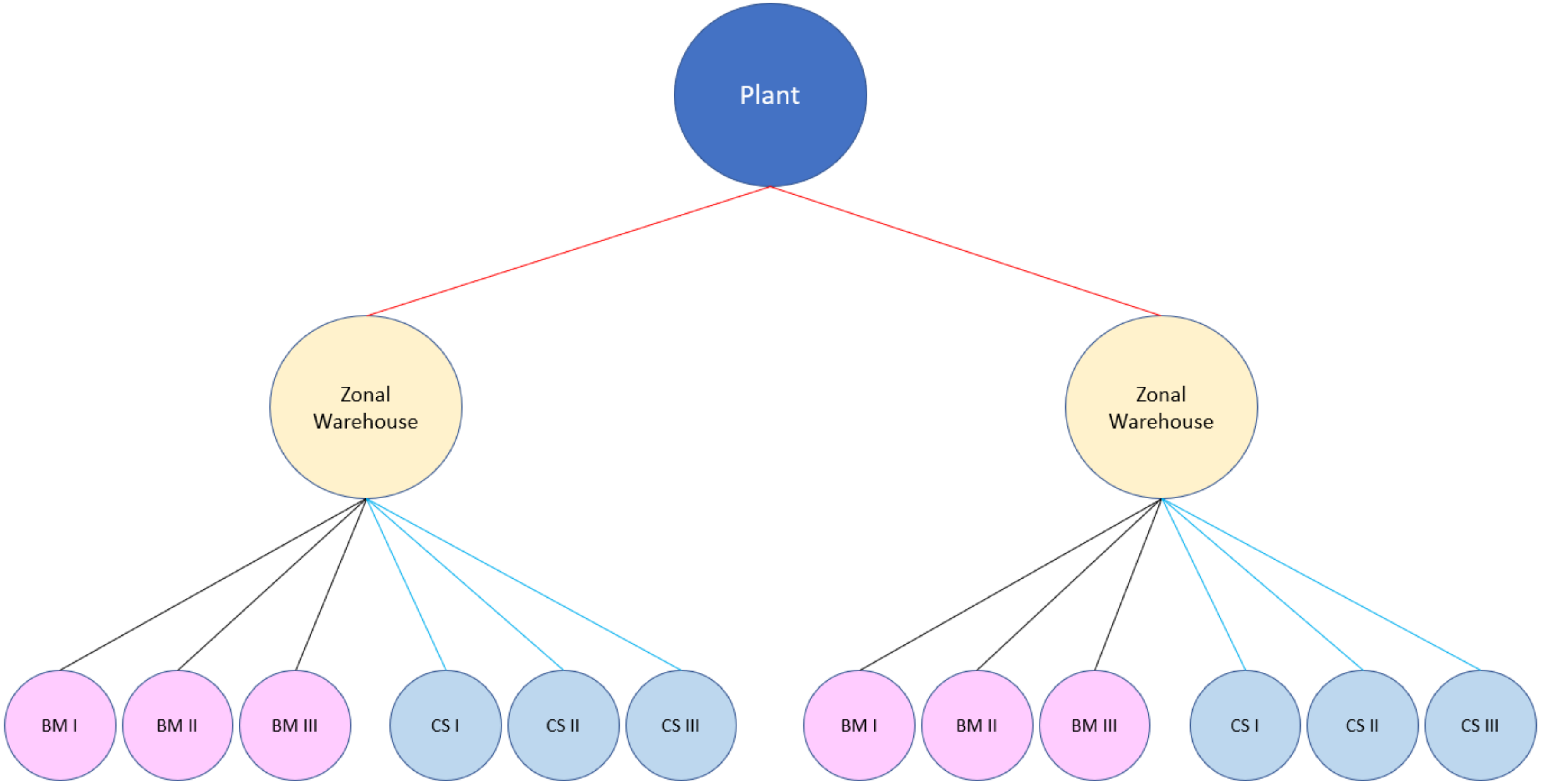
Model I – Distribution ex-central warehouse at the existing location



Note. Model-I illustrates the set-up of a central warehouse in the same location as the present warehouse or some other location, depending on the availability of land and consents. The distribution ex-central warehouse is on the same model as currently, i.e., 75% DTS and 25% to merchants. Quantities would be aggregated over Auckland.

Figure 5.10

Zonal distribution model (Model-II)



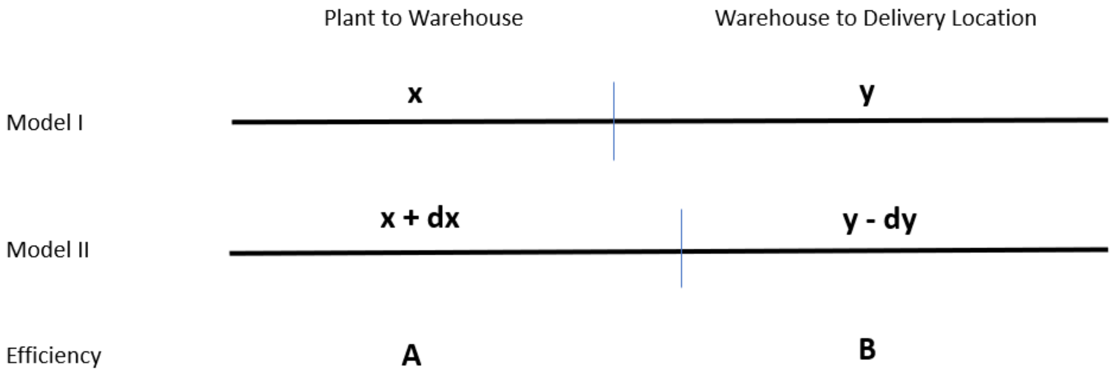
Note. Model-II illustrates the set-up of zonal distribution arrangements at various locations (North, South, East, West, Centre) in Auckland.
Each of these facilities may be integrated with an existing BM or be an independent entity, depending upon the business model and warehousing strategy adopted.
BM – Builders' Merchant, CS – Construction Site

From a comparison of the two systems, it emerges logically that Model I entails adding the costs of transporting manufactured material from the plant outside Auckland to the overall distribution costs (as they exist in the current distribution configuration). This transportation is potentially highly efficient since deliveries will likely be fully consolidated. Distribution to merchants has not been analysed as part of this study. However, for the sake of building a comparison with Model-II, it is assumed that the operational efficiencies are the same as that for the DTS system, as also the financial model for transportation is the same, i.e., 'per tonne'. Model I, therefore, adds the 'long-haul' transportation costs to the distribution costs of the existing system.

In the case of Model II, an elementary examination reveals that deliveries from the plant are taking place to warehouses within the distribution zone. These 'zonal' warehouses are further 'ahead' (towards the final delivery locations) as compared to the centralised warehouse in Model-I. The consolidated delivery to these 'zonal' warehouses, therefore, implies higher transportation efficiency for a longer segment of the delivery route to the final delivery location (be it the construction site or the BM) compared to Model I. Furthermore, since these 'zonal' warehouses are located closer to the delivery locations, the inefficiency of the delivery process now exists in a shorter transportation segment.

Figure 5.11

Comparison of transportation efficiencies of Model-I and Model-II



Note. A>B

Further, to minimise the aggregated distances travelled for deliveries from the 'zonal' warehouses; ideally, the warehouse needs to be located at a 'centroidal' location within the zone. Since the uptake of delivery of various sites is not the same, the centroidal location will need to consider the tonnages as well as the distances. The tonnages will provide weight to distance to the sites, and the centroidal location will tend to shift towards locations with a higher product of uptake and the distance from the warehouse.

5.8.2 Zonal Warehouses in Auckland

To undertake an analysis of the potential location (centroidal) (Trent & Joubert, 2022) of warehouses in the Auckland region, the following were done: -

- Dividing Auckland into five hypothetical zones *viz* Centre (C), North (N), South (S), West (W), and East (E).
- Each zone has delivery areas, which have been obtained from the clean dataset.
- Each delivery area has an uptake in terms of tonnages available from the dataset.
- An arbitrary location was selected as the reference location within each distribution zone *viz* C – Auckland CBD, N – Albany, S – Takanini, W – Onehunga, and E – East Tamaki.
- For all delivery areas located within a zone, the distance and the bearing from the reference point were obtained using Google Maps (Measure Distance and Protractor).
- The bearing from the reference point was used to convert the distance into a horizontal and vertical component (with signs of the components based on the four trigonometrical quadrants, taking the top left as Quadrant I and bottom left as Quadrant IV, moving clockwise from 0 to 2Π).
- Each component distance was then weighted by multiplying it with the uptake tonnage. Appendix F shows the tabulated data for all five zones.
- The sum of the products of the weighted components was then converted to a per-unit value by dividing it by the sum of the tonnages.
- The resultant horizontal and vertical components indicated the centroidal position based on distances as well as uptake tonnages in terms of the displacement (correction) from the chosen reference point within the zone in terms of distances and bearings. These distances, along with the bearings, were plotted on the map with reference to the zonal reference point.

Table 5.5 shows the results (centroidal location in terms of distance components and the distance and the bearing from the chosen reference point within the zone).

Table 5.5

Centroidal locations in delivery zones in terms of shift (correction) from the chosen reference

Zone	Reference Point	Shift Horizontal Component (km)	Shift Vertical Component (km)	Shift Distance (km)	Shift Bearing (Degrees)	Direction
C	Auckland CBD	0.377	-2.1009	2.13	-79.83	SW
E	East Tamaki	-0.9598	4.5183	4.62	101.99	NE
N	Albany	1.9642	1.5887	2.53	38.97	NW
S	Takanini	2.178	-2.7797	3.53	-51.92	SW
W	Onehunga	7.3591	2.6345	7.82	19.70	NW

Figure 5.12

Centroidal warehouse location for Centre zone (with reference to Auckland CBD)

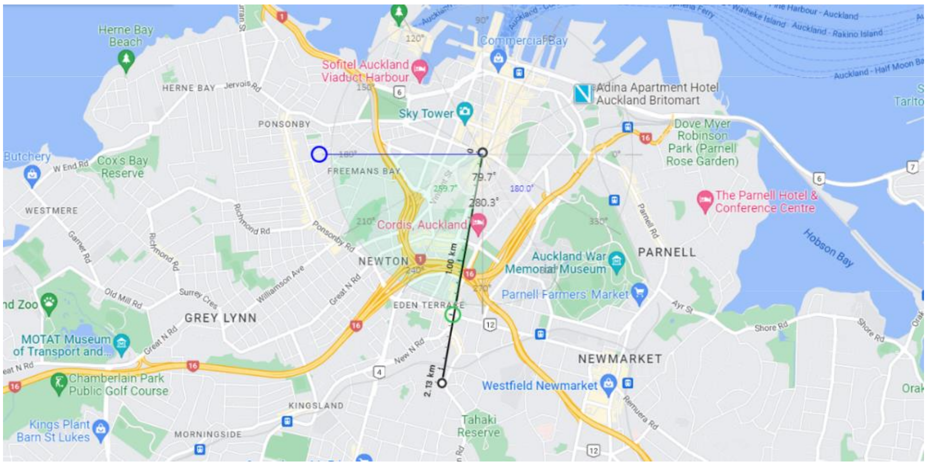


Figure 5.13

Centroidal warehouse location for East zone (with reference to East Tamaki, Auckland)

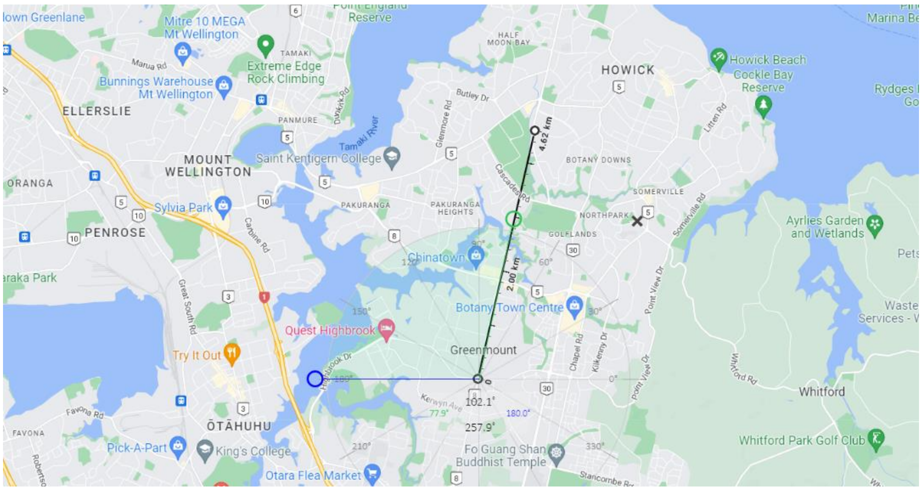


Figure 5.14

Centroidal warehouse location for North zone (with reference to Albany, Auckland)

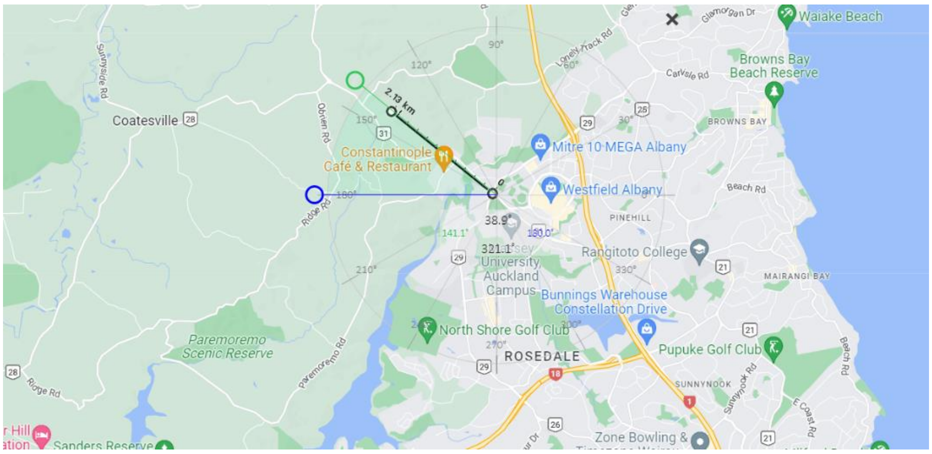


Figure 5.15

Centroidal warehouse location for South zone (with reference to Takanini, Auckland)

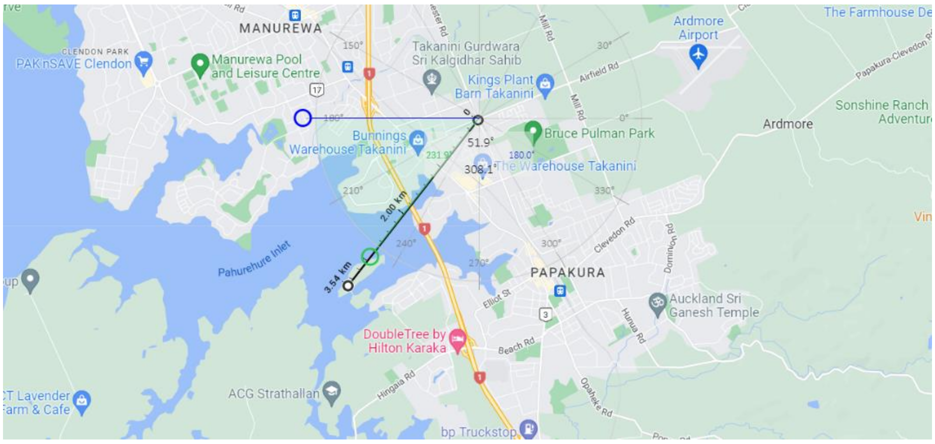
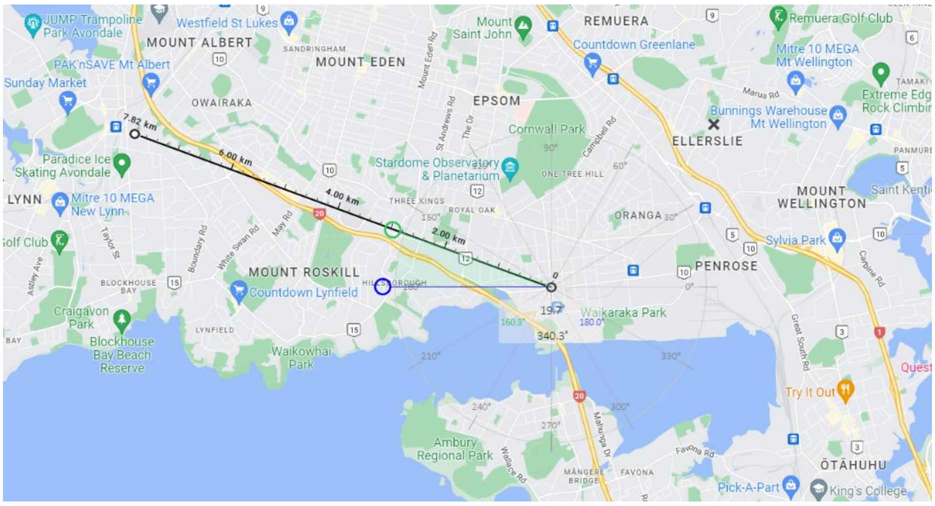


Figure 5.16

Centroidal warehouse location for West zone (with reference to Onehunga, Auckland)



The above analysis (Table 5.5 and Figure 5.12 to Figure 5.16) shows that except for Onehunga and East Tamaki, the other reference points are a fair indicator of the potential zonal warehouse locations. However, at times, the points indicated by the analysis may appear absurd (e.g., being inside a water body) because the distances used for analysis are 'as the crow flies'. Further, the attribution of areas to zones may be geographically skewed (e.g., the centre zone starts from Auckland CBD and extends to Penrose, while Onehunga, which is adjacent to Penrose, is categorised in the west zone). Also, the geographical lay of the land at times may have intervening non-urban/reserve zones (e.g., the south zone is fairly constricted up to Takanini but expands out south of Takanini with Pahurehure Entrance as the intervening water body).

The material uptake has also influenced the locations in various areas of the zone (from historical data used for analysis). It, therefore, aligns with the development pattern within the zones. In the final analysis, the recommended zonal warehouse locations are as follows: -

- **Centre zone** In the area of Newmarket. However, it may be considered at Grey Lynn considering intensive urbanisation in the Newmarket area.
- **East zone** In the area of Highland Park in the Howick peninsula. Since it is indicative, locations like Botany Downs or Pakuranga may also be considered.
- **North zone** Albany may continue to be the preferred warehouse location, being well connected and a large business centre for Northshore.
- **South zone** The analysis shows the requirement of a small southward shift for the warehouse from Takanini, owing to the development in Karaka, Bombay, Drury, Pukekohe etc.
- However, considering Takanini is a large business centre, and its connectivity is better than Papakura (especially in terms of motorway connectivity), it may continue to be the preferred warehouse location.
- **West zone** The analysis shows the requirement of a shift of the zonal warehouse from Onehunga towards New Lynn. This may be a feasible solution, also merging the warehouse for the centre zone recommended at Grey Lynn.

Alternately, a warehouse at Onehunga may continue to service the west and the centre zones, given Onehunga is a major industrial hub and its connectivity as compared to New Lynn or Grey Lynn is better.

5.8.3 Integrating Merchants into Warehousing and Distribution

As has been brought out earlier, about 75% of the distribution in Auckland is on the DTS model. As a result, the quantum of inventory of plasterboard with BMs is minimal and, in all probability, moving in very small penny packets in retail sales. However, the storage areas of BMs would have been designed for warehousing 100% of sales since DTS is a recent implementation. A business relation to use the available space with one or a group of merchants in a particular location may be formed to avoid establishing an exclusive warehouse. This model is likely to be effective and efficient in terms of staffing as well as minimal or no ownership costs for infrastructure and overheads. The current transport model can continue to be used.

5.9 Validation of Research Outputs

The aspects discussed above were presented to the concerned functionaries of the company who provided the data. Being evidence-based, the outcomes were accepted for consideration by the company. The following were specifically discussed: -

- The study reflects an average of 26 trucks operating daily with approximately 330 tonnes of material despatched (as of 2020). Over time, the number of trucks undertaking daily trips has reduced to approximately 20 per day, while the tonnages delivered have increased upwards to approximately 500 tonnes per day. A classical illustration of ‘doing more with less’.

- Also, from about 75% of deliveries in Auckland on the DTS model in 2020, today, nearly 80% of the deliveries in Auckland are on the DTS model. Clearly, the research outcomes are aligned with the company’s strategic and operational thinking.

- As a corollary to the above, the need for ICT tools for planning operations was acknowledged by all functionaries. This, however, needs to be based on the company’s long-term sustainability strategy.

- The discussion on waste management and integration of reverse logistics with deliveries moved in two directions. The first one was the means of collecting waste on site and ensuring that waste is ‘clean’ to be effectively utilised as a raw material for new production. Waste bags were considered the best alternative, with a financial incentive for the developer/contractor for every ‘clean’ waste delivery they achieved.

- In any case, an intrinsic financial incentive exists by way of not paying the company currently undertaking waste removal from the site. Identification of the source of the waste bag (the site from where a bag comes) can easily be resolved using RFID tagging.

- In case the waste ‘pick-ups’ cannot be integrated with forward deliveries every time, a reasonable assumption in any operational scenario, a mobile application to enable the construction site to inform the availability of waste to the WH is considered a potential solution. Any truck in the vicinity of the site would then pick up the waste bag(s).

- The granularities of communication and nomination of trucks for the purpose would need to be worked out based on an algorithm or be managed through a ‘control station’.

- The potential contribution of the above aspects in reducing embodiment of resources the manufactured plasterboard and the built asset these were being used in was acknowledged.

- As to the distributed DTS model suggested for bulk despatches from outside Auckland and DTS deliveries from more than one location within Auckland, these being based on uptake by actual construction sites within the zone was understood.

- The dissociation of the location of BMs from the sites they serviced was well received by the audience, particularly because of ‘levelling’ of the urban development playfield rather than sales being constrained by locations of BMs vis-à-vis construction sites.

- The graphical tool for contracting transport services, though simple, was again received well by the audience as a means to continuously infuse financial sustainability into the business model, as well as the transport operations.

The above aspects, in effect, provide substantial triangulation for research outputs.

5.10 Scope for Future Work

As evidenced by the literature, there is a major scarcity of data pertaining to transport operations in the freight industry. The issue becomes even more acute in the case of the construction sector since the transportation function is almost fully, if not fully, outsourced. Construction stakeholders, therefore, are unable to record data on transport movements. Data, however, is the key to understanding efficiencies and improving them.

Discussion of energy efficiency and the creation of governmental road maps drives research on logistics issues in construction to serious relevance. In the context of this study, the dataset used pertains to a very narrow segment of the NZ construction sector. The operations it represents have connotations from the perspectives of SC design, business models, logistics, and transport function. This study has analysed only one facet of the operational strategy that the dataset represents, of quantifying efficiencies achieved as a result of a particular distribution philosophy being followed and the potential to build improved efficiencies into the very same operations that the dataset represents.

5.11 Chapter Summary

Where chapter 4 drew inferences from observations, this chapter transformed them into tangible business cases. It commences by generalising the transport operations into a model comprised of loads and distances, which can be used to evaluate and assess various operational aspects.

The aspect of backhaul from chapter 4 is next discussed in terms of potential implementation mechanisms and quantification of potential efficiency improvements. Doing so brings out a means to integrate reverse logistics with forward logistics, a major challenge in the freight transport sector.

Next, improved transport efficiencies are converted to tangible outputs in terms of actual figures pertaining to the reduction in emissions and their monetised impacts. It further discusses fleet management imperatives from the data analysis, considering the current sustainability compulsions for businesses.

The next portion of the chapter is dedicated to changes in ways of doing business, specifically discussing non-price attributes in tendering and contracting, integrated planning process, further increasing distribution through the DTS model, finally discussing the contextual connotations of the ‘per km’ and ‘per tonne’ financial models, with a graphical solution for selection.

The last part of the chapter discusses a distributed DTS system in the event of the manufacturing plant and the associated central warehouses moving out of Auckland. This section uses a weighted uptake matrix to suggest centroidal locations for zoned warehouses for a distributed DTS model.

Chapter 6 Conclusion

6.1 Revisiting the Research Framework

This research started with a few research questions and objectives. This chapter discusses whether they have been answered and, if so, how. It has focussed on problem development and stands at the intersection of SCs, logistics, the construction context, and transport and its sustainability with an NZ focus.

In trying to answer these questions, the research process moved back and forth between quantitative and qualitative methods. First, quantitative methods were used for initial data analysis, followed by the substantiation of inferences qualitatively. This was again followed by quantitative methods for optimising, finally validating interpretations qualitatively.

6.2 Review of the Research Methodology Adopted

6.2.1 Research Methodology

As a domain, all research has similar milestones (Figure 3.3). The approach to be adopted stems from the point of commencement of research, the aims and objectives, at what point the hypotheses are developed, and whether they are applied further (Spens & Kova´cs, 2005).

The problem in the case of this study pertains to assessing improvement in operational efficiency of the transportation component of the selected (narrow) segment of the New Zealand CSC based on implemented distribution model. It further forays into estimating further optimisation potential. Effectively, the considerations guiding this research (material delivery-to-site from the manufacturer's premises) reduce a potentially complex problem to a relatively simple one, from the perspective of uncertainty (well-defined scope of operations, minimal stochasticity assumed, making operations substantially deterministic in terms of assessment parameters).

It is similarly posited in terms of the actual transport network to be analysed, which presents two nodes joined by one link, though the destination link may fragment into more than one (manifesting in multiple drop trips). The parameters requiring measurement are distances, loads, and costs, which are quantifiable. The problem investigated, therefore, has been categorised as generic, quantifiable, and simple in terms of the Scope-Complexity (S-C) classification (Belardo & Pazer, 1985).

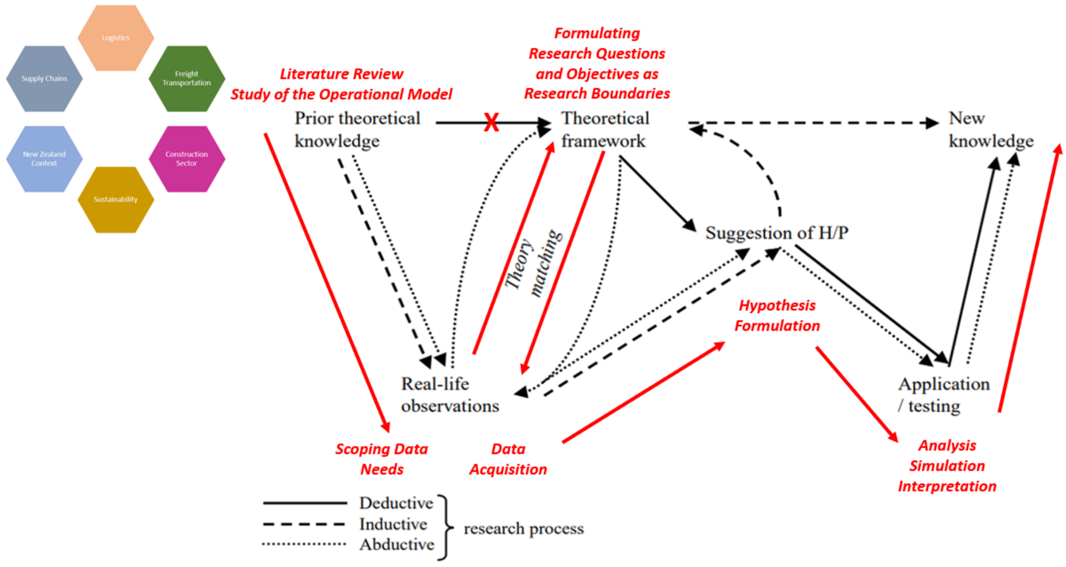
Addressing the problem, however, required a prior understanding of the CSC in general, the selected segment in particular, the theoretical frameworks governing the domains at the intersection of which the problem stands (SCM, Logistics, Freight Transport, Construction, New Zealand, Sustainability), and the operational model to be studied.

It does not, however, involve developing a theoretical framework from prior theoretical knowledge, and therefore, eliminates the deductive approach. Prior theoretical knowledge, however, is a driver for scoping data needs, which further loop into the research questions to form the research system boundary. The theoretical limits imposed by the RQs and ROs, in turn, guide data acquisition.

Based on data scoping and data acquisition, the broad hypothesis for basing the study is formulated. This step is common for all approaches from the real-life observation stage. The research process cannot adopt the inductive course from hypothesis development, since no new theory is being developed. Existing theoretical knowledge is being substantiated and interpreted through experiment. This stage is represented by Analysis, Simulation, Interpretation, which finally merges into new knowledge..

Figure 6.1

Superimposition of the adopted research methodology on the generic 'research route chart'



Note. (Based on Spens & Kova´cs, 2005)

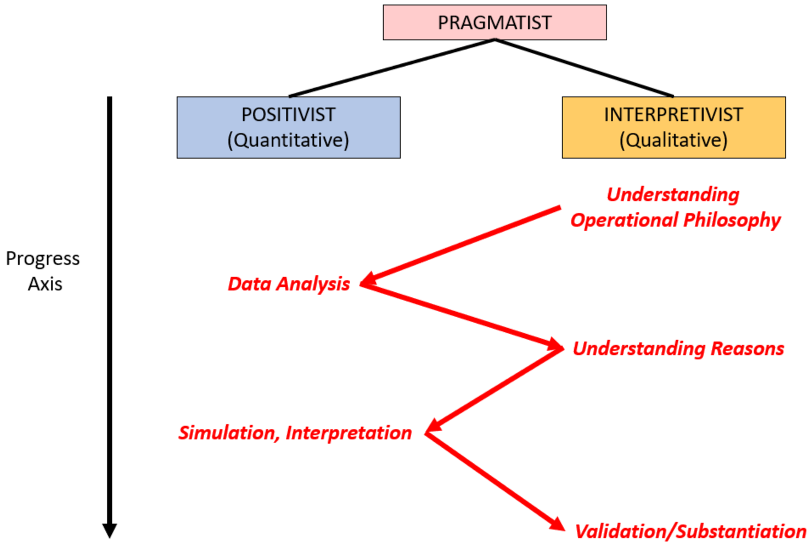
6.2.2 The Research Paradigm in the Background

The varying requirements of various components of the problem under investigation pointed to the pragmatist approach as best suited to address the problem. The positivist leanings within the pragmatic approach enable quantification of transport operations in terms of parameters needed for answering the research questions and, therefore, objectively evaluating logistics practices. In contrast, the interpretive approach to understanding the New Zealand CSC segment under investigation provides a rich understanding of logistical functions, and heuristics for further application.

The pragmatist approach also substantiates alternating between quantitative analysis and qualitative triangulation of the outcomes of analysis. The qualitative component is engrained in the existing theoretical knowledge and a qualitative understanding of the operational model of plasterboard distribution through interaction with the company functionaries (logistics manager). This is followed by the quantitative aspect of data requirement scoping, data acquisition and data analysis. The outcomes of analysis are substantiated through qualitative means by being presented to the company management and obtaining their viewpoint. Finally, the inferences and recommendations based on the analysis outcomes form the last segment of qualitative research. Figure 6.2 illustrates the paradigm-based progress of research.

Figure 6.2

Paradigm based alternating between quantitative and qualitative methods



Note. (Based on Figure 3.5)

The literature supports this approach, where-in the interdisciplinary nature of the domain demands employing alternative research paradigms (Garver & Mentzer, 1999;

Mentzer & Kahn, 1995; Meredith *et al*., 1989; Naslund, 2002; Solem, 2003; Wahyuni, 2012), due to a predominant research paradigm resulting in dominant methods not being suitable for a complex and applied research field such as logistics (Naslund, 2002).

6.3 Findings

6.3.1 General Findings

Based on the analysis of operational data pertaining to distribution of plasterboard in Auckland, the following general findings pertaining to supply chain and logistics issues emerged: -

- Supply of plasterboard for construction projects in New Zealand is a monopoly, with 95% of the market share consistently held by one company for the last about two decades.

- The distribution of plasterboard has three SC actors involved, i.e., the manufacturer, the Builders' Merchants (referred to as 'merchants' in New Zealand), and the consumers (who may be developers or builders, depending upon the size of the project).

- Over the last about seven years, the manufacturer has vertically integrated the distribution function as an extension of the manufacturing operations, and then outsourced the transportation function on a 2PL model.

- A major share of the plasterboard supply in Auckland (nearabout 75%) is delivered direct to site by the manufacturer using the vertically integrated logistics model.

- However, the invoicing for the material and monetary transactions with the end-user, and the delivery details such as location, approximate date of delivery etc., continue to be handled by the merchant on whom the end-consumer is dependent.

- This evidences the importance of the BM in the CSC as a 'creditor' or 'banker' for the developer or builder.

- The manufacturer provides the transport contractor with the premises for loading and despatch of trucks, and the working space for documentation and other administrative aspects related to transportation of consignments on trucks.

- Planning of deliveries, implying loading of trucks, and deciding the sequence of their destinations and drops over the course of a day, is undertaken by the transport contractor. The manufacturer plays no role in this activity.

- Approximately 330 tonnes of plasterboard are despatched every day as interpreted from the dataset. On an average, the loading efficiency of trucks is approximately 56%, translating into unutilised (lost) capacity of 252 tonnes every day.

- Each truck makes two to three trips every day, each trips having anywhere between one to four drops. The number of drops with four or more drops is less than 1% of the total number of trips considered.

- The pricing mechanism for plasterboard delivery is on a ‘per tonne’ basis within Auckland.

- The GVMs and payload capacities of trucks vary; every truck does not have an on-board crane; and each truck model exhibits a typical loading efficiency irrespective of its employment (delivery destinations).

- The truck model undertaking maximum deliveries has a loading efficiency in the middle order, while the truck model exhibiting consistently high loading efficiency has low numbers in service.

- With an overall loading efficiency of 56% across the fleet, a capacity utilisation (tonne-km) of 27% is being achieved; 72% of the tonne-km capacity of the fleet is going unutilised.

- Direct to site deliveries, as opposed to all deliveries through the BM, have led to a reduction of truck movement distances by about 30% (translating to about 11.1 km per trip).

- Plasterboard manufacture can use about 10% waste plasterboard as raw material.

6.3.2 Inferences from Findings

The findings may be inferred as follows: -

- There exists substantial potential for improved loading and reduction in truck movements, through the application of optimisation strategies, especially using IT and OR tools.
- The pricing model for transportation does not create incentives for improved transport operations in line with sustainability objectives.
- The literature indicates about 30% waste arisings of plasterboard on construction sites, which provides an opportunity for integrating waste removal with fresh material deliveries, to potentially improve capacity utilisation of trucks.
- Integrated planning with the combined participation of the manufacturer and the transport contractor, based on mechanisms for achieving sustainability objectives, could assist in improving the static (loading efficiency) as well as dynamic (capacity utilisation) filling rates of trucks.
- There are SC implications of integrating waste removal into the delivery logistics.

6.4 Analysis

6.4.1 Analyses Undertaken

Based on the dataset available, the following analyses were undertaken: -

- Application of the transportation model from Operations Research as an optimisation tool for improving loading efficiencies of trucks and, therefore, their capacity utilisation.
- Quantification of the potential improvements in transportation operations.
- Quantification of the sustainability benefits of improved transport operations (reduced emissions, decreased truck movements).

- Validating the outcomes from different perspectives of the same problem.
- An indicative monetisation of the sustainability benefits.

6.4.2 Outcomes of Analyses

Outcomes of the analyses undertaken are as follows: -

- Formulation of a generalised trip model for the distribution operations of plaster board in terms of nodes, travel distances, and loads (both fresh material and waste from sites).
- Improvement of truck loading efficiency from 56% to about 93% on an average, across the complete fleet through application of the transportation model. This results in a reduction of approximately 16 trips daily.
- Improvement of capacity utilisation from approximately 27% to about 49% through improved capacity utilisation through optimised operations using the transportation model.
- A further improvement of approximately 10% in the capacity utilisation of trucks by integrating reverse logistics of plasterboard waste removal from site on the same trucks supplying fresh plasterboard to sites.
- Formulation of a graphical tool for pricing mechanism selection during tender evaluation.

An indicative quantification of sustainability benefits of the above improvements in transportation operations are as follows: -

- Annual reduction of 53,000 litres in diesel consumption translating to 142,953 kg CO2-e emissions reduction from improved capacity utilisation of trucks.
- Reduction of 16 trucks, implying their removal from the road. This translates to approximately 206,000 km reduction in truck movement annually. In addition, this can directly be associated with issues such as congestion, reduction of damage to road infrastructure, noise etc.

- Monetised benefit of NZ$375,000 from reduced transport movements as well as improved capacity utilisation annually.

6.4.3 Inferences from Analyses

The outcomes from the analyses provide the following indicators: -

- The need to shift distribution to the DTS model incrementally in Auckland, and as a step change in other regions (Waikato, Wellington, Christchurch).
- The need to integrate reverse logistics for improved sustainability of transport operations, as well as a step in the direction of circular economy in plasterboard manufacture.
- Fleet configuration in terms of standardisation (availability of crane on each vehicle).
- Fleet composition for higher sustainability of transport operations (truck models exhibiting comparatively higher capacity utilisation).
- Fleet transition from the existing composition to the desired composition in terms of truck models through phased discard and acquisition.
- Transitioning from diesel operation to sustainable powering technologies through interim cleaner fuels such as LPG or CNG, pending proliferation/maturing of technology (electric/hydrogen powering).
- Potential for including NPAs in tendering/contracting to counter the pricing mechanism (‘per tonne’) for improved sustainability of transport operations.
- The need to implement joint/integrated planning mechanisms for transport operations in particular and fleet management in general.
- Monetised sustainability benefits, aligning with the sustainability statement/vision of the company.
- Transformation of analytical tools from ‘cost reduction’ to ‘resource reduction’ tools.

- The potential for applying graph theory for further optimisation of transport operations (‘Hamiltonian Path’ and the such like)

6.5 Limitations

Before discussing the study’s contribution to knowledge, it is pertinent to elucidate its limitations: -

- The study pertains to a narrow segment of the CSC, associated with manufactured products for construction. The outcomes may not be fully indicative of the implications for the CSC at large (especially transportation of bulk materials such as aggregate, steel etc.).

- The operational data, and therefore, the outputs of the analyses undertaken are specific to Auckland, which is a typical manifestation of a an ‘elongated sprawl’. The results may not be entirely applicable to other regions with a larger (broader) physical expanse.

- The work undertaken is a retrospective analysis, i.e., the data pertained to operations already performed.

- The optimisation model is based on operations ‘as-executed’. Hence, any future optimisation needs to start with human intervention in configuring operations, however inefficient it may be. This would be followed up with an optimisation exercise.

- This aspect potentially reduces the processing power and the complexity of algorithms required for achieving optimisation (application of transportation model on operations scheduled through human intervention model instead of application of VRP).

- Integration of waste removal does not consider the temporal displacement between fresh material supply and waste generation on-site. The mechanisms for reverse logistics integration will need to be worked out separately.

- The sustainability impacts and monetisation are broad estimates, without considering the specific operating parameters of the specific vehicle models.

6.6 Contribution to Knowledge

The study contributes to knowledge in more than one ways, i.e., by substantiating existing literature, by producing new knowledge, and by benchmarking/quantifying in the New Zealand (Auckland) context. Table 6.1 brings out the study's contribution to knowledge.

Table 6.1

The Study's Contribution to Knowledge

Inference/Outcome	Contribution to Knowledge
Analysis of transport operations pertaining to the CSC in New Zealand	***New knowledge in terms of parameter analysis by applying specific metrics***
Quantification of the benefits of bypassing one echelon (BM) in the SC for distribution of manufactured products for construction	***New knowledge in the Auckland sprawl context; Indicates applicability in other regions of New Zealand and similarly configured regions globally***
Merging of the supply chain and the construction site	***Substantiates existing literature through achievement of integration; New knowledge in terms of quantification of benefits realised from integration***
Linkages between supplier-based SC configuration and logistics efficiency	***Substantiates existing literature***
Impact of pricing model on efficiency of transport operations	***New knowledge through heuristic inference***
Application of 'transportation model' for uniform channel costs	***New knowledge in terms of transformation from 'cost minimisation' to 'resource minimisation' tool***
Conversion of problem from high complexity to low complexity without any impact on outcomes	***New knowledge in terms of simplifying the problem from a VRP to a TSP merely by the initial intervention being human***
The need for integrated planning and use of IT tools for improving operational efficiency	***Substantiates existing literature***
Quantification of sustainability benefits from optimisation of transport operations	***New knowledge in the New Zealand context developed based on existing domestic research***
Insights into fleet management	***New knowledge in terms of specific parameters to be considered from analysis undertaken***
Impact of pricing mechanism on tendering/contracting	***New knowledge in terms of development of graphical tool for pricing mechanism selection***
Role of NPAs in sustainability	***Substantiates existing literature in confirming the role of NPAs; New knowledge in terms of specific NPAs that may be utilised for tendering/contracting in the context of the transport component of the CSC***

Mechanisms for improving sustainability e.g., congestion pricing	***Outcomes substantiate existing literature***
Impact of business model (DTS) on market competitiveness	***New knowledge in the form of hard evidence illustrating dissociation of physical location from area of work from difference in uptakes of regions vs developers/contractors located there***
Ways of doing business as a means to improve sustainability and not just cost competitiveness	***Hard evidence of sustainability outcomes of vertical integration of the distribution function with manufacturing***

6.7 Answering the Research Questions

6.7.1 Metrics for Assessing Sustainability Impacts

The study discusses the background of efficiencies of the transportation function in terms of loads and distances. It adopts two fundamental metrics to base the analysis *viz* loading efficiency and capacity utilisation, the former static and the latter dynamic.

6.7.2 Quantifying Sustainability Impacts

The discussion chapter quantifies the sustainability impacts in terms of reduced emissions and congestion, including an indicative monetisation, as a result of the distribution model adopted, superior planning, and integrated reverse logistics (waste removal).

6.7.3 Potential for Reducing the Gap Between Existing and Utilised Truck Capacities

The chapter on analysis first develops the problem, then analyses it ‘as is’, and finally applies the transportation model as a superior planning methodology to improve efficiencies of transport operations. In doing so, it quantifies improved efficiencies through reduction in transport whilst maintaining operating outputs, a business KRA.

6.7.4 Sustainability Benefits of Integrating Reverse Logistics

The study substantiates an improvement in the capacity utilisation of trucks to the tune of about 10% as a result of integrating reverse logistics. The primary sustainability benefits discussed are the reduction in per unit emissions and utilisation of plasterboard waste from Auckland in the production of new plasterboard without impacting quality (waste reduction and diversion from landfill).

6.7.5 Fleet Management

From the analysis of distribution patterns in terms of capacity utilisation and loading efficiency of various models of trucks, pointers towards fleet management both in the long- and the short-term are given.

Long-term fleet management primarily pertains to the sustainability impacts of improved technology and a transition plan to reach there, pending maturity of the technology in the NZ context.

Short-term fleet management aspects discuss standardisation of the fleet to those models that deliver the most, pointing to those that may need to be discarded, and integrating effective material handling expedients (cranes) across the fleet.

Short-term fleet management also discusses introducing integrated planning using ICT tools.

6.7.6 Supply Chain Management Implications

SCs, especially in the construction domain, are extensive. Working on the end-to-end SC is likely to be very laborious, and the governing parameters would most likely have changed at the end of it. Specific outputs, therefore, have been extracted from the study of a very narrow segment of the CSC in NZ. The operational concept of the segment has been broken down into elemental domains as pointers towards inter-domanial connotations and likely research directions.

The study quite unambiguously brings out the impacts of VI of the distribution function as an extension of manufacturing. By ‘adopting’ the transportation function, the manufacturer has created sustainability opportunities in the areas of integrated planning, use of ICT tools, and waste management, all of which have direct implications on the efficiency of transport. ***The selected hypothesis ‘Vertical Integration in a Supply Chain will improve logistics efficiency’ stands proved in this instance.***

6.8 The Overall Conclusion

The overall conclusion of the study is as follows: -

> There appears to be substantial operational slack in the transport component of the construction supply chain pertaining to

manufactured products in New Zealand. Significant efficiency gains can be realised through vertical integration of logistics with manufacturing and employing simple IT based optimisation tools. These can potentially result in significant and quantifiable sustainability benefits in all three dimensions.

6.9 Recommendations

6.9.1 Policy

The research clearly brings out that there is an operational slack where-in vehicle capacities are going substantially underutilised. A phased/graded 'carrot and stick' approach forms basis of the set of recommendations for improving transport efficiencies and sustainability, as a generalisation of outcomes of the analyses undertaken: -

- Tendering and contracting for transport procurement by public agencies need to include non-price attributes as trend-setters and emulable examples.

- Driving behavioural change through education and awareness campaigns for users of transport and transport contractors.

- Regulation for minimum capacity utilisation of freight transport, supported by technology implementation (cameras, load cells, sensors) for disincentivising vehicles not meeting the minimum specified loading criteria.

- Congestion charging for Auckland CBD and surrounding areas.

- Adoption of construction transport standards such as CLOCS (Construction Logistics and Community Safety) from the UK.

- Pilot programmes for establishing consolidation centres or cross-docking stations for transferring loads on to vehicles entering the city or highly congested areas of Auckland. The consolidation centres may be public or privately owned.

- A roadmap for phasing out diesel, and the use of cleaner fuels (such as LPG, LNG, CNG) in the interim.

- A clearly articulated construction waste management policy, supported by relevant regulation.

6.9.2 Logistics Management

Recommendations for tacking the operational slack and improving sustainability of logistics operations at the company level are as follows: -

- Data capture needs to be an essential part of operational philosophy.
- Design of transport operations around the company's sustainability statement to include planning tools (ICT-based means of improving operational philosophy and implementation), resources (sustainable transport technology and operations), and performance parameters (design of suitable performance indices).
- Managing the transport process through planning, monitoring, and control. Processes and performance indicators need to be put in place to achieve this.
- Accountability to be built-in within the organisation for those managing logistics/transport and on the service providers to achieve optimal performance benchmarks forming part of the contracting arrangements.
- Putting in place a mechanism for data collection and evaluating performance indicators based on day-to-day operations.
- Integrated planning of transport operations with the involvement of the manufacturer as well as the transport contractor.
- Use of NPAs in tender evaluation, contracting, and contract monitoring.
- Phased discard of under-performing trucks and standardisation of the fleet with consistently high performing vehicles.
- The need to equip all trucks with integral cranes.
- A phased programme of fleet conversion to cleaner fuels along with a transition plan through interim cleaner fuels till market and technology maturity are achieved in New Zealand.
- Considering the financial implications of upgrading fleet composition, the company may need to work out an incentive model, as well as financial support

to the transport contractor to change the fleet composition (vehicle models) as well as fleet configuration (every vehicle having a crane) over time.

- Integrating reverse logistics (waste removal from site) along with forward logistics of material delivery.
- This may need employing monetary incentives for end-consumers of plasterboard providing usable waste.
- Freight transport ownership models may also be examined by the company. In New Zealand, both extremes of transport ownership models exist in the construction industry – fully company owned (Fulton Hogan) and fully outsourced (Fletchers).

6.9.3 Future Research

As evidenced by the literature, there is a major scarcity of data pertaining to transport operations in the freight industry. The issue becomes even more acute in the case of the construction sector since the transportation function is almost fully, if not fully, outsourced.

Construction stakeholders, therefore, are unable to record data on transport movements. Data, however, is the key to understanding efficiencies and improving them.

Discussion of energy efficiency and the creation of governmental road maps drives research on logistics issues in construction to serious relevance. In the context of this study, the dataset used pertains to a very narrow segment of the New Zealand construction sector.

The operations it represents have connotations from the perspectives of SC design, business models, as well as logistics, specifically the transport function. This study has analysed only one facet of the operational strategy that the dataset represents; that of quantifying efficiencies achieved as a result of a particular distribution philosophy being followed, and the potential to build improved efficiencies into the very same operations from which the dataset emerged.

The following research gaps have been discovered during the course of this study: -

- **Data availability** Most businesses do not have the means and the business imperative to capture and analyse operational data as an efficiency enhancement tool.
- **Lack of awareness of logistics systems** Logistics costs, especially in the construction domain, are hidden costs, aggregated with the supply of material or services. A disaggregation of costs is considered essential for optimisation.
- **Efficiency of BM-centric transport operations** An off-shoot of the above gap is the gap in knowledge pertaining to the efficiency of BM-centric transport operations and their quantification.
- **Applicability of tools from other scientific domains for solving logistics problems** Logistics borrows tools from other scientific domains. This presents a gap in knowledge pertaining to applicability, research, and adoption/implementation.
- **The reality of volumetric loads** Considering volumetric loads in transport operations as opposed to considering only weight-based filling rates.
- **New Zealand-centric benchmarking of transport optimisation benefits** Quantification of sustainability benefits of transport optimisation in various regions of New Zealand to be able to arrive at benchmarks.

The above gaps indicate possibilities for the following research as future work: -

- Using the business model and data available with BMs to undertake a data-substantiated comparison of DTS and MD models, quantify time, distance, and speed efficiencies achieved realistically.
- Assess the efficiencies achieved in terms of reduction in truck trips by applying the transportation model from the perspective of actual measurement of distances and, therefore, quantifying efficiencies achieved in terms of capacity utilisation.

- Undertake a comparison of the distribution undertaken in urban areas under the DTS model with last-mile solutions in the context of the Auckland conurbation.
- Compare load consolidation undertaken from the construction site perspective to consolidation achieved in the CSC from the suppliers' perspective.
- Draw a comparison of the vertically integrated SC studied in this research to a similar (direct-to-customer) SC from the manufacturing domain.
- Draw parallels for long-term fleet management and sustainability impacts with the freight transport business (both long haul and urban distribution).
- Quantification of specific sustainability benefits of integrated transport planning.
- Sustainability impacts of including non-price attributes in the tender evaluation and contract award processes in the freight transport domain.

6.10 Conclusive Answers?

This study first developed a problem on the basis of the availability of data, then provided a contextual analysis of the problem, again using the same data that enabled problem formulation in the first place. Along the way, it quantified certain parameters, developed inferences from others, and further developed those inferences into quantified parameters and tangible interpretations.

Does it give conclusive answers?

No, it does not. Instead, it examines contextually, infers logically, quantifies selectively, and interprets tangibly to suggest further possibilities.

6.11 Closing Remarks

Transport is a domain in itself; however, its operations are naturally fragmented because every other business domain has a transportation component within it. Construction sector fragmentation only accentuates this. As a result, obtaining coherent and reliable data streams from the transportation business associated with construction is near nigh impossible. The scarcity of such data is an acknowledged reality in the research domain.

This study overcame the existing data availability handicap, based entirely on operational data and its analysis. Rather than participants opine ab-initio, this research took their opinions as substantiation of the work done and inferences drawn. And quite happily, they converged.

It has been able to demonstrate the association between transport operations, business efficiency, and sustainability impacts through the application of very simple supply chain and business management principles, opening the pathway for further research and operations-based improvement in the sustainability of the construction domain.

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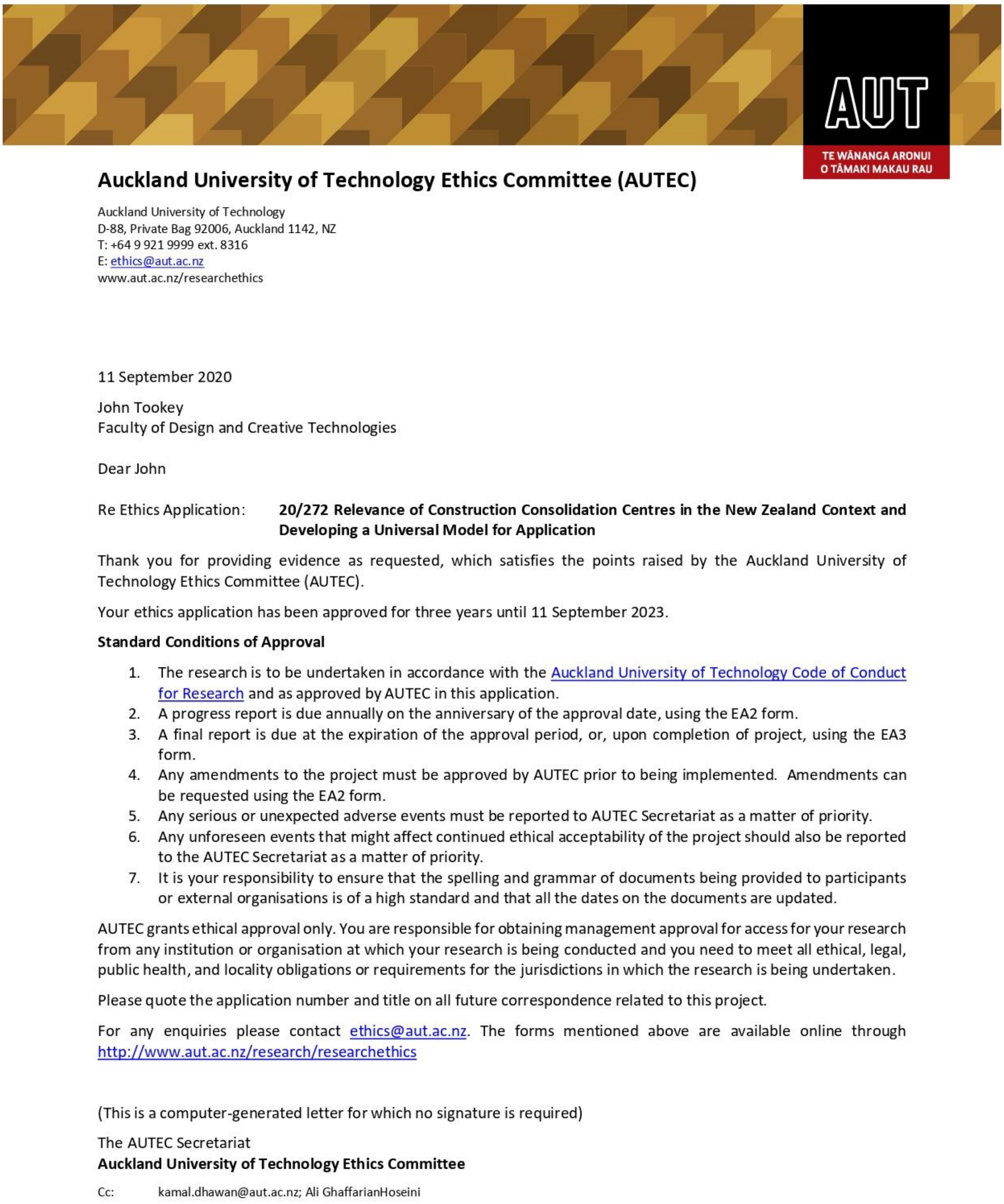
Appendices

Appendix A *Ethics approval*

a) Initial ethics approval



TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

11 September 2020

John Tookey
Faculty of Design and Creative Technologies

Dear John

Re Ethics Application: **20/272 Relevance of Construction Consolidation Centres in the New Zealand Context and Developing a Universal Model for Application**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 11 September 2023.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard and that all the dates on the documents are updated.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

Please quote the application number and title on all future correspondence related to this project.

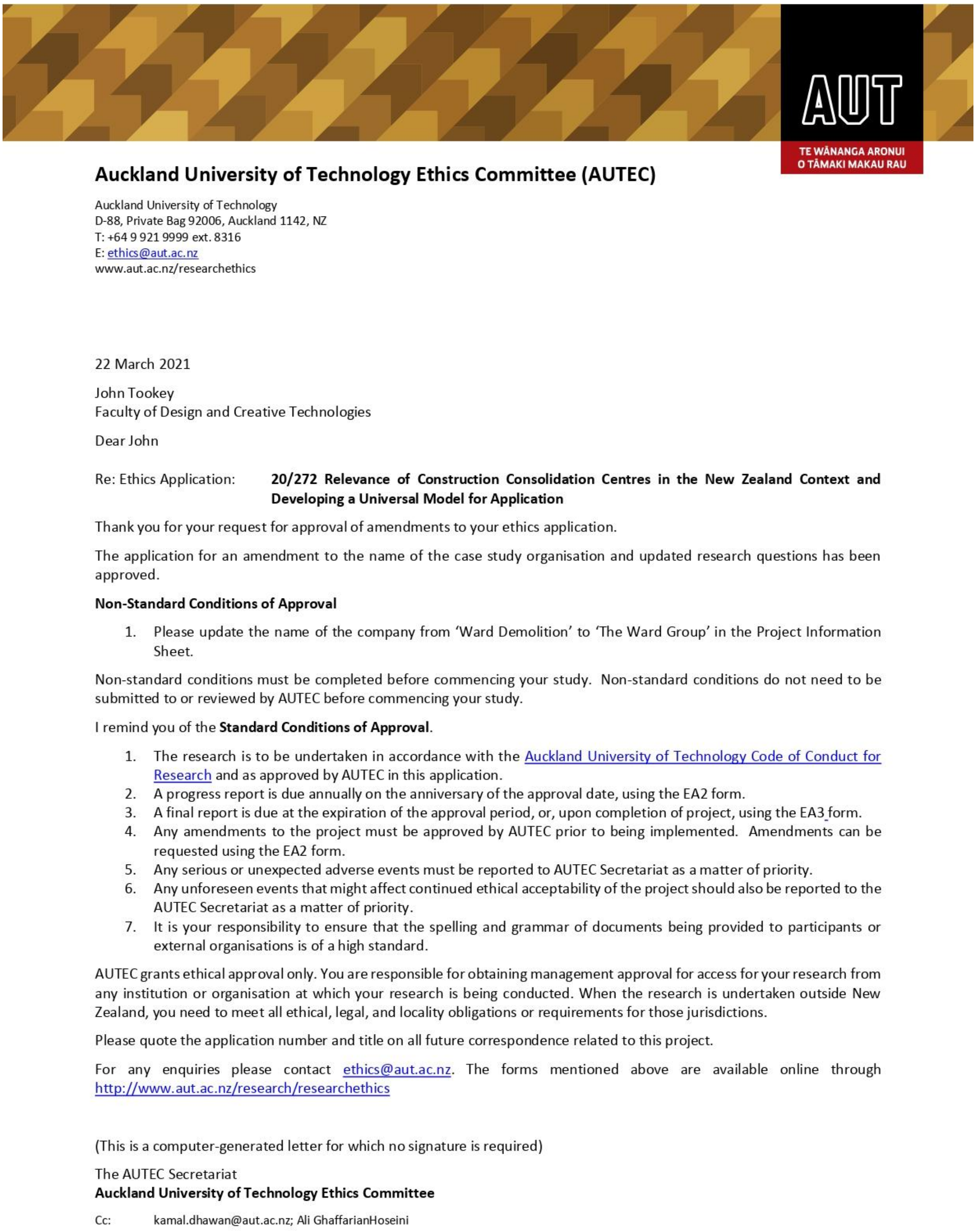
For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: kamal.dhawan@aut.ac.nz; Ali GhaffarianHoseini

b) First amendment approval (for change of organisation)



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O TĀMAKI MAKAU RAU

Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

22 March 2021

John Tookey
Faculty of Design and Creative Technologies

Dear John

Re: Ethics Application: **20/272 Relevance of Construction Consolidation Centres in the New Zealand Context and Developing a Universal Model for Application**

Thank you for your request for approval of amendments to your ethics application.

The application for an amendment to the name of the case study organisation and updated research questions has been approved.

Non-Standard Conditions of Approval

1. Please update the name of the company from 'Ward Demolition' to 'The Ward Group' in the Project Information Sheet.

Non-standard conditions must be completed before commencing your study. Non-standard conditions do not need to be submitted to or reviewed by AUTEC before commencing your study.

I remind you of the **Standard Conditions of Approval**.

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.

AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted. When the research is undertaken outside New Zealand, you need to meet all ethical, legal, and locality obligations or requirements for those jurisdictions.

Please quote the application number and title on all future correspondence related to this project.

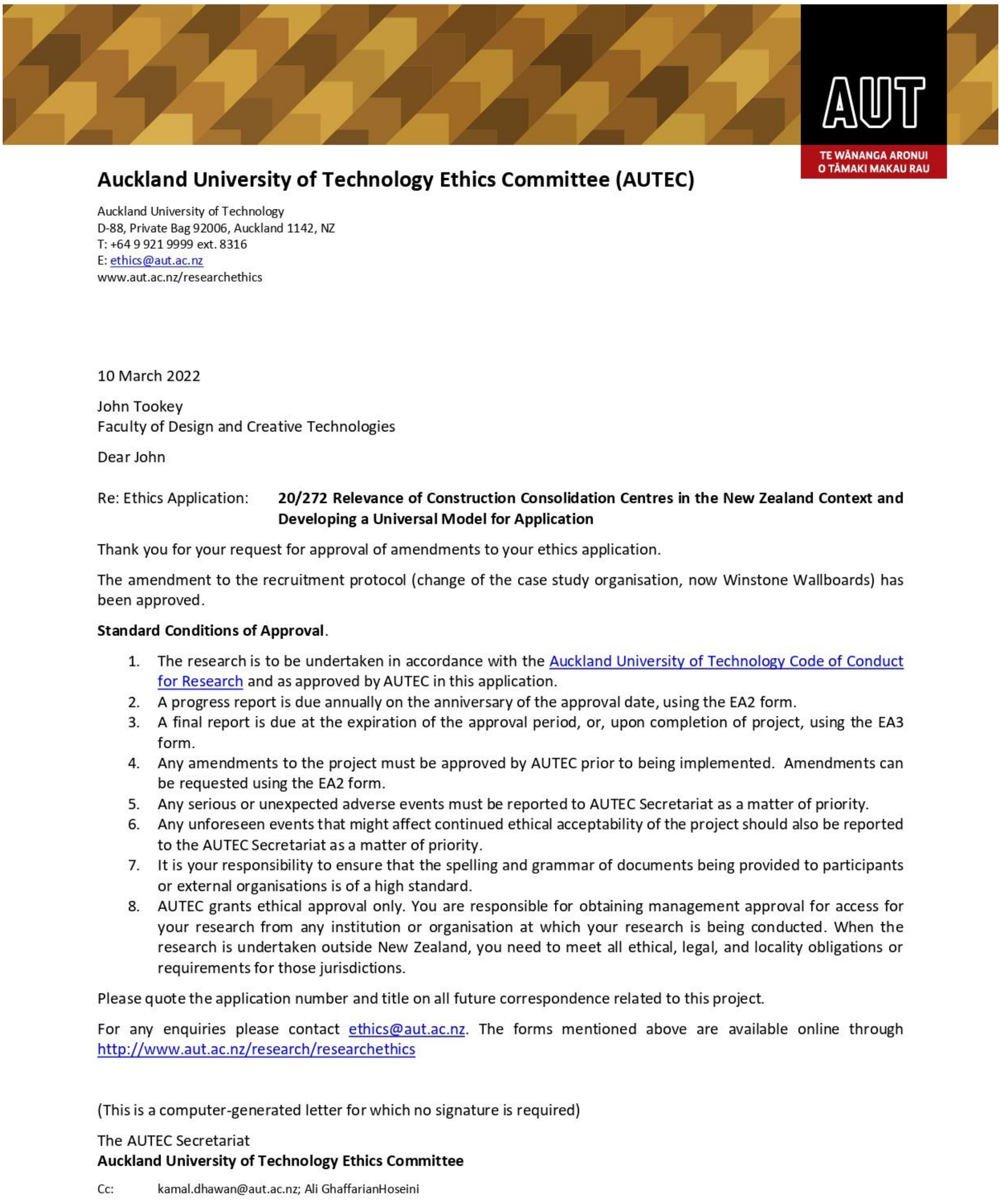
For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: kamal.dhawan@aut.ac.nz; Ali GhaffarianHoseini

c) Second amendment approval (change of organisation)



Auckland University of Technology Ethics Committee (AUTEC)

Auckland University of Technology
D-88, Private Bag 92006, Auckland 1142, NZ
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

10 March 2022

John Tookey
Faculty of Design and Creative Technologies

Dear John

Re: Ethics Application: **20/272 Relevance of Construction Consolidation Centres in the New Zealand Context and Developing a Universal Model for Application**

Thank you for your request for approval of amendments to your ethics application.

The amendment to the recruitment protocol (change of the case study organisation, now Winstone Wallboards) has been approved.

Standard Conditions of Approval.

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC in this application.
2. A progress report is due annually on the anniversary of the approval date, using the EA2 form.
3. A final report is due at the expiration of the approval period, or, upon completion of project, using the EA3 form.
4. Any amendments to the project must be approved by AUTEC prior to being implemented. Amendments can be requested using the EA2 form.
5. Any serious or unexpected adverse events must be reported to AUTEC Secretariat as a matter of priority.
6. Any unforeseen events that might affect continued ethical acceptability of the project should also be reported to the AUTEC Secretariat as a matter of priority.
7. It is your responsibility to ensure that the spelling and grammar of documents being provided to participants or external organisations is of a high standard.
8. AUTEC grants ethical approval only. You are responsible for obtaining management approval for access for your research from any institution or organisation at which your research is being conducted. When the research is undertaken outside New Zealand, you need to meet all ethical, legal, and locality obligations or requirements for those jurisdictions.

Please quote the application number and title on all future correspondence related to this project.

For any enquiries please contact ethics@aut.ac.nz. The forms mentioned above are available online through http://www.aut.ac.nz/research/researchethics

(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: kamal.dhawan@aut.ac.nz; Ali GhaffarianHoseini

d) Information sheet for participants

AUT
TE WĀNANGA ARONUI
O TĀMAKI MAKAU RAU

Participant Information Sheet

This Information Sheet is for the benefit of all participants from Winstone Wallboards.

Date Information Sheet Produced:

March 2022

Project Title

The Relevance of Construction Consolidation Centres in the New Zealand Context and Development of a Universal Model for application.

An Invitation

I am Kamal Dhawan, undergoing Ph D in Supply Chain Management (Construction Logistics) from Auckland University of Technology. My research pertains to investigating the benefits which may be accrued from the optimisation of transport operations within the construction logistics domain in the Construction Supply Chain. It will specifically seek data and professional opinions from actors involved in the planning and execution of transport operations for Winstone Wallboards. I request your participation, you being a member of Winstone Wallboards, and your professional capability and position to offer professional opinions on logistics and connected management issues and/or to make operational data available to fulfil the aims of my research.

This research is proposed as a pathway for the award of a PhD Degree to me from Auckland University of Technology (AUT).

I do not visualise any conflicts of interest between me, you, my organisation (AUT), your organisation or our respective hierarchies of reporting and/or mentoring. The choice to participate is entirely yours without any compulsion whatsoever. If you choose to participate, the participation will neither advantage you nor disadvantage you. You are free to retract your participation at any point of time, after agreeing to participate, if you so feel.

What is the purpose of this research?

The purpose of this research is to arrive at the possible sustainability benefits to the construction industry as a result of optimisation of a logistics-hub based transport operations for material delivery as well as C&D waste transportation. The broad research framework is as follows:-

Research Problem Effects of implementing Construction Supply Chain Management principles in the New Zealand context, on the performance of its construction sector.

Research Aim To examine the effect of optimisation a logistics-hub based transport operations for material delivery as well as C&D waste transportation in New Zealand in achieving sustainability outcomes in the economic, environmental, and social domains.

The study is proposed to be undertaken by means of a Mixed Model Research based on an Exploratory Case Study with Qualitative and Quantitative methods as embedded units for data collection and analysis to answer the following Research Questions:-

With a given location of the logistics hub, what would be an optimal solution to vehicle employment in the context of a 'continuously shifting scenario' of operations?

What is the optimal location of a logistics hub considering the focus of operations?

What are the metrics which can be used for benchmarking the results of vehicle movements for logistics hub served transport operations?

What productivity improvements (cost and time savings) are possible by the optimisation of the transportation function?

What sustainability benefits are accruable by optimisation of transport operations?

What are the possible effects of optimisation of transport operations when considered in conjunction with a technology mix of transport?

The findings of this research may be used for presentations and academic publications such as conference papers, journal papers, thesis etc.

How was I identified and why am I being invited to participate in this research?

You are being invited to participate in the study, being in a management/leadership role in your organisation, hence, a part of the decision-making process and/or part of operations of the organisation, who would be able to offer appropriate and sound professional opinions and make available appropriate and relevant operational data from the logistics hub.

How do I agree to participate in this research?

Your agreement to participate in this study will be communicated by means of a consent form to be filled up by you. The consent form will be handed over to you for filling up by me in confidence and also collected back by me.

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are free to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. If used, the data provided by you will not be identifiable and associable to you. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

The relevant details of the project and methodologies proposed to be adopted for addressing various Research Questions, how data is proposed to be collected, synthesised, analysed and the expected outcomes for each Research Objective are attached in the form of a 'Project Brief for Participants', at Appendix A to this Information Sheet.

Data Collection for the research will take place in two distinct parts.

The first stage of data collection will be in the form of questionnaires and interviews. Interviews will not be audio-taped, only notes will be prepared by the primary researcher. This would be collected from management functionaries of Winstone Wallboards involved in transport management and operations. This data will primarily pertain to strategic issues, the implemented management and business models of the logistics hub, professional opinions, and experience of the functionaries. Subsequently, the data will be aggregated on a computer. Documents will be preserved for the mandated period of time only as evidence that data has not been fudged for purposes of the research and will be destroyed thereafter. The data collection means will not attribute identity, hierarchical position, designation or role to the interviewee or the answerer of the questionnaire.

The second stage of data collection will be in the form of a survey. This would be obtained from the Project Manager. Data in the form of logs being maintained and data being collected as part of the day-to-day business operations of the organisation, such as output of implemented MIS will form part of this stage. This data is also proposed to be aggregated on a computer for purposes of extracting tangible outcomes, as well as making it entirely unattributable to an individual or organisational sub-unit.

What are the discomforts and risks?

No discomforts or risks are foreseen in the research since the interaction will be undertaken in the premises of your workplace or in a public place, after you agree to it, and the nature of interaction is proposed for the purpose of obtaining professional information and opinions, which you are comfortable in giving, without any kind of compulsion. Your privacy will be protected as brought out in a subsequent section in this form. No outcomes of the research will directly be associated with you by the researcher. All data collected will be aggregated and normalised prior to being used for the purposes of the research and will not be identifiable as having been given by you. The researcher will also maintain strict confidentiality of the information made available to him.

What are the benefits?

This research will lead to the conferring of a PhD on me by the Auckland University of Technology. The benefits of the research per-se, are mentioned in the Project Brief being made available to you. A summary of the benefits are as follows:-

Participants

Participants will be benefitted professionally from the outcomes by getting a clearer understanding of the performance parameters benchmarking outcomes of transport operations analysis.

The research will also enable them to use the outcomes as drivers for change and improvement, in addition to providing an optimised transport operations model.

Researcher

In-depth insight into construction logistics both conceptual and contextual, and being awarded a PhD degree.

Wider Community

Push for improved sustainability of the construction industry.

Anticipated reduction of negative social and environmental impacts of transport operations, leading to improvement in sustainability of the company's operations.

Contextual transferability of outcomes to peer domains such as retail supply chains, and policymaking in diverse fields such as transportation sector, urban planning, energy policies etc.

How will my privacy be protected?

The research will not attribute your identity, hierarchical position, designation, or role to any part of the research, either for opinions provided or for data collected, including in notes taken during interviews and questionnaires answered by you. No personal opinions will either be sought from you or be recorded as part of data collection. No individual opinions will either be referred to or be published. All data collected will be aggregated for purposes of drawing research outcomes and will be normalised for purposes of benchmarking and comparison.

Your name will not be divulged to anyone including other participants, nor will data collected from you be shared across or between participants. The information given by you will not be disclosed to any other participant or to anyone else either within the organisation or outside it. Any results, outcomes or research summary made available to the organisation at the end of the research will be based entirely on aggregated and normalised data. The consent form signed off by you will be stored for the mandated period separately from other research components to prevent any possible association of these with the research data at a later date.

Confidentiality is limited.

What are the costs of participating in this research?

There is no monetary cost of participating in this research. However, approximately two hours per fortnight of the participants' time on an average are likely required for participating in the research. This may continue for approximately a year, though most likely your participation will not be required every week. Suitable advance intimation will be given to you and your participation will be at your convenience. As a broad estimate, approximately 40 hours of your time are likely required over one year (a week worth of standard working hours over one year of research).

What opportunity do I have to consider this invitation?

Participation in this research is entirely voluntary. To familiarise you with the research, a project brief is attached with this document. You will have a period of four weeks from the day the Information Sheet is handed over to you for considering your participation and intimating the same, either way, without any compulsion to participate, whatsoever.

Will I receive feedback on the results of this research?

Yes. The research outcomes and findings will be made available to your organisation in a summarised manner to be read in conjunction with the Project Brief being made available to you along with the Participant Information Sheet

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Professor John E. Tookey, john.tookey@aut.ac.nz, +(649) 921 9999 ext 9512

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz* , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please retain this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:-

Researcher Contact Details:

Kamal Dhawan, email: kamal.dhawan@aut.ac.nz

Project Supervisor Contact Details:

Professor John E. Tookey, email: john.tookey@aut.ac.nz, +(649) 921 9999 ext 9512

Approved by the Auckland University of Technology Ethics Committee on *10 March 2022*, AUTEC Reference number *20/272*.

e) Project brief for participants

Appendix 'A' to Participant Information Sheet

PROJECT BRIEF FOR PARTICIPANTS

Introduction Construction in New Zealand is on the upswing, with construction estimates on the rise over the next 10 – 12 years. Each construction project is unique in terms of the product (the infrastructure or building being constructed), and a customised logistical pattern for each of its phases. Construction follows work, transporting large quantities of materials and associated waste, equipment, machinery and workforce to, from and between construction sites, transportation costs representing between 10% - 20% of its cost profile. Optimisation of transportation can lead to economisation of construction costs and can beneficially affect Health & Safety (H & S) parameters and Social & Environmental (S & E) impacts of construction activity. The traditional New Zealand construction industry is fragmented, having generally not yet adopted Supply Chain Management (SCM) principles. Consolidation, as a part of logistics and Construction Supply Chain Management (CSCM), is a pragmatic and implementable beginning for optimising construction transportation and reducing its unwanted impacts.

Consolidation of transport for material delivery and C&D waste transportation can lead to economisation of construction costs and can beneficially affect Health & Safety (H & S) parameters and Social & Environmental (S & E) impacts of construction activity. The traditional New Zealand construction industry is fragmented, having generally not yet adopted Supply Chain Management (SCM) principles. Consolidation, as a part of logistics and Construction Supply Chain Management (CSCM), is a pragmatic and implementable beginning for optimising construction transport and reducing its unwanted impacts, thereby, making the complete exercise sustainable.

Winstone Wallboards are New Zealand's largest supplier of gypsum plasterboard, drywall systems, associated products and services. Transport operations undertaken by Winstone Wallboards provide a unique contextual research opportunity, in the form of modelling and analysing transport operations, with the aim of suggesting means to optimise these, creating contextual benchmarks for cost benefits, H & S parameters and S & E effects, metrics being drawn from previous research.

Research Problem Effects of implementing Construction Supply Chain Management principles in the New Zealand context, on the performance of its construction sector.

Research Aim To examine the effect of optimisation of construction related transport operations in New Zealand towards achieving sustainability outcomes.

Broad Research Methodology The study is proposed to be undertaken by means of a Mixed Model Research based on an Exploratory Case Study with Qualitative and Quantitative methods as embedded units for data collection and analysis to answer the following Research Questions:-

With a given location of the logistics hub, what would be an optimal solution to vehicle employment in the context of a 'continuously shifting scenario' of operations?

What is the optimal location of a logistics hub considering the focus of operations?

What are the metrics which can be used for benchmarking the results of vehicle movements for logistics hub served transport operations?

What productivity improvements (cost and time savings) are possible by the optimisation of the transportation function?

What sustainability benefits are accruable by optimisation of transport operations?

What are the possible effects of optimisation of transport operations when considered in conjunction with a technology mix of transport?

Detailed Methodology Proposed to be Adopted

Research Methodologies can be broadly categorized into Mono Method, Multi Method and Mixed Method methodologies. Objectives pertaining to the above Research Questions would each have a qualitative as well as a quantitative component, the former addressing managerial and implementation issues and opinions, and the latter quantifying the operational aspects. Quantification of qualitative data may be undertaken as a means to achieve triangulation of results. Hence, a Mixed Model Research Methodology is proposed to be employed for the study.

Amongst the research strategies discussed in literature, the Case Study strategy is considered the most appropriate for conduct of the proposed research due to the following reasons:-

Yin (2003) defines a case study as "*A Case Study is an empirical enquiry that investigates a contemporary phenomenon within its real life context; when the boundaries between the context are not clearly evident and in which multiple sources of evidence are used.*"

A Case Study investigates a specific phenomenon through an in-depth limited scope study, address context-bound knowledge and local realities. The independent or intervening variables are not controlled but outcomes and processes are measured extensively and systematically. It permits studying operations in their natural settings, generation of theories and inclusion of how and why questions. It is a useful tool when no prior research work exists.

A case study is a research strategy which focuses on dynamics present within a single setting.

A Case Study provides an intensive, holistic description of a single, bounded unit situated in a specific context to provide insights into real life situations. It is a versatile strategy which permits the use of a variety of research methods, the ability to establish rapport with research subjects and obtaining a sufficiently rich description that can be transferred to similar situations.

The research is proposed in an area which is entirely groundbreaking in the context of New Zealand, therefore, contemporary, for which no contextual literature or data in the form of a precedence exist. Processes within the scope of the research are proposed to be measured extensively, and has singularity of setting available for detailed investigation.

Further, the following four questions point to whether a case study is appropriate as a Research Strategy for a particular study or not (Ponelis, 2015):-

Can the phenomenon of interest be studied outside its natural setting?

No, since it is entirely contextual to the localized setting of the operations of Winstone Wallboards.

Must the study focus on contemporary events?

Yes, to be able to find contextual outcomes so that the basic research problem may be answered in the affirmative or negative with individual outcomes contributing to various facets of the stated research problem.

Is control or manipulation of subjects or events necessary [or possible]?

No, since research is proposed to be conducted on an 'as-is, where-is' basis. Theoretical manipulation of parameters can be undertaken for a 'what-if' perspective, where the scenario(s) cannot be or are not being implemented, and therefore, not available for investigation.

Does the phenomenon of interest enjoy an established theoretical base?

Yes, it does. The entire exercise is being undertaken based on outcomes of similar implementations in West Europe, East Europe and continental USA, some of which have been referred to in the Literature Review.

The Proposed Case Study

The Single Exploratory Case Study is proposed to have qualitative and quantitative components as sub-units. Each sub-unit will relate to an independent aspect of the transport operations. Results obtained from each of the proposed sub-units will attempt to achieve the research objective defining the sub-unit, and therefore, answer the linked research question. The overall combination of results of each sub-unit when considered as a set of results of the Case Study, will point to an answer for the overall Research Aim *viz* to quantify accrual of sustainability benefits, as a result of optimisation of transport operations, keeping in view that the implementation is taking place in a set of physical environment constants, *viz* location, peculiarities of the region, and that operations based on a 'continuously shifting scenario'. Generalisations of the results may be undertaken during subsequent studies where-in the results achieved may be linked to the governing variables, and therefore, implementation in other environments within the broad context of New Zealand may be commented upon.

f) Consent Forms

Consent Form

Project title: ***The relevance of construction consolidation centres in the New Zealand context and developing a universal model for application***

Supervisor: ***Professor John E. Tookey***

Researcher: ***Kamal Dhawan***

○ I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that notes will be taken during the interviews and that they will also be audio-taped and transcribed.

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.

○ I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.

○ I agree to take part in this research.

○ I wish to receive a summary of the research findings (please tick one): Yes○ No○

Participant's signature: ……………………………………………………………………………………

Participant's name: ……………………………………………………………………………………

Participant's Contact Details (if appropriate):

………………………………………………………………………………………

………………………………………………………………………………………

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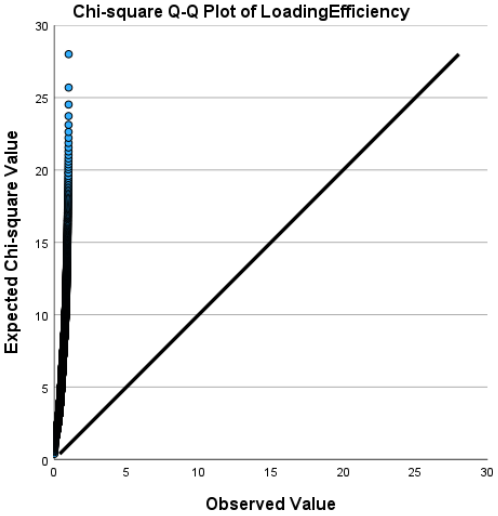
………………………………………………………………………………………

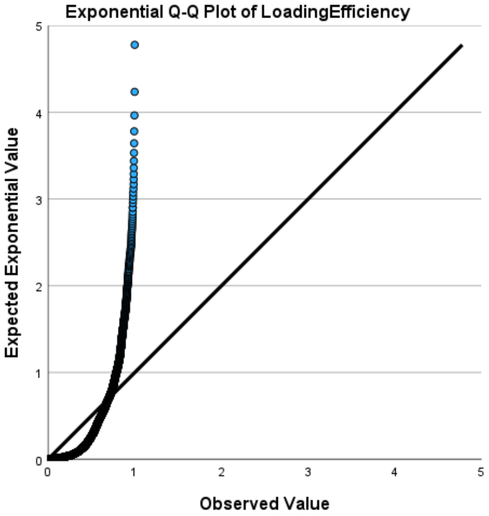
Date:

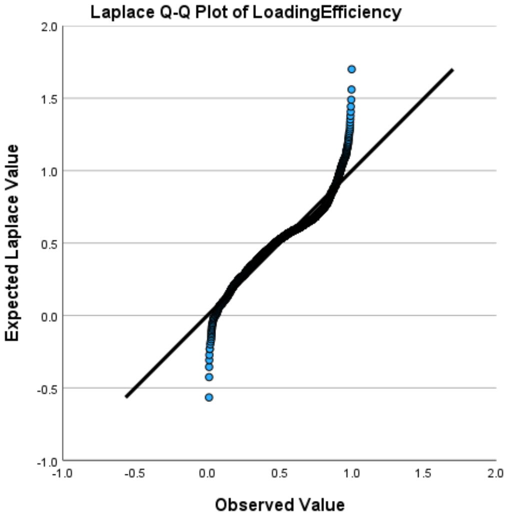
Approved by the Auckland University of Technology Ethics Committee on 10 March 2022 AUTEC Reference number 20/272

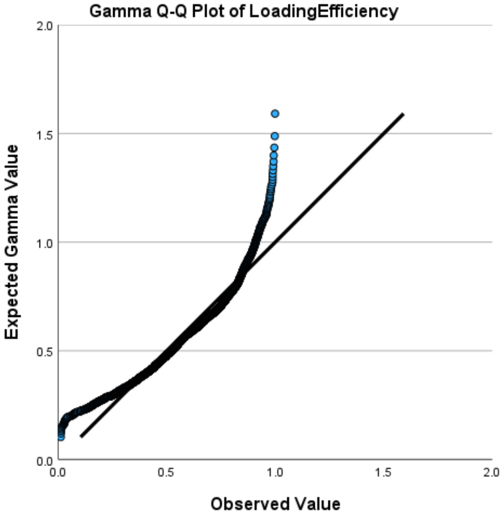
Note: The Participant should retain a copy of this form.

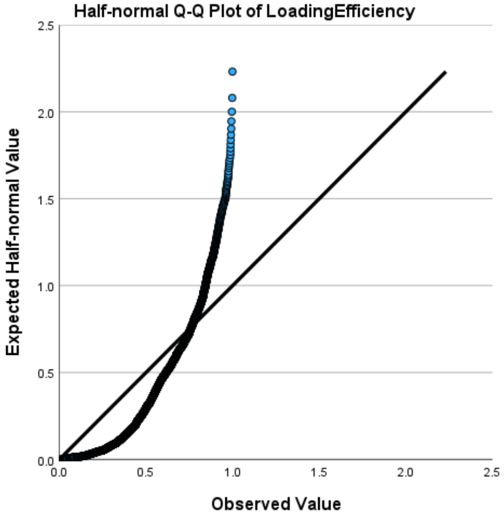
Appendix B *Q-Q plots of loading efficiency vs various statistical distributions (SPSS)*

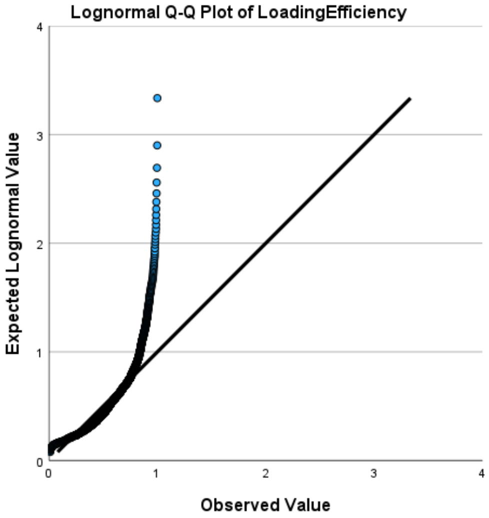

Chi-square Q-Q Plot of LoadingEfficiency

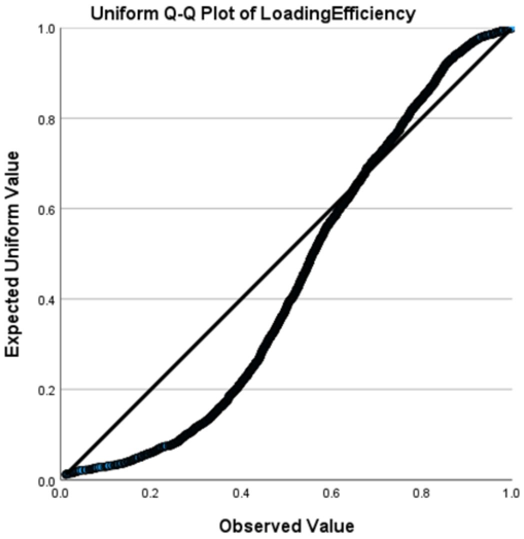

Exponential Q-Q Plot of LoadingEfficiency

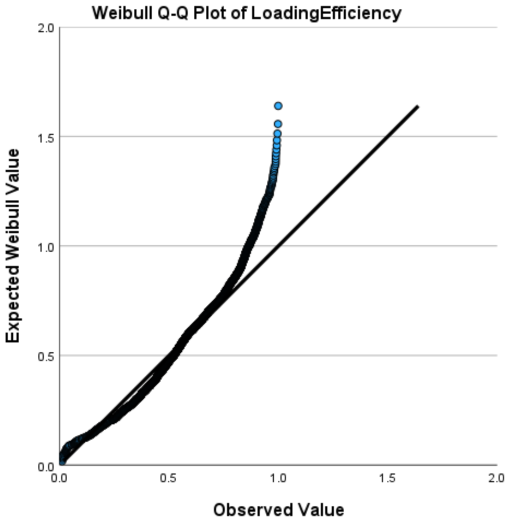

Laplace Q-Q Plot of LoadingEfficiency


Gamma Q-Q Plot of LoadingEfficiency

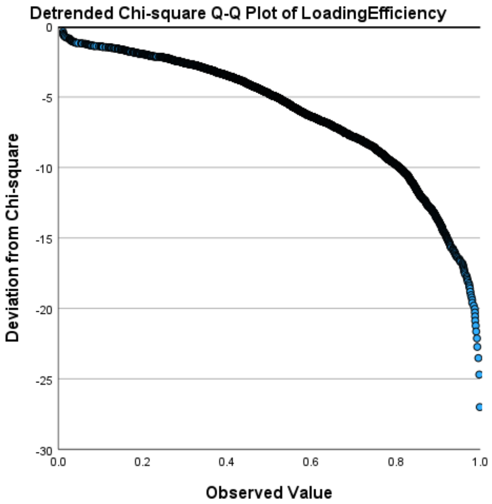

Half-normal Q-Q Plot of LoadingEfficiency

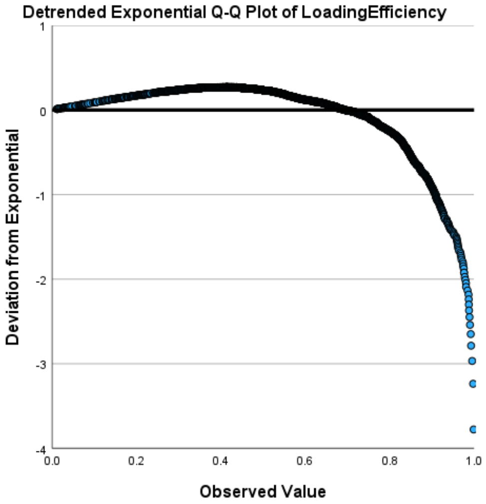

Lognormal Q-Q Plot of LoadingEfficiency

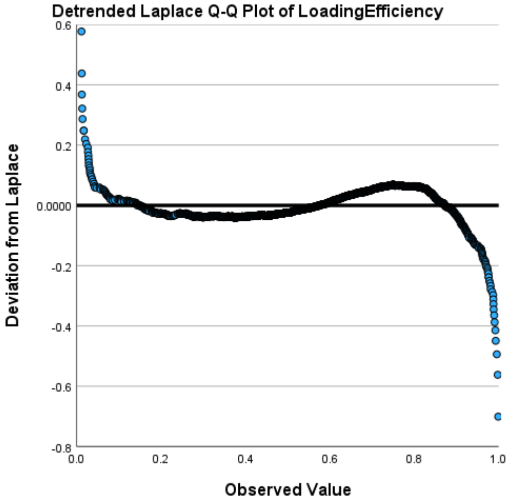

Uniform Q-Q Plot of LoadingEfficiency
Expected Uniform Value
Observed Value
0.0
0.2
0.4
0.6
0.8
1.0

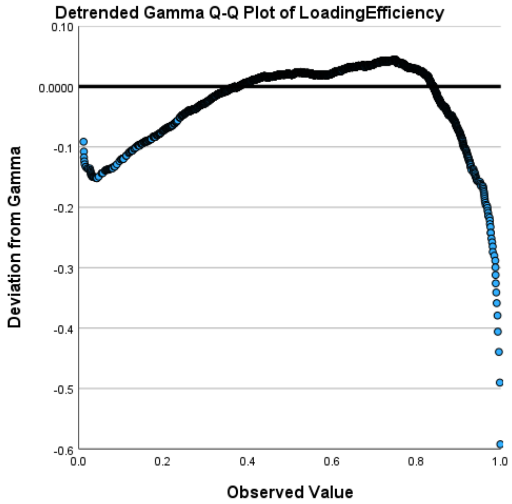

Weibull Q-Q Plot of LoadingEfficiency
Expected Weibull Value
Observed Value
0.0
0.5
1.0
1.5
2.0

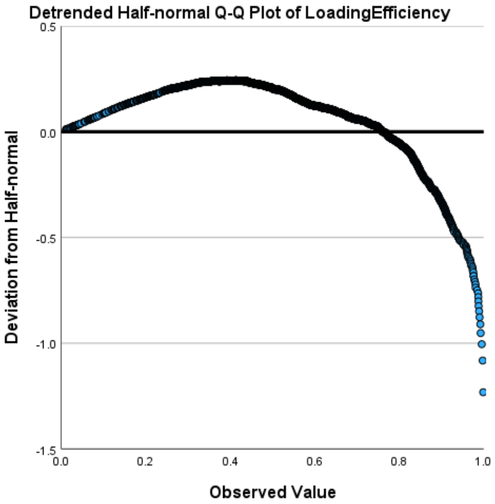
Appendix C *Detrended Q-Q plots of loading efficiency vs various statistical distributions (SPSS)*

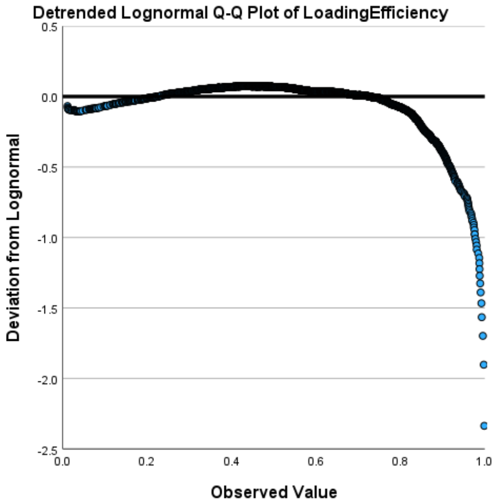


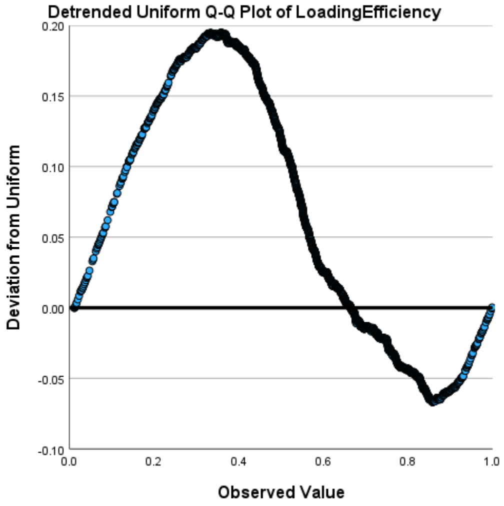


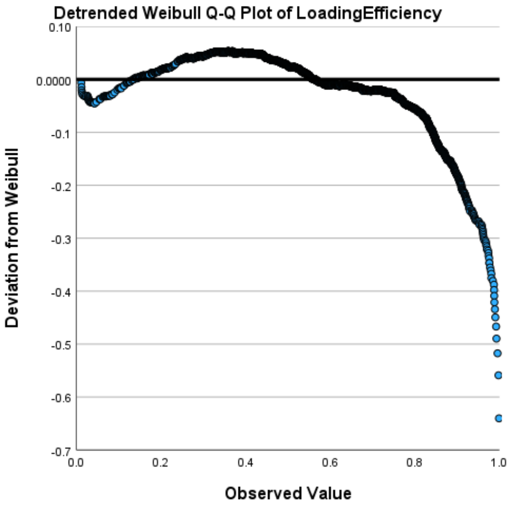




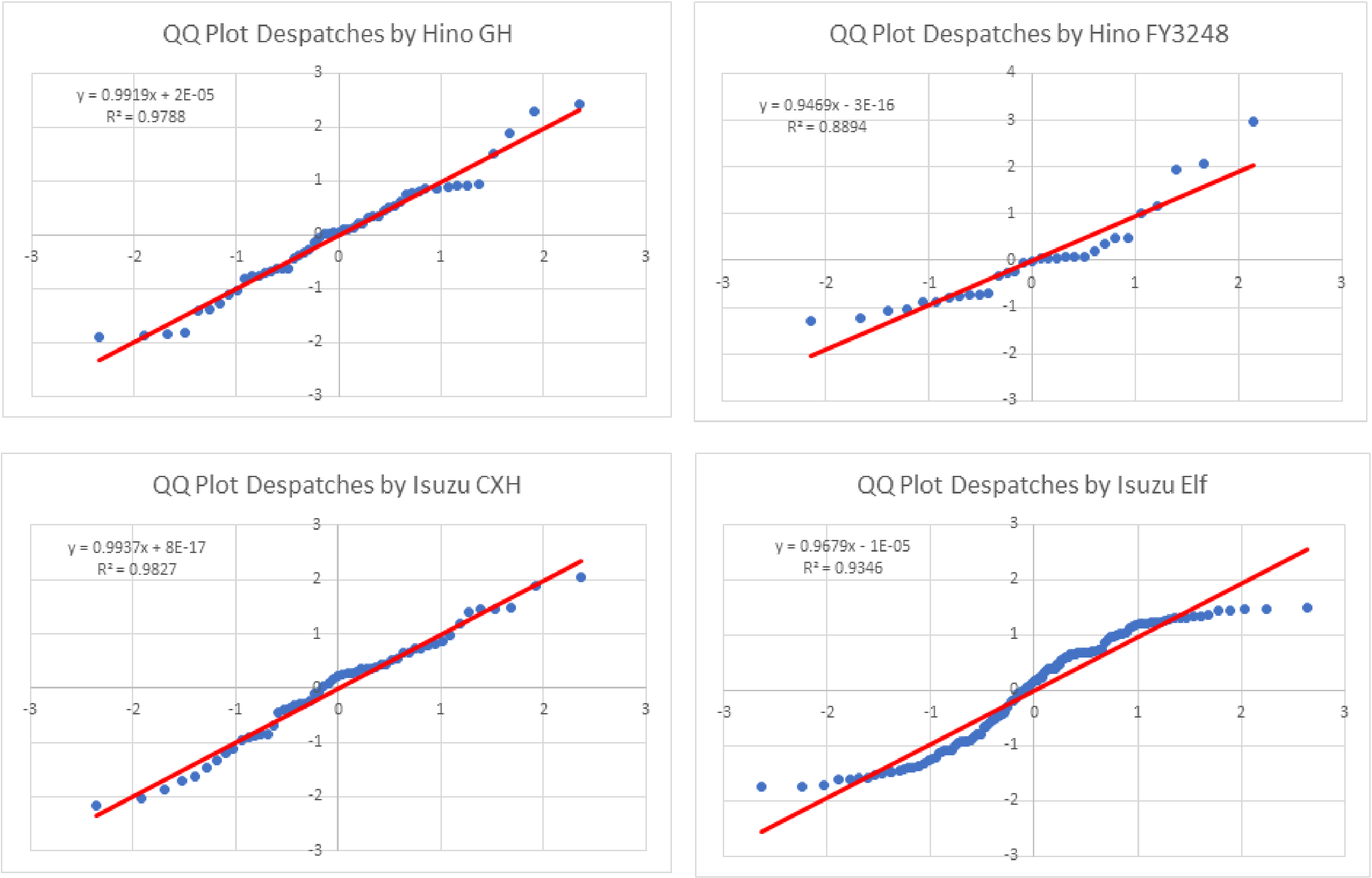


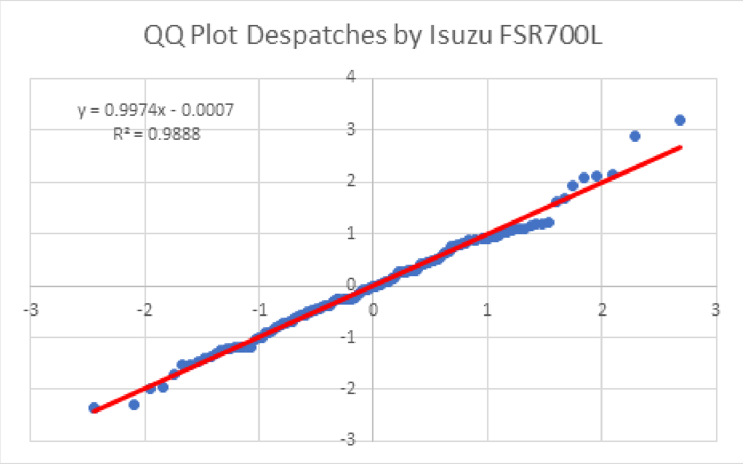


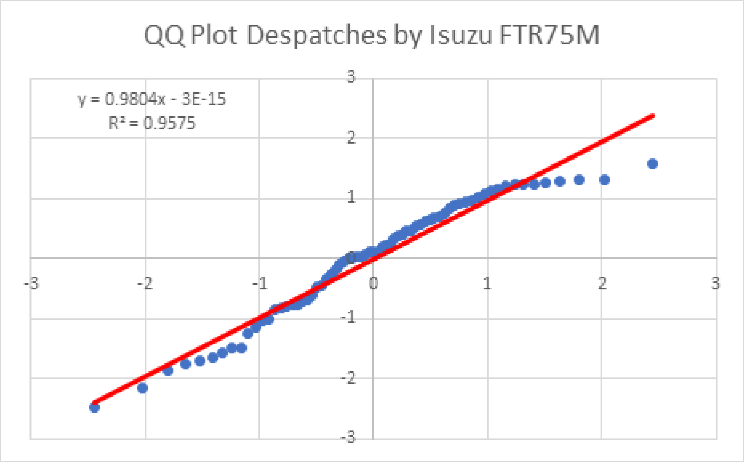

Detrended Uniform Q-Q Plot of LoadingEfficiency
Deviation from Uniform
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
0.0
0.2
0.4
0.6
0.8
1.0
Observed Value

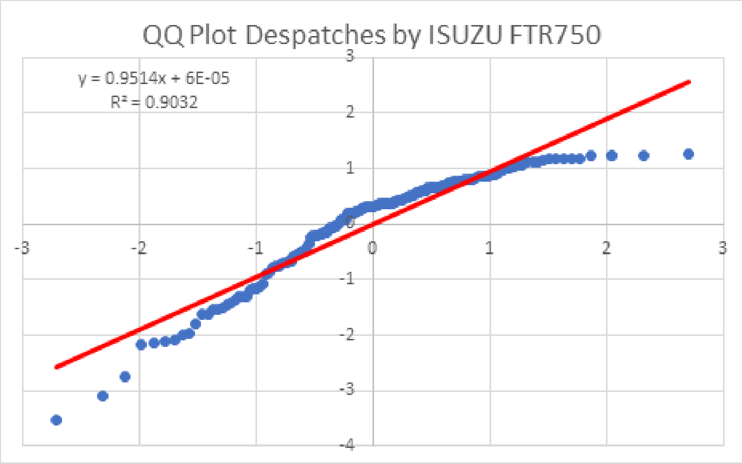

Detrended Weibull Q-Q Plot of LoadingEfficiency
Deviation from Weibull
0.10
0.0000
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
0.0
0.2
0.4
0.6
0.8
1.0
Observed Value

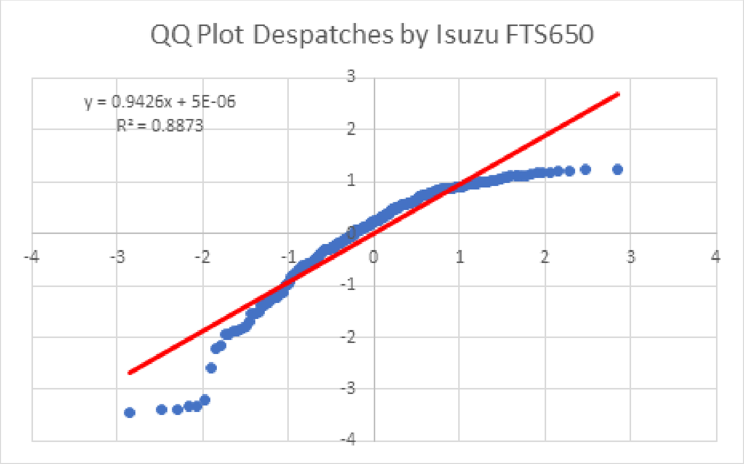
Appendix D *Normal Q-Q plots of despatch by various truck models for testing the normality of despatch data (MSExcel)*

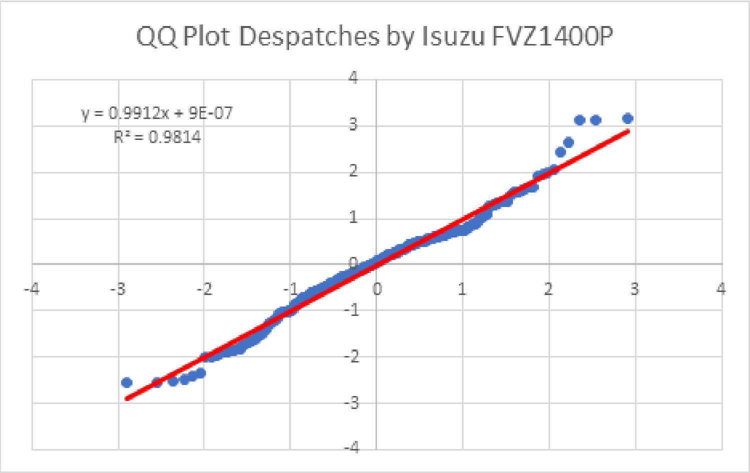


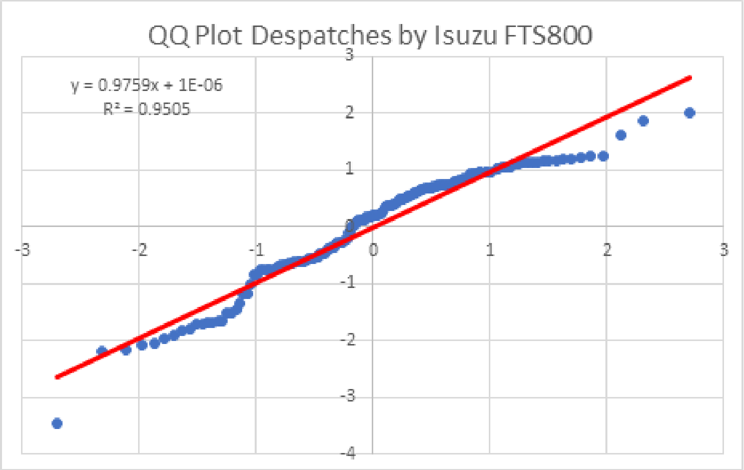

QQ Plot Despatches by Isuzu FSR700L
y = 0.9974x - 0.0007
R² = 0.9888
4
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

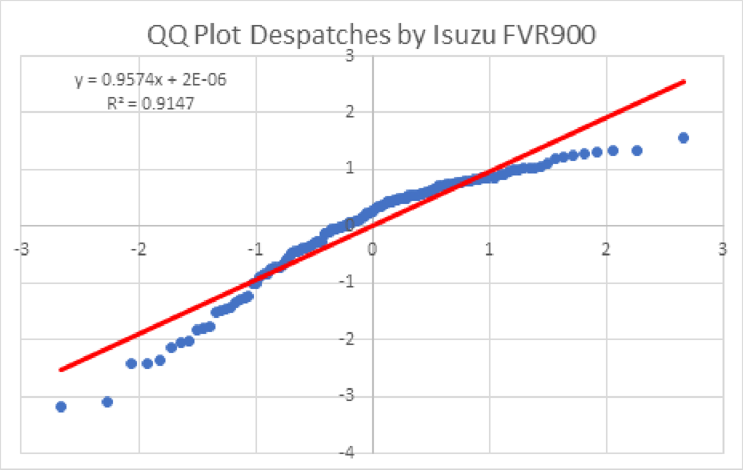

QQ Plot Despatches by Isuzu FTR75M
y = 0.9804x - 3E-15
R² = 0.9575
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3


QQ Plot Despatches by ISUZU FTR750
y = 0.9514x + 6E-05
R² = 0.9032
3
2
1
0
-1
-2
-3
-4
-3
-2
-1
0
1
2
3


QQ Plot Despatches by Isuzu FTS650
y = 0.9426x + 5E-06
R² = 0.8873
3
2
1
0
-1
-2
-3
-4
-4
-3
-2
-1
0
1
2
3
4


QQ Plot Despatches by Isuzu FVZ1400P
y = 0.9912x + 9E-07
R² = 0.9814
4
3
2
1
0
-1
-2
-3
-4
-4
-3
-2
-1
0
1
2
3
4


QQ Plot Despatches by Isuzu FTS800
y = 0.9759x + 1E-06
R² = 0.9505
3
2
1
0
-1
-2
-3
-4
-3
-2
-1
0
1
2
3


QQ Plot Despatches by Isuzu FVR900
y = 0.9574x + 2E-06
R² = 0.9147
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2
1
0
-1
-2
-3
-4
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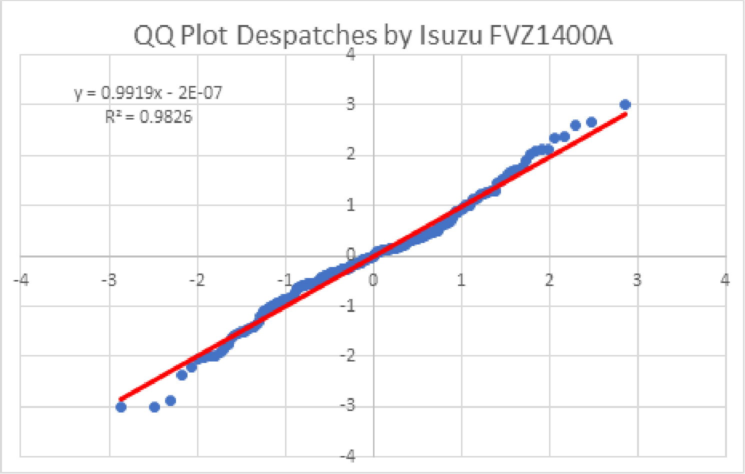
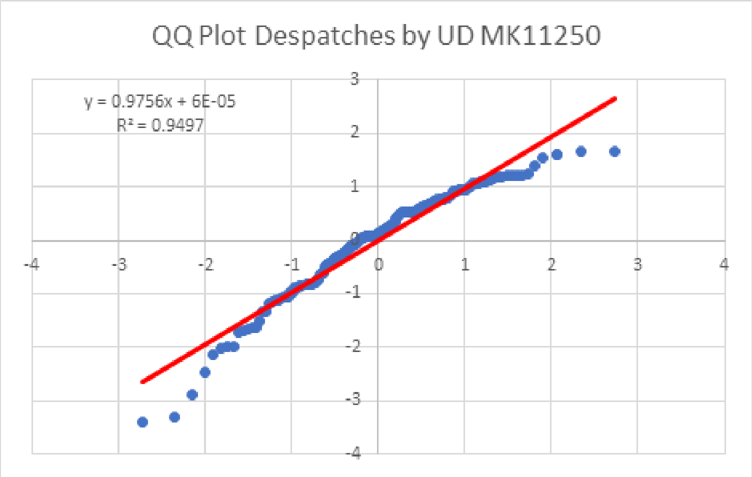
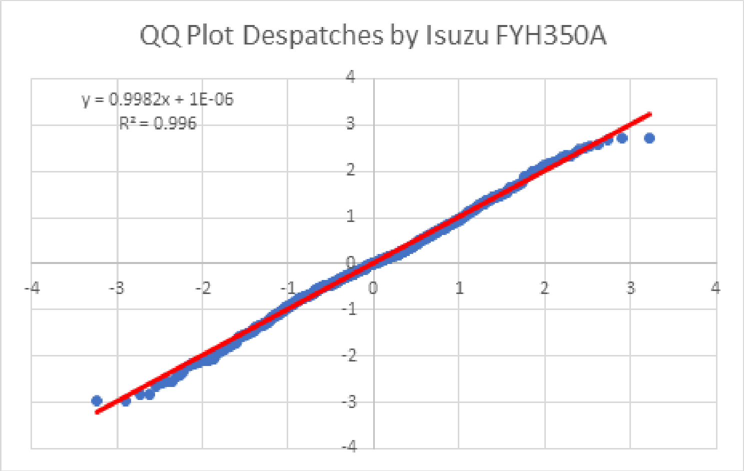
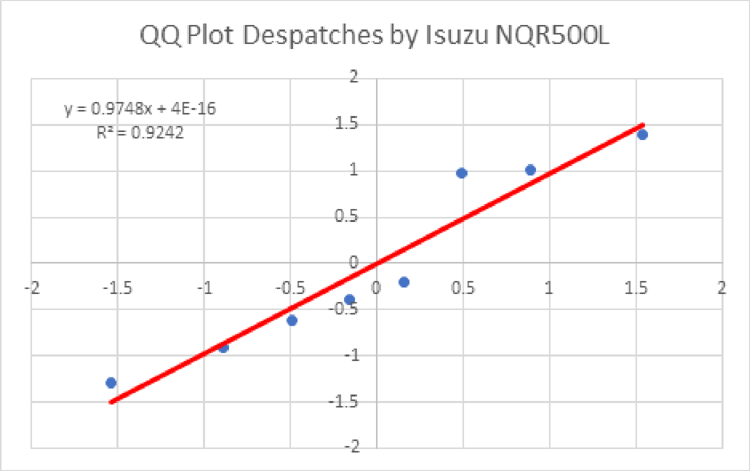
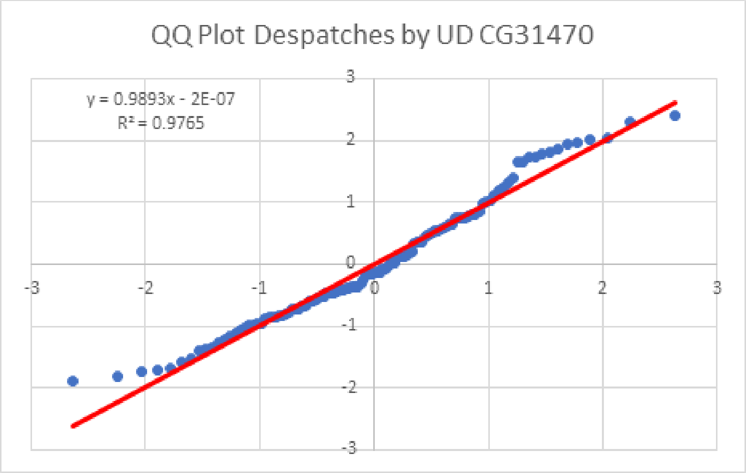
-2
-1
0
1
2
3

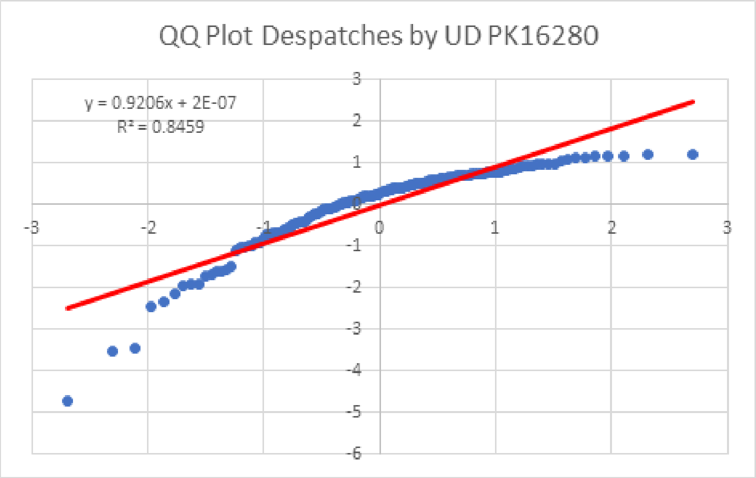

QQ Plot Despatches by Isuzu FVZ1400A
y = 0.9919x - 2E-07
R² = 0.9826
4
3
2
1
0
-1
-2
-3
-4
-4
-3
-2
-1
0
1
2
3
4


QQ Plot Despatches by UD MK11250


QQ Plot Despatches by Isuzu FYH350A

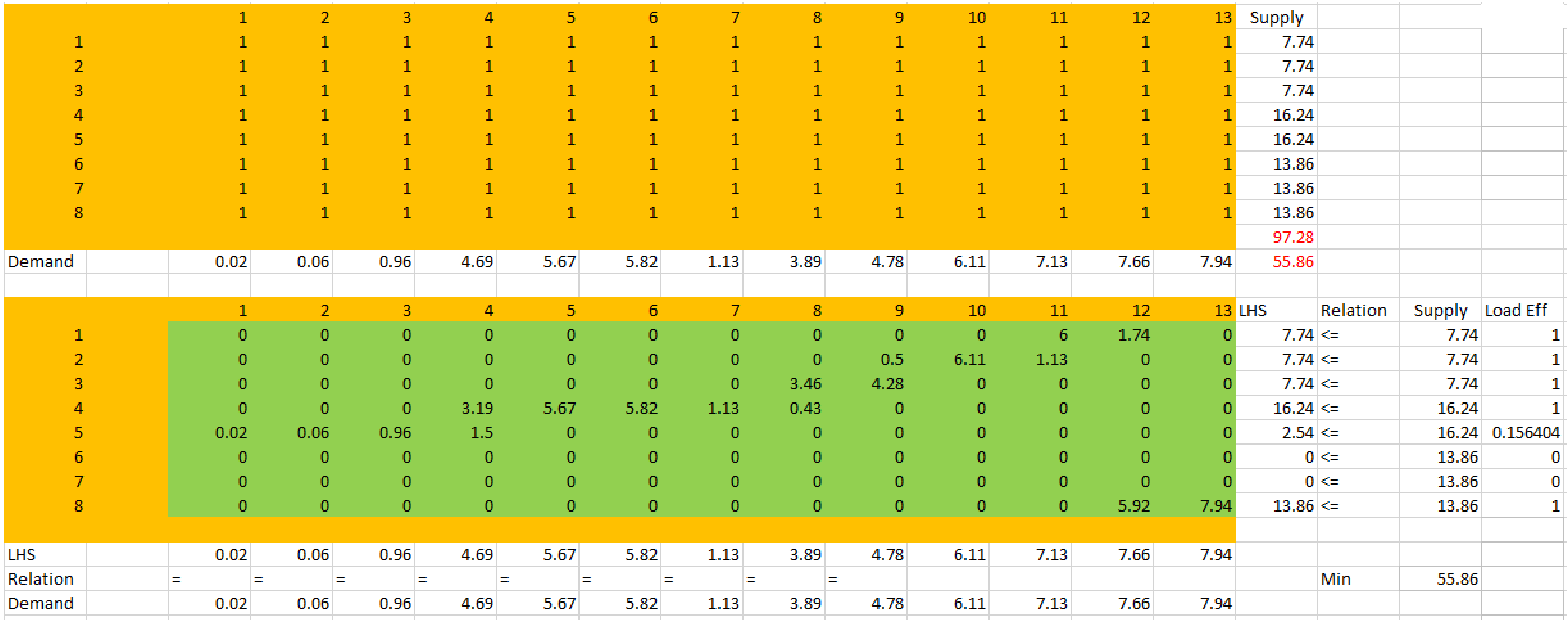

QQ Plot Despatches by Isuzu NQR500L


QQ Plot Despatches by UD CG31470


QQ Plot Despatches by UD PK16280
y = 0.9206x + 2E-07
R² = 0.8459
3
2
1
0
-1
-2
-3
-4
-5
-6
-3
-2
-1
0
1
2
3

Appendix E *Application of transportation model to daily truck trips for optimising transport (MSExcel)*

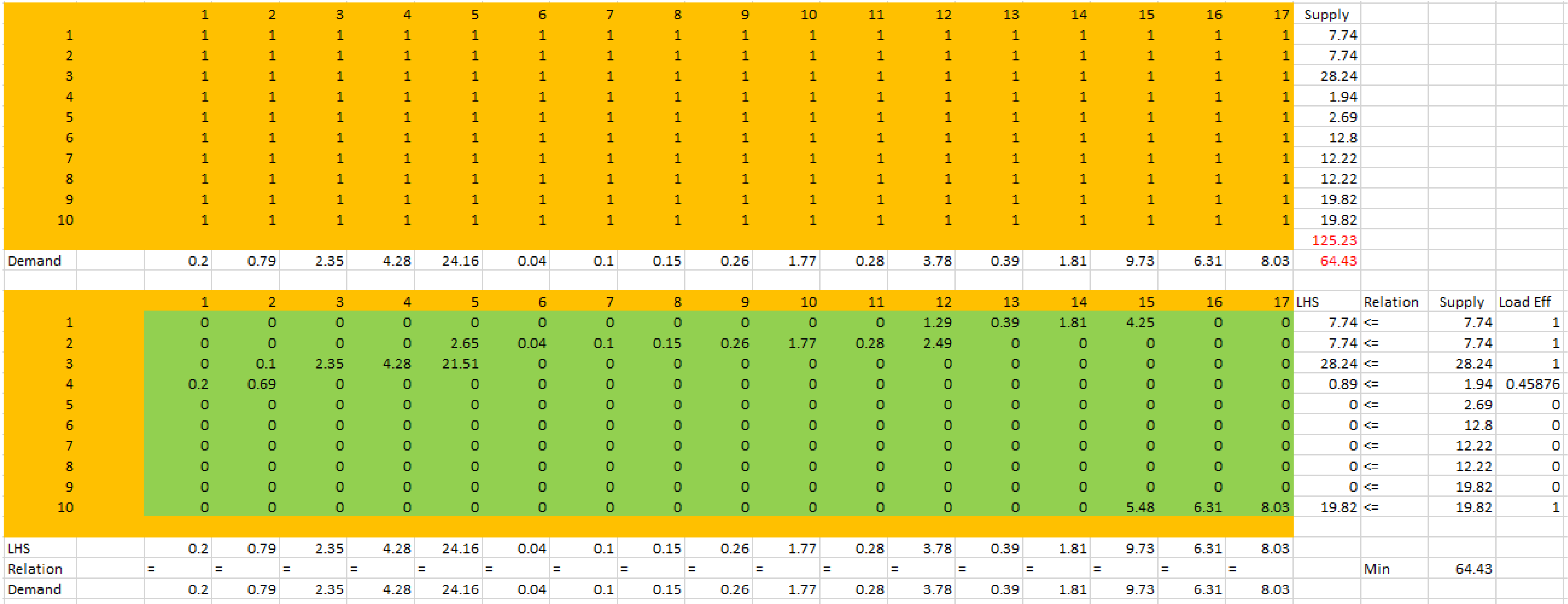
a) 01 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
2		1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
3		1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
4		1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
5		1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
6		1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
7		1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
8		1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
															97.28
Demand		0.02	0.06	0.96	4.69	5.67	5.82	1.13	3.89	4.78	6.11	7.13	7.66	7.94	55.86

		1	2	3	4	5	6	7	8	9	10	11	12	13	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	6	1.74	0	7.74	<=	7.74	1
2		0	0	0	0	0	0	0	0	0.5	6.11	1.13	0	0	7.74	<=	7.74	1
3		0	0	0	0	0	0	0	3.46	4.28	0	0	0	0	7.74	<=	7.74	1
4		0	0	0	3.19	5.67	5.82	1.13	0.43	0	0	0	0	0	16.24	<=	16.24	1
5		0.02	0.06	0.96	1.5	0	0	0	0	0	0	0	0	0	2.54	<=	16.24	0.156404
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
8		0	0	0	0	0	0	0	0	0	0	0	5.92	7.94	13.86	<=	13.86	1
LHS		0.02	0.06	0.96	4.69	5.67	5.82	1.13	3.89	4.78	6.11	7.13	7.66	7.94				
Relation		=	=	=	=	=	=	=	=	=						Min	55.86	
Demand		0.02	0.06	0.96	4.69	5.67	5.82	1.13	3.89	4.78	6.11	7.13	7.66	7.94				

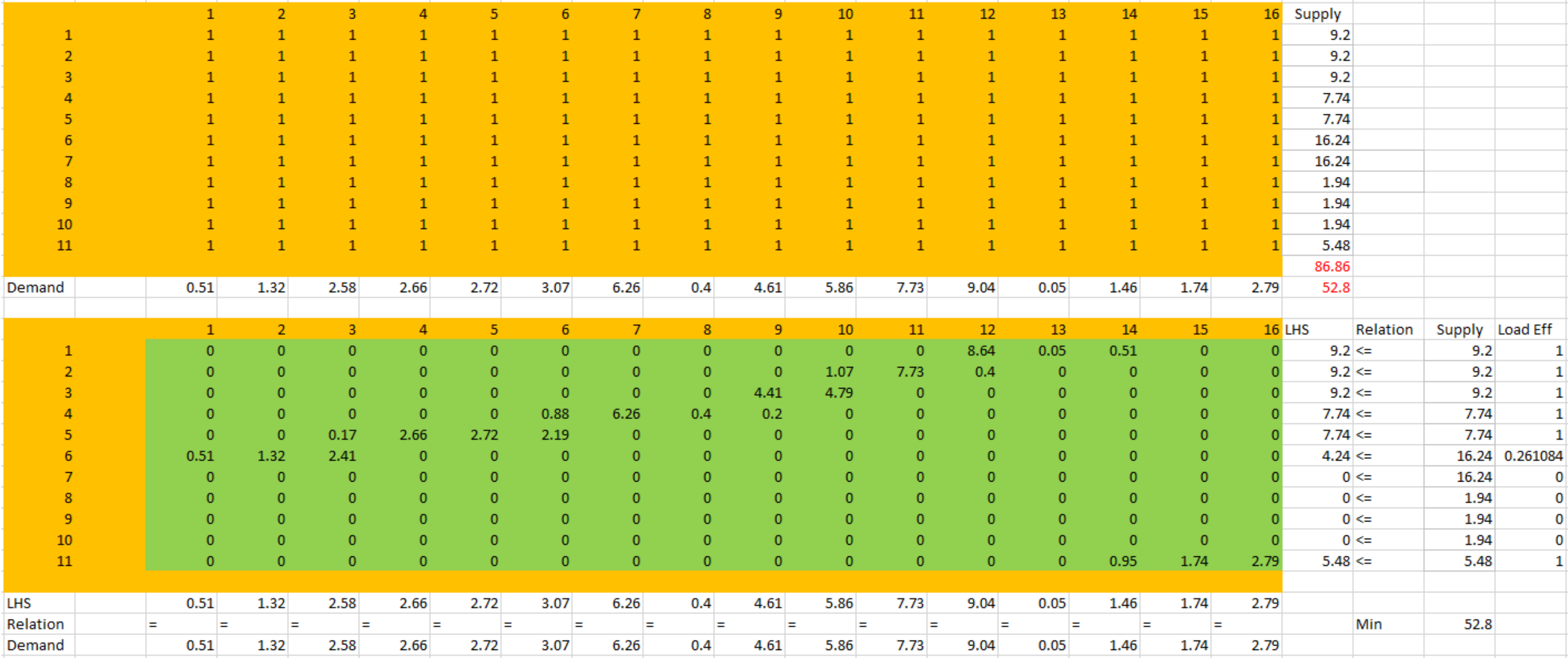
b) 02 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	28.24
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2.69
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.22
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.22
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.82
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.82
																			125.23
Demand		0.2	0.79	2.35	4.28	24.16	0.04	0.1	0.15	0.26	1.77	0.28	3.78	0.39	1.81	9.73	6.31	8.03	64.43

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	1.29	0.39	1.81	4.25	0	0	7.74	<=	7.74	1
2		0	0	0	0	2.65	0.04	0.1	0.15	0.26	1.77	0.28	2.49	0	0	0	0	0	7.74	<=	7.74	1
3		0	0.1	2.35	4.28	21.51	0	0	0	0	0	0	0	0	0	0	0	0	28.24	<=	28.24	1
4		0.2	0.69	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.89	<=	1.94	0.45876
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	2.69	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.8	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.22	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.22	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.82	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.48	6.31	8.03	19.82	<=	19.82	1
LHS		0.2	0.79	2.35	4.28	24.16	0.04	0.1	0.15	0.26	1.77	0.28	3.78	0.39	1.81	9.73	6.31	8.03				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	64.43	
Demand		0.2	0.79	2.35	4.28	24.16	0.04	0.1	0.15	0.26	1.77	0.28	3.78	0.39	1.81	9.73	6.31	8.03				

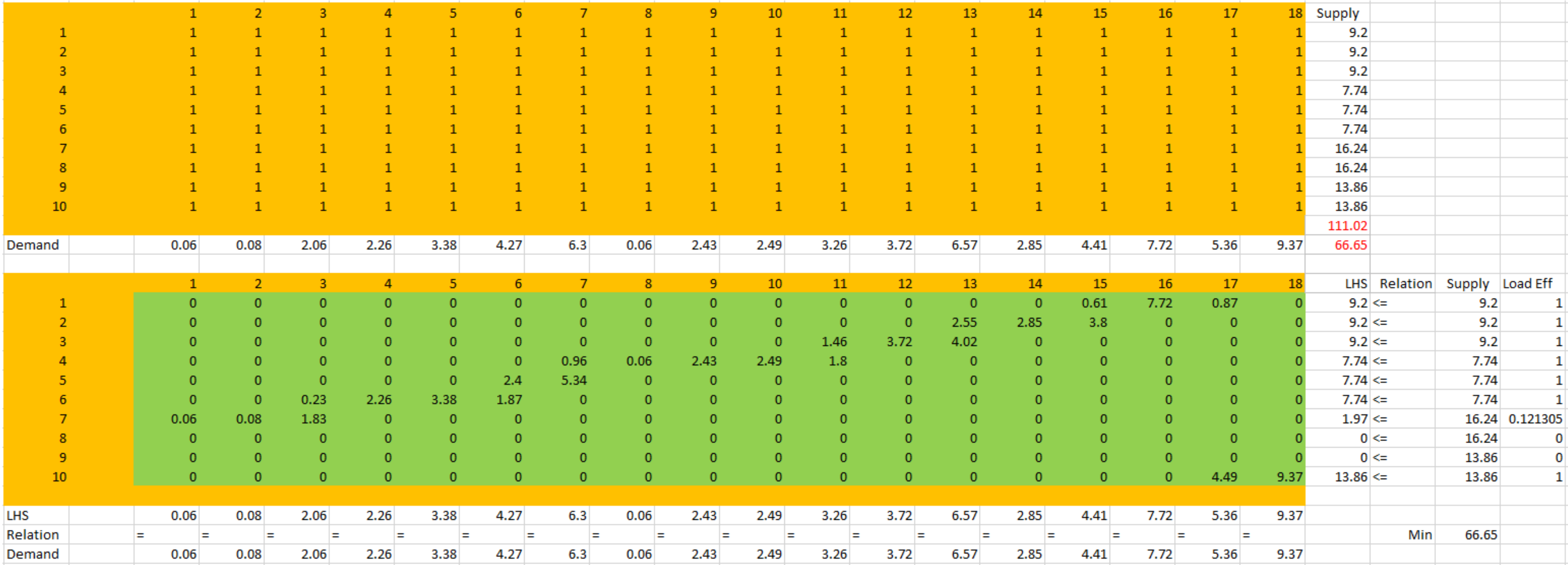
c) 05 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.48
																		86.86
Demand		0.51	1.32	2.58	2.66	2.72	3.07	6.26	0.4	4.61	5.86	7.73	9.04	0.05	1.46	1.74	2.79	52.8

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	8.64	0.05	0.51	0	0	9.2	<=	9.2	1
2		0	0	0	0	0	0	0	0	0	1.07	7.73	0.4	0	0	0	0	9.2	<=	9.2	1
3		0	0	0	0	0	0	0	0	4.41	4.79	0	0	0	0	0	0	9.2	<=	9.2	1
4		0	0	0	0	0	0.88	6.26	0.4	0.2	0	0	0	0	0	0	0	7.74	<=	7.74	1
5		0	0	0.17	2.66	2.72	2.19	0	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
6		0.51	1.32	2.41	0	0	0	0	0	0	0	0	0	0	0	0	0	4.24	<=	16.24	0.261084
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0.95	1.74	2.79	5.48	<=	5.48	1
LHS		0.51	1.32	2.58	2.66	2.72	3.07	6.26	0.4	4.61	5.86	7.73	9.04	0.05	1.46	1.74	2.79				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	52.8	
Demand		0.51	1.32	2.58	2.66	2.72	3.07	6.26	0.4	4.61	5.86	7.73	9.04	0.05	1.46	1.74	2.79				

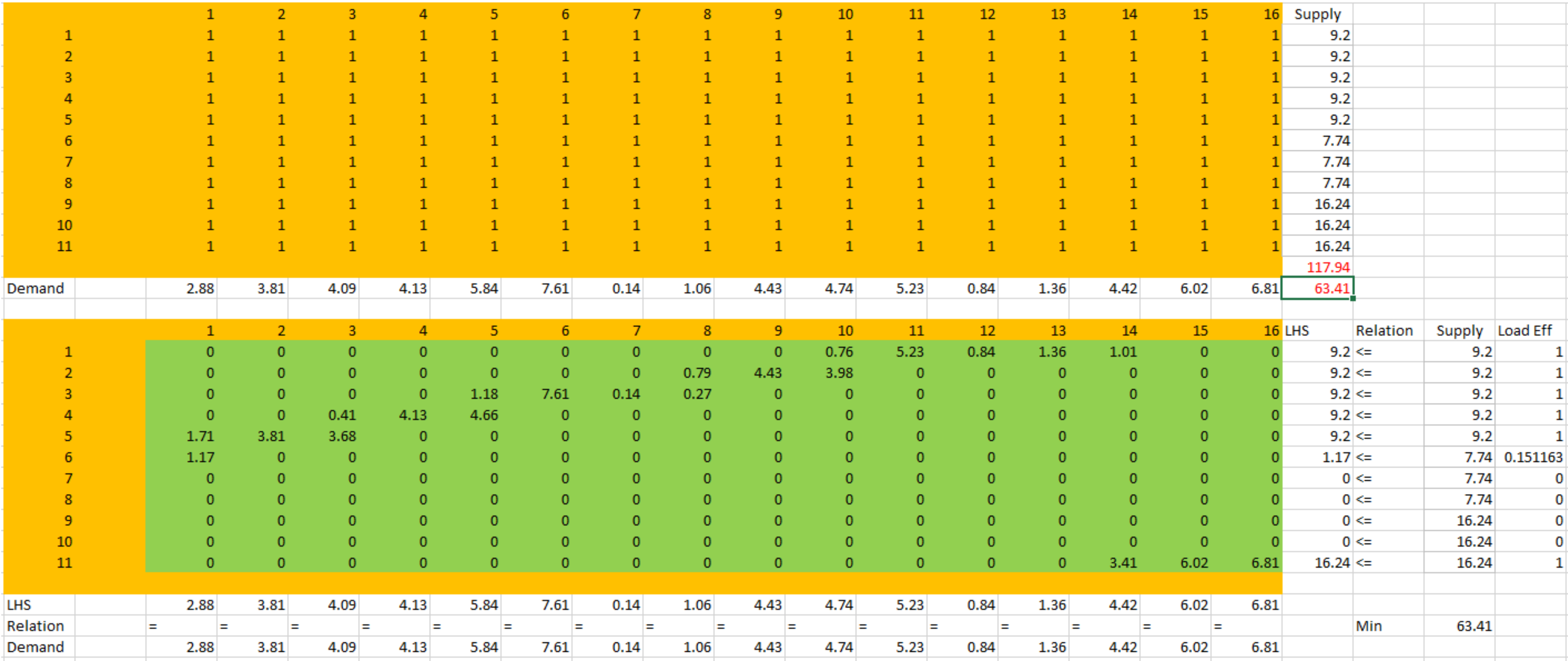
d) 06 October 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
																			111.02
Demand	0.06	0.08	2.06	2.26	3.38	4.27	6.3	0.06	2.43	2.49	3.26	3.72	6.57	2.85	4.41	7.72	5.36	9.37	66.65

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.61	7.72	0.87	0	9.2	<=	9.2	1
2	0	0	0	0	0	0	0	0	0	0	0	0	2.55	2.85	3.8	0	0	0	9.2	<=	9.2	1
3	0	0	0	0	0	0	0	0	0	0	1.46	3.72	4.02	0	0	0	0	0	9.2	<=	9.2	1
4	0	0	0	0	0	0	0.96	0.06	2.43	2.49	1.8	0	0	0	0	0	0	0	7.74	<=	7.74	1
5	0	0	0	0	0	2.4	5.34	0	0	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
6	0	0	0.23	2.26	3.38	1.87	0	0	0	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
7	0.06	0.08	1.83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.97	<=	16.24	0.121305
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.49	9.37	13.86	<=	13.86	1
LHS	0.06	0.08	2.06	2.26	3.38	4.27	6.3	0.06	2.43	2.49	3.26	3.72	6.57	2.85	4.41	7.72	5.36	9.37				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	66.65	
Demand	0.06	0.08	2.06	2.26	3.38	4.27	6.3	0.06	2.43	2.49	3.26	3.72	6.57	2.85	4.41	7.72	5.36	9.37				

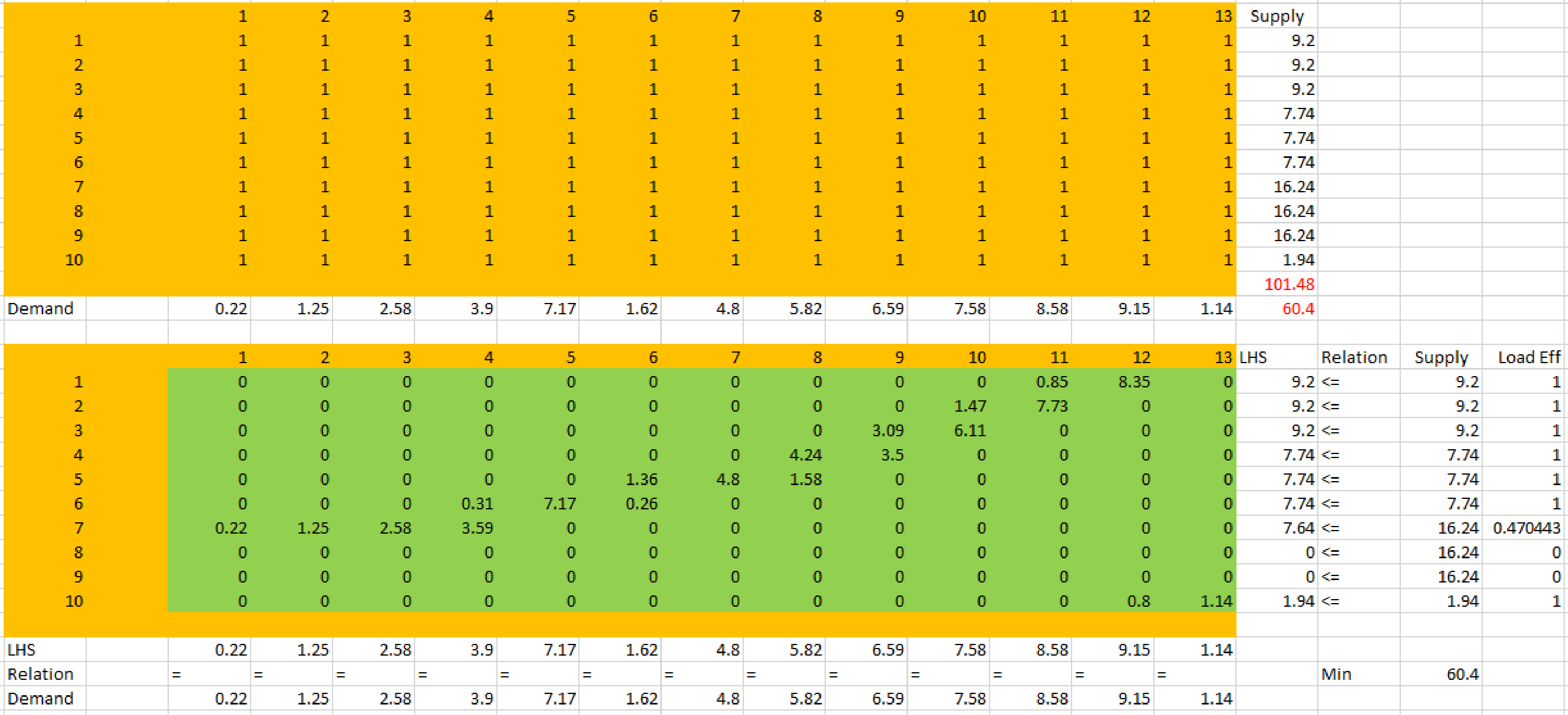
e) 07 October 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
																	117.94
Demand	2.88	3.81	4.09	4.13	5.84	7.61	0.14	1.06	4.43	4.74	5.23	0.84	1.36	4.42	6.02	6.81	63.41

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	0.76	5.23	0.84	1.36	1.01	0	0	9.2	<=	9.2	1
2	0	0	0	0	0	0	0	0.79	4.43	3.98	0	0	0	0	0	0	9.2	<=	9.2	1
3	0	0	0	0	1.18	7.61	0.14	0.27	0	0	0	0	0	0	0	0	9.2	<=	9.2	1
4	0	0	0.41	4.13	4.66	0	0	0	0	0	0	0	0	0	0	0	9.2	<=	9.2	1
5	1.71	3.81	3.68	0	0	0	0	0	0	0	0	0	0	0	0	0	9.2	<=	9.2	1
6	1.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.17	<=	7.74	0.151163
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	7.74	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	7.74	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	3.41	6.02	6.81	16.24	<=	16.24	1
LHS	2.88	3.81	4.09	4.13	5.84	7.61	0.14	1.06	4.43	4.74	5.23	0.84	1.36	4.42	6.02	6.81				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	63.41	
Demand	2.88	3.81	4.09	4.13	5.84	7.61	0.14	1.06	4.43	4.74	5.23	0.84	1.36	4.42	6.02	6.81				

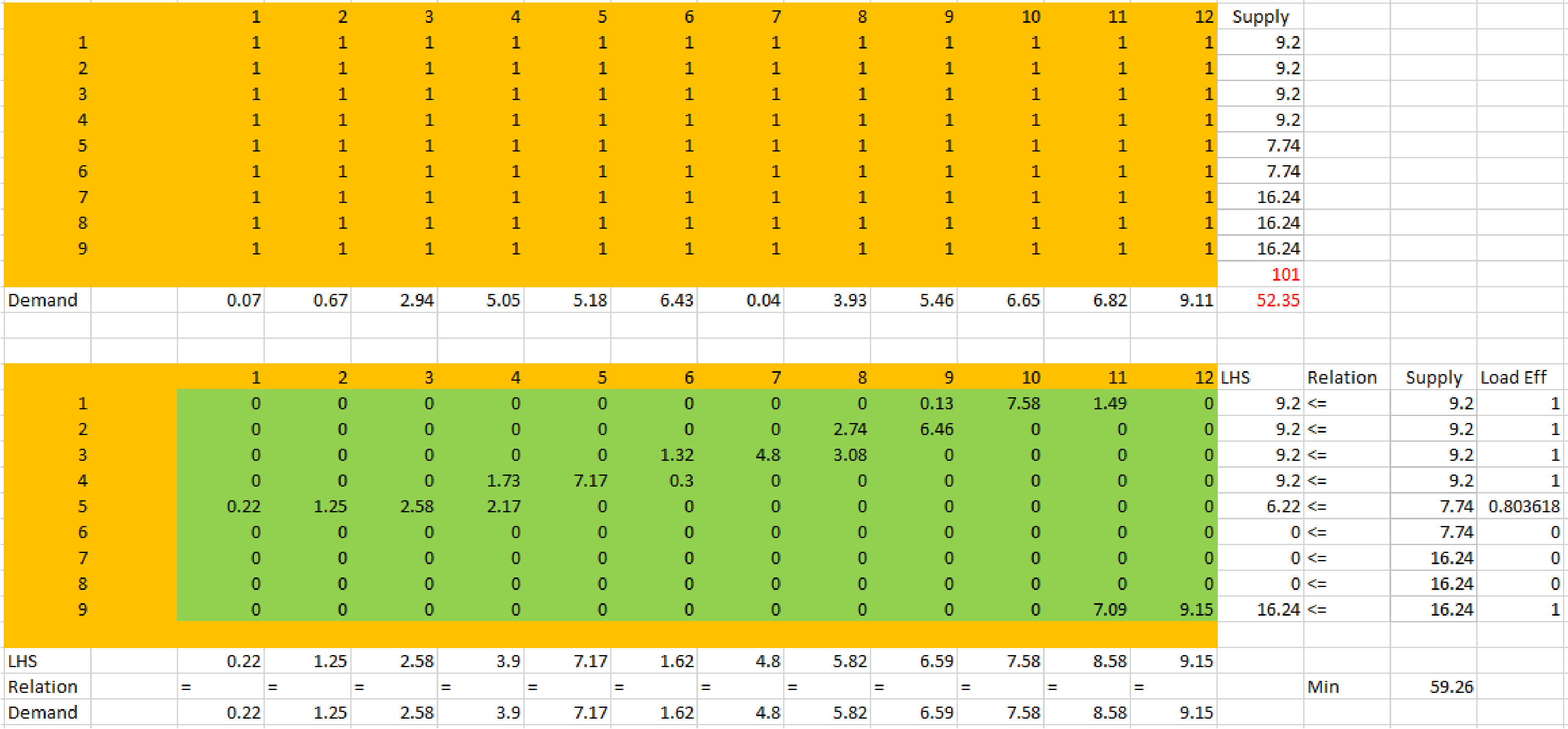
f) 08 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2		1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3		1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
4		1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
5		1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
6		1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
7		1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
8		1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
9		1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
															101.48
Demand		0.22	1.25	2.58	3.9	7.17	1.62	4.8	5.82	6.59	7.58	8.58	9.15	1.14	60.4

		1	2	3	4	5	6	7	8	9	10	11	12	13	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0.85	8.35	0	9.2	<=	9.2	1
2		0	0	0	0	0	0	0	0	0	1.47	7.73	0	0	9.2	<=	9.2	1
3		0	0	0	0	0	0	0	0	3.09	6.11	0	0	0	9.2	<=	9.2	1
4		0	0	0	0	0	0	0	4.24	3.5	0	0	0	0	7.74	<=	7.74	1
5		0	0	0	0	0	1.36	4.8	1.58	0	0	0	0	0	7.74	<=	7.74	1
6		0	0	0	0.31	7.17	0.26	0	0	0	0	0	0	0	7.74	<=	7.74	1
7		0.22	1.25	2.58	3.59	0	0	0	0	0	0	0	0	0	7.64	<=	16.24	0.470443
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
10		0	0	0	0	0	0	0	0	0	0	0	0.8	1.14	1.94	<=	1.94	1
LHS		0.22	1.25	2.58	3.9	7.17	1.62	4.8	5.82	6.59	7.58	8.58	9.15	1.14				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=		Min	60.4	
Demand		0.22	1.25	2.58	3.9	7.17	1.62	4.8	5.82	6.59	7.58	8.58	9.15	1.14				

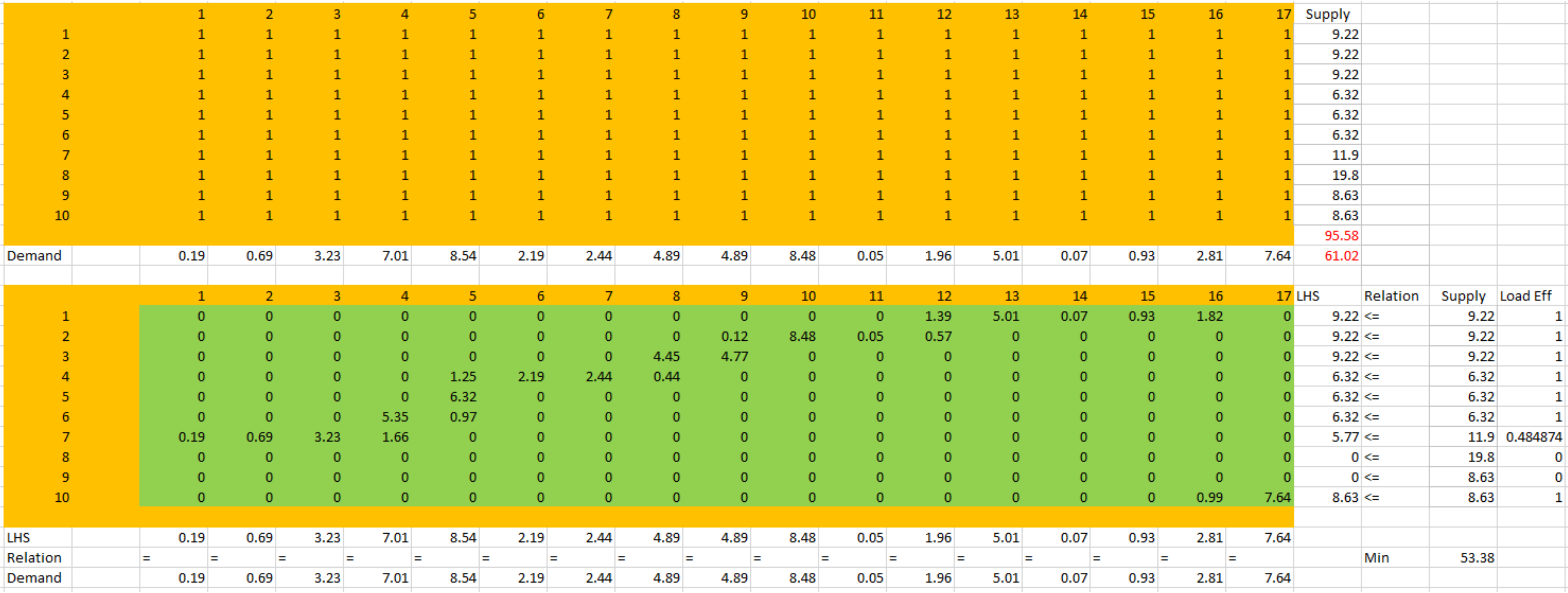
g) 09 October 2020



		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	9.2
2		1	1	1	1	1	1	1	1	1	1	1	1	9.2
3		1	1	1	1	1	1	1	1	1	1	1	1	9.2
4		1	1	1	1	1	1	1	1	1	1	1	1	9.2
5		1	1	1	1	1	1	1	1	1	1	1	1	7.74
6		1	1	1	1	1	1	1	1	1	1	1	1	7.74
7		1	1	1	1	1	1	1	1	1	1	1	1	16.24
8		1	1	1	1	1	1	1	1	1	1	1	1	16.24
9		1	1	1	1	1	1	1	1	1	1	1	1	16.24
														101
Demand		0.07	0.67	2.94	5.05	5.18	6.43	0.04	3.93	5.46	6.65	6.82	9.11	52.35

		1	2	3	4	5	6	7	8	9	10	11	12	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0.13	7.58	1.49	0	9.2	<=	9.2	1
2		0	0	0	0	0	0	0	2.74	6.46	0	0	0	9.2	<=	9.2	1
3		0	0	0	0	0	1.32	4.8	3.08	0	0	0	0	9.2	<=	9.2	1
4		0	0	0	1.73	7.17	0.3	0	0	0	0	0	0	9.2	<=	9.2	1
5		0.22	1.25	2.58	2.17	0	0	0	0	0	0	0	0	6.22	<=	7.74	0.803618
6		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	7.74	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
9		0	0	0	0	0	0	0	0	0	0	7.09	9.15	16.24	<=	16.24	1
LHS		0.22	1.25	2.58	3.9	7.17	1.62	4.8	5.82	6.59	7.58	8.58	9.15				
Relation		=	=	=	=	=	=	=	=	=	=	=	=		Min	59.26	
Demand		0.22	1.25	2.58	3.9	7.17	1.62	4.8	5.82	6.59	7.58	8.58	9.15				

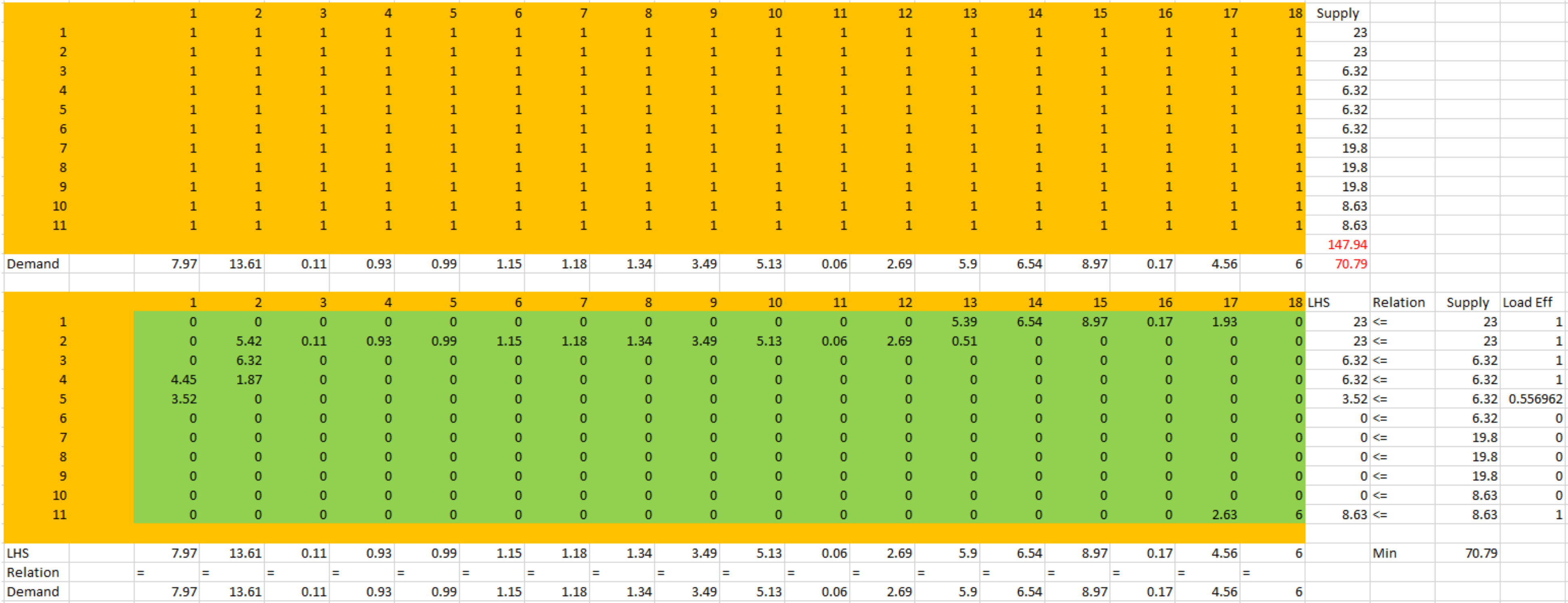
h) 12 October 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	11.9
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
9	1	1	1	1	1	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	1	1	1	1	1	8.63
																		95.58
Demand	0.19	0.69	3.23	7.01	8.54	2.19	2.44	4.89	4.89	8.48	0.05	1.96	5.01	0.07	0.93	2.81	7.64	61.02

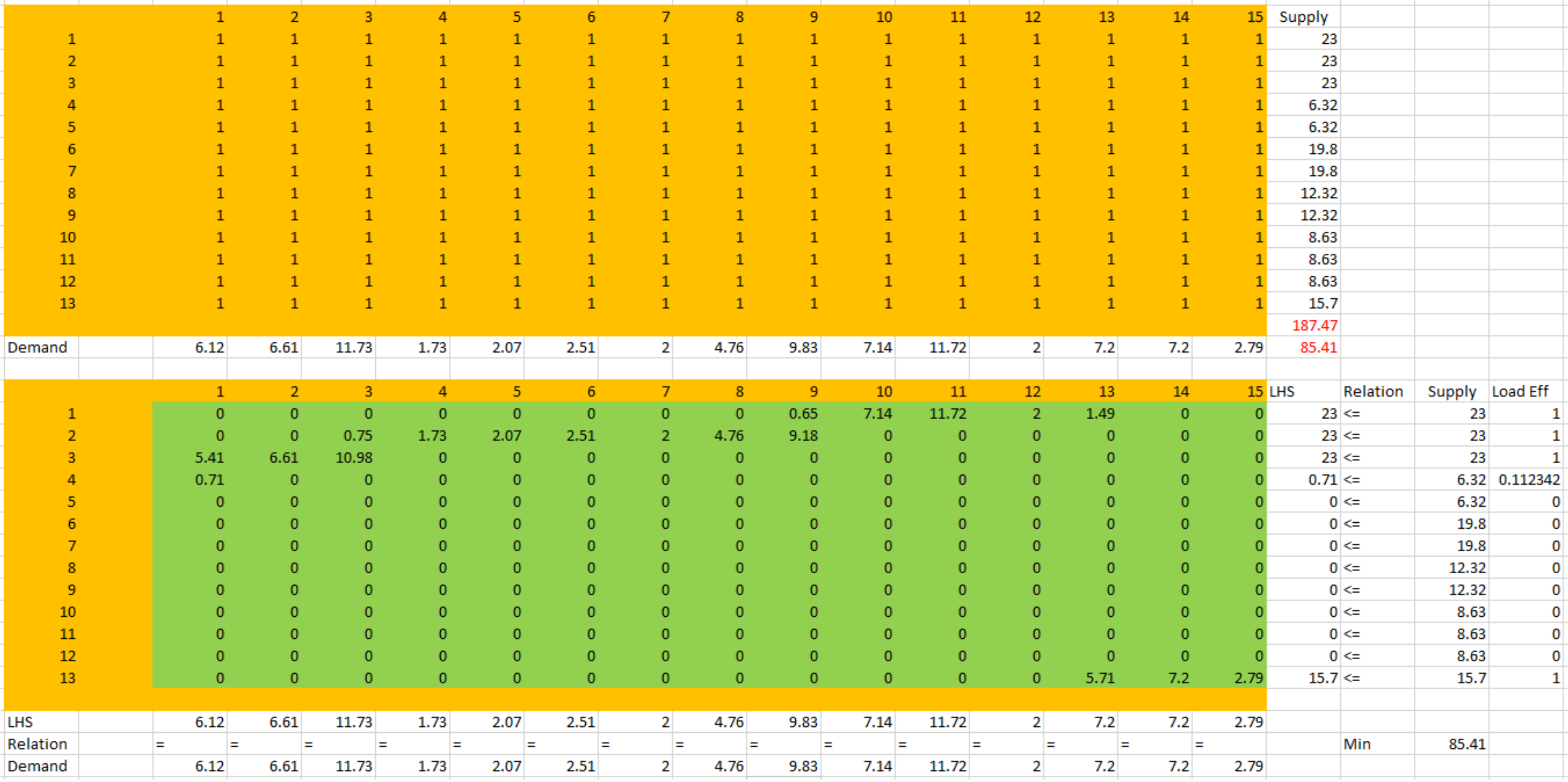
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	0	0	1.39	5.01	0.07	0.93	1.82	0	9.22	<=	9.22	1
2	0	0	0	0	0	0	0	0	0.12	8.48	0.05	0.57	0	0	0	0	0	9.22	<=	9.22	1
3	0	0	0	0	0	0	0	4.45	4.77	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
4	0	0	0	0	1.25	2.19	2.44	0.44	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
5	0	0	0	0	6.32	0	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
6	0	0	0	5.35	0.97	0	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
7	0.19	0.69	3.23	1.66	0	0	0	0	0	0	0	0	0	0	0	0	0	5.77	<=	11.9	0.484874
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.99	7.64	8.63	<=	8.63	1
LHS	0.19	0.69	3.23	7.01	8.54	2.19	2.44	4.89	4.89	8.48	0.05	1.96	5.01	0.07	0.93	2.81	7.64				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	53.38	
Demand	0.19	0.69	3.23	7.01	8.54	2.19	2.44	4.89	4.89	8.48	0.05	1.96	5.01	0.07	0.93	2.81	7.64				

i) 13 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63			
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63			
																				147.94			
Demand		7.97	13.61	0.11	0.93	0.99	1.15	1.18	1.34	3.49	5.13	0.06	2.69	5.9	6.54	8.97	0.17	4.56	6	70.79			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	0	5.39	6.54	8.97	0.17	1.93	0	23	<=	23	1
2		0	5.42	0.11	0.93	0.99	1.15	1.18	1.34	3.49	5.13	0.06	2.69	0.51	0	0	0	0	0	23	<=	23	1
3		0	6.32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
4		4.45	1.87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
5		3.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.52	<=	6.32	0.556962
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.63	6	8.63	<=	8.63	1
LHS		7.97	13.61	0.11	0.93	0.99	1.15	1.18	1.34	3.49	5.13	0.06	2.69	5.9	6.54	8.97	0.17	4.56	6		Min	70.79	
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=				
Demand		7.97	13.61	0.11	0.93	0.99	1.15	1.18	1.34	3.49	5.13	0.06	2.69	5.9	6.54	8.97	0.17	4.56	6				

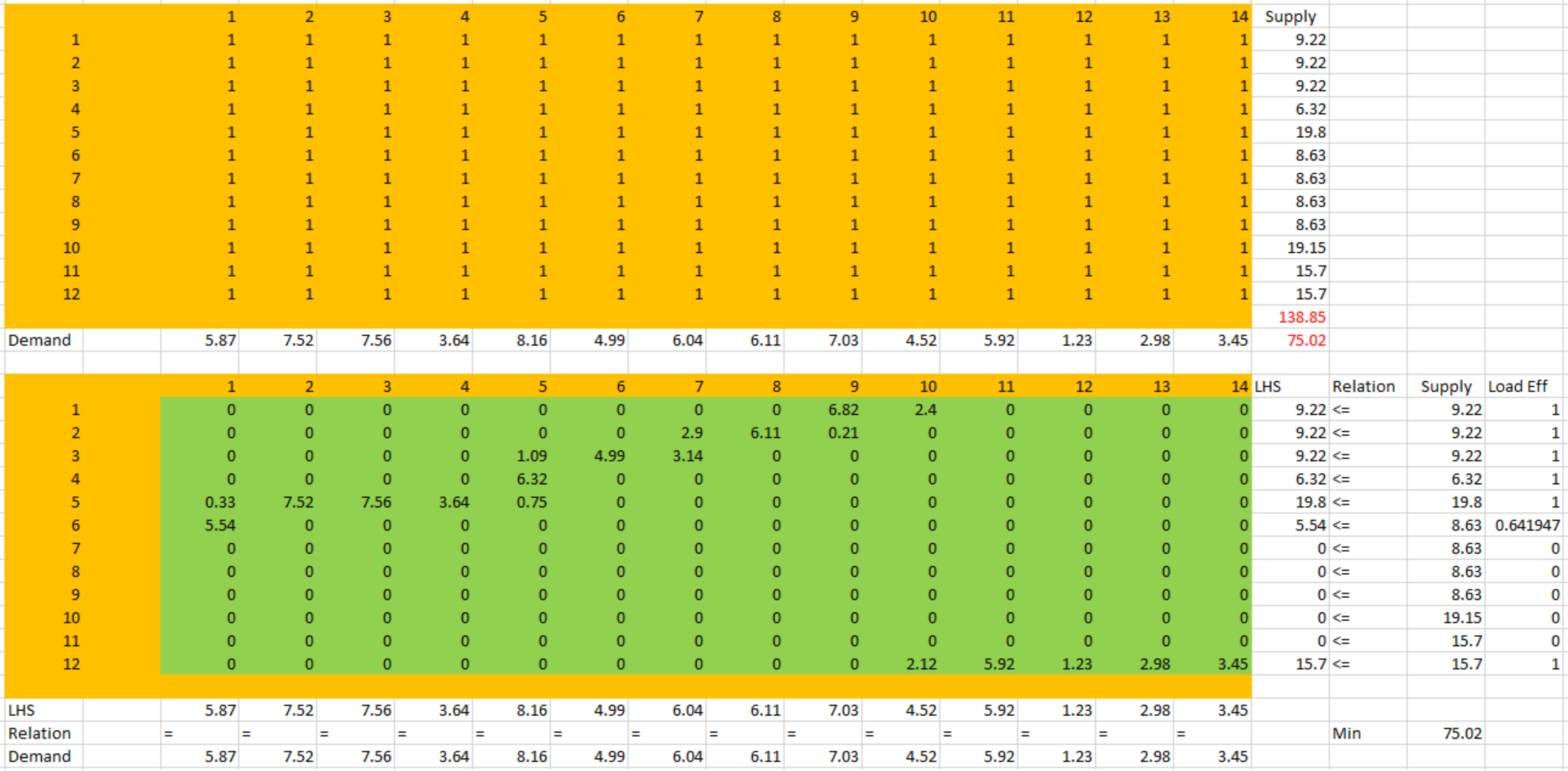
j) 14 October 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																187.47
Demand	6.12	6.61	11.73	1.73	2.07	2.51	2	4.76	9.83	7.14	11.72	2	7.2	7.2	2.79	85.41

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0.65	7.14	11.72	2	1.49	0	0	23	<=	23	1
2	0	0	0.75	1.73	2.07	2.51	2	4.76	9.18	0	0	0	0	0	0	23	<=	23	1
3	5.41	6.61	10.98	0	0	0	0	0	0	0	0	0	0	0	0	23	<=	23	1
4	0.71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.71	<=	6.32	0.112342
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
13	0	0	0	0	0	0	0	0	0	0	0	0	5.71	7.2	2.79	15.7	<=	15.7	1
LHS	6.12	6.61	11.73	1.73	2.07	2.51	2	4.76	9.83	7.14	11.72	2	7.2	7.2	2.79				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	85.41	
Demand	6.12	6.61	11.73	1.73	2.07	2.51	2	4.76	9.83	7.14	11.72	2	7.2	7.2	2.79				

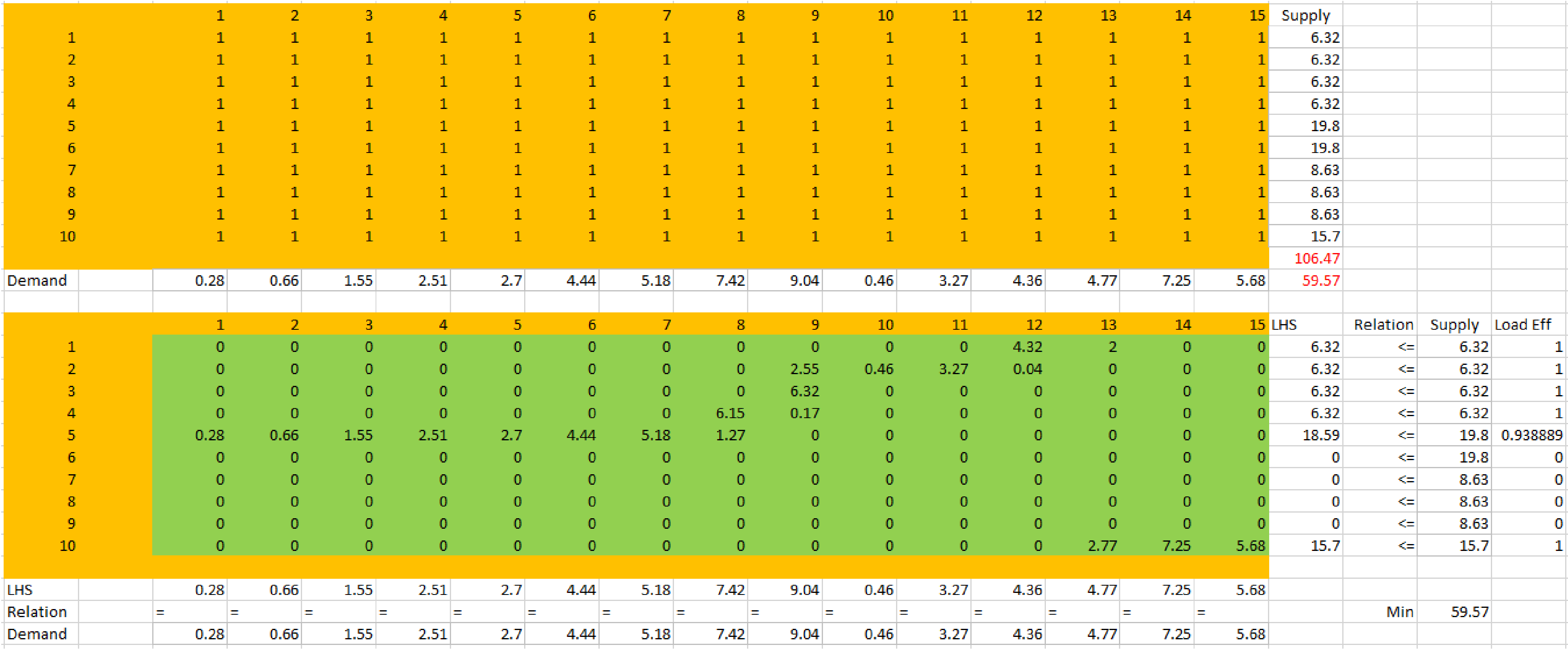
k) 15 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
6		1	1	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	1	1	8.63
8		1	1	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	1	1	8.63
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.15
11		1	1	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	1	1	15.7
																138.85
Demand		5.87	7.52	7.56	3.64	8.16	4.99	6.04	6.11	7.03	4.52	5.92	1.23	2.98	3.45	75.02

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	6.82	2.4	0	0	0	0	9.22	<=	9.22	1
2		0	0	0	0	0	0	2.9	6.11	0.21	0	0	0	0	0	9.22	<=	9.22	1
3		0	0	0	0	1.09	4.99	3.14	0	0	0	0	0	0	0	9.22	<=	9.22	1
4		0	0	0	0	6.32	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
5		0.33	7.52	7.56	3.64	0.75	0	0	0	0	0	0	0	0	0	19.8	<=	19.8	1
6		5.54	0	0	0	0	0	0	0	0	0	0	0	0	0	5.54	<=	8.63	0.641947
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.15	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	2.12	5.92	1.23	2.98	3.45	15.7	<=	15.7	1
LHS		5.87	7.52	7.56	3.64	8.16	4.99	6.04	6.11	7.03	4.52	5.92	1.23	2.98	3.45				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	75.02	
Demand		5.87	7.52	7.56	3.64	8.16	4.99	6.04	6.11	7.03	4.52	5.92	1.23	2.98	3.45				

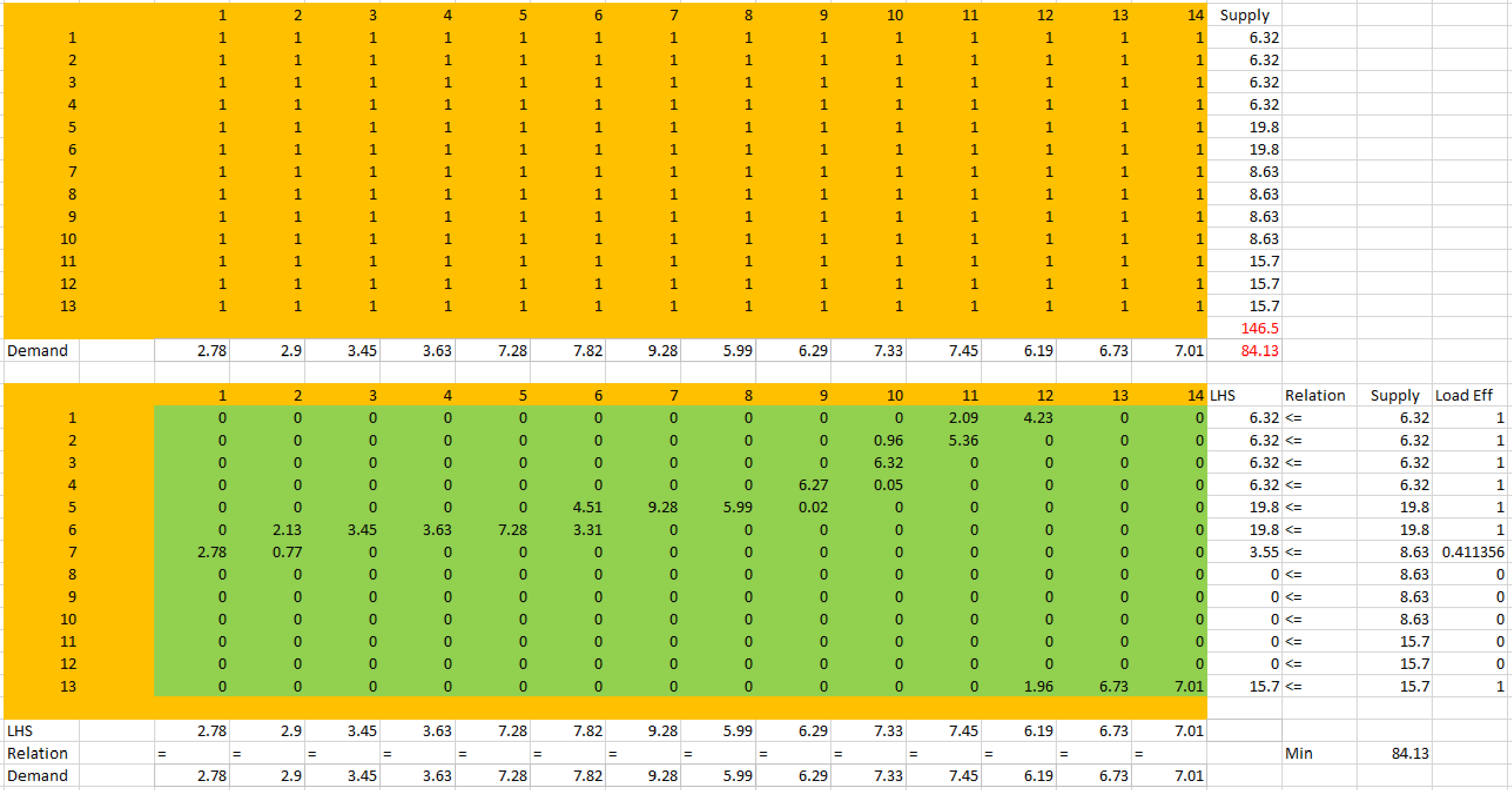
l) 16 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
7		1	1	1	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	1	1	1	8.63
9		1	1	1	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	1	1	1	15.7
																	106.47
Demand		0.28	0.66	1.55	2.51	2.7	4.44	5.18	7.42	9.04	0.46	3.27	4.36	4.77	7.25	5.68	59.57

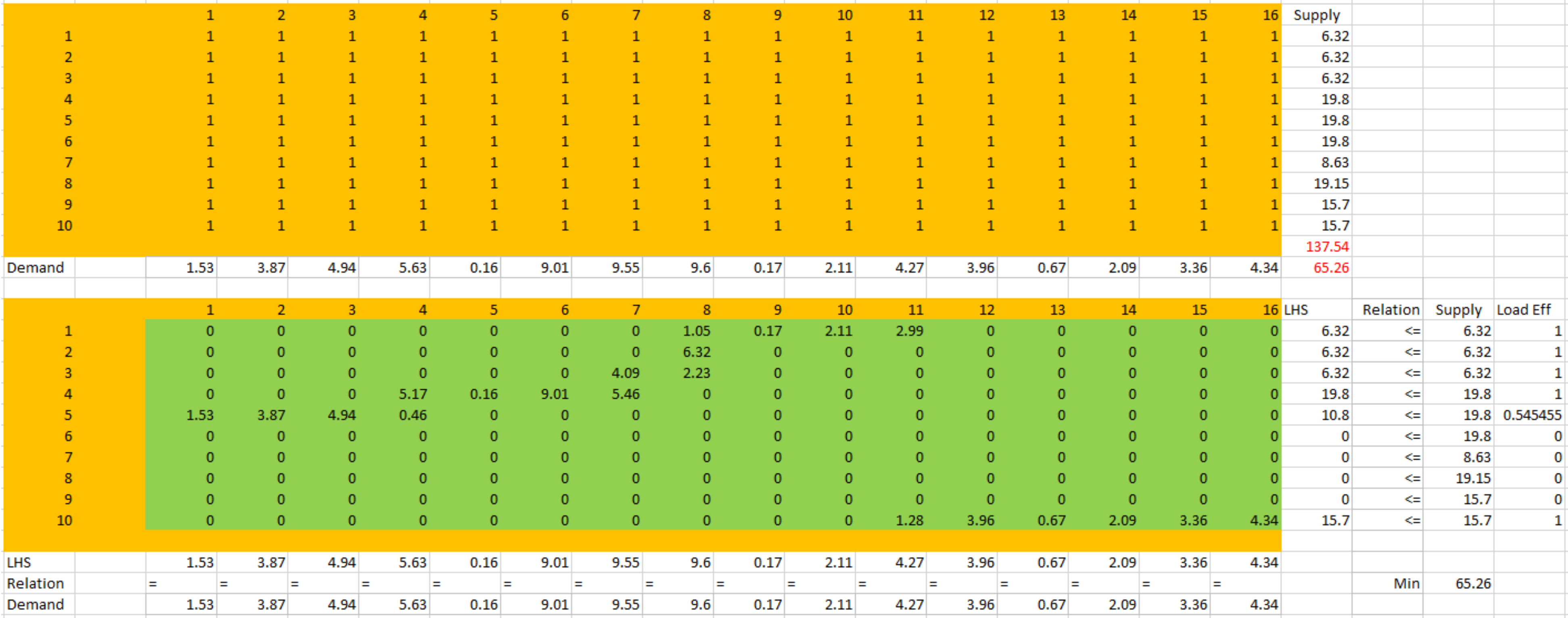
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	4.32	2	0	0	6.32	<=	6.32	1
2		0	0	0	0	0	0	0	0	2.55	0.46	3.27	0.04	0	0	0	6.32	<=	6.32	1
3		0	0	0	0	0	0	0	0	6.32	0	0	0	0	0	0	6.32	<=	6.32	1
4		0	0	0	0	0	0	0	6.15	0.17	0	0	0	0	0	0	6.32	<=	6.32	1
5		0.28	0.66	1.55	2.51	2.7	4.44	5.18	1.27	0	0	0	0	0	0	0	18.59	<=	19.8	0.938889
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	0	0	0	0	0	0	0	0	0	0	2.77	7.25	5.68	15.7	<=	15.7	1
LHS		0.28	0.66	1.55	2.51	2.7	4.44	5.18	7.42	9.04	0.46	3.27	4.36	4.77	7.25	5.68				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	59.57	
Demand		0.28	0.66	1.55	2.51	2.7	4.44	5.18	7.42	9.04	0.46	3.27	4.36	4.77	7.25	5.68				

m) 19 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
7		1	1	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	1	1	8.63			
9		1	1	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	1	1	8.63			
11		1	1	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	1	1	15.7			
13		1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7			
																146.5			
Demand		2.78	2.9	3.45	3.63	7.28	7.82	9.28	5.99	6.29	7.33	7.45	6.19	6.73	7.01	84.13			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	2.09	4.23	0	0	6.32	<=	6.32	1
2		0	0	0	0	0	0	0	0	0	0.96	5.36	0	0	0	6.32	<=	6.32	1
3		0	0	0	0	0	0	0	0	0	6.32	0	0	0	0	6.32	<=	6.32	1
4		0	0	0	0	0	0	0	0	6.27	0.05	0	0	0	0	6.32	<=	6.32	1
5		0	0	0	0	0	4.51	9.28	5.99	0.02	0	0	0	0	0	19.8	<=	19.8	1
6		0	2.13	3.45	3.63	7.28	3.31	0	0	0	0	0	0	0	0	19.8	<=	19.8	1
7		2.78	0.77	0	0	0	0	0	0	0	0	0	0	0	0	3.55	<=	8.63	0.411356
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
13		0	0	0	0	0	0	0	0	0	0	0	1.96	6.73	7.01	15.7	<=	15.7	1
LHS		2.78	2.9	3.45	3.63	7.28	7.82	9.28	5.99	6.29	7.33	7.45	6.19	6.73	7.01				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	84.13	
Demand		2.78	2.9	3.45	3.63	7.28	7.82	9.28	5.99	6.29	7.33	7.45	6.19	6.73	7.01				

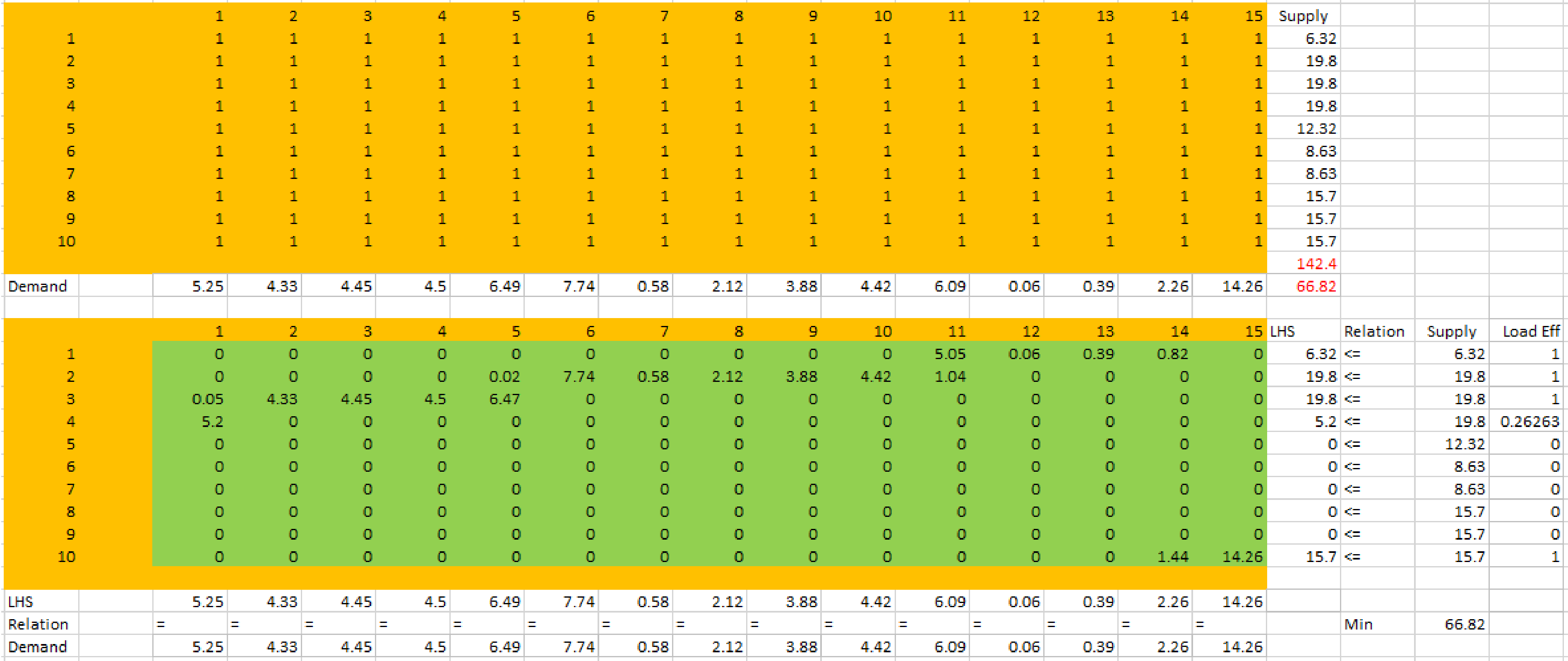
n) 20 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
7		1	1	1	1	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	1	1	1	1	19.15
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																		137.54
Demand		1.53	3.87	4.94	5.63	0.16	9.01	9.55	9.6	0.17	2.11	4.27	3.96	0.67	2.09	3.36	4.34	65.26

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	1.05	0.17	2.11	2.99	0	0	0	0	0	6.32	<=	6.32	1
2		0	0	0	0	0	0	0	6.32	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
3		0	0	0	0	0	0	4.09	2.23	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
4		0	0	0	5.17	0.16	9.01	5.46	0	0	0	0	0	0	0	0	0	19.8	<=	19.8	1
5		1.53	3.87	4.94	0.46	0	0	0	0	0	0	0	0	0	0	0	0	10.8	<=	19.8	0.545455
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.15	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
10		0	0	0	0	0	0	0	0	0	0	1.28	3.96	0.67	2.09	3.36	4.34	15.7	<=	15.7	1
LHS		1.53	3.87	4.94	5.63	0.16	9.01	9.55	9.6	0.17	2.11	4.27	3.96	0.67	2.09	3.36	4.34				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	65.26	
Demand		1.53	3.87	4.94	5.63	0.16	9.01	9.55	9.6	0.17	2.11	4.27	3.96	0.67	2.09	3.36	4.34				

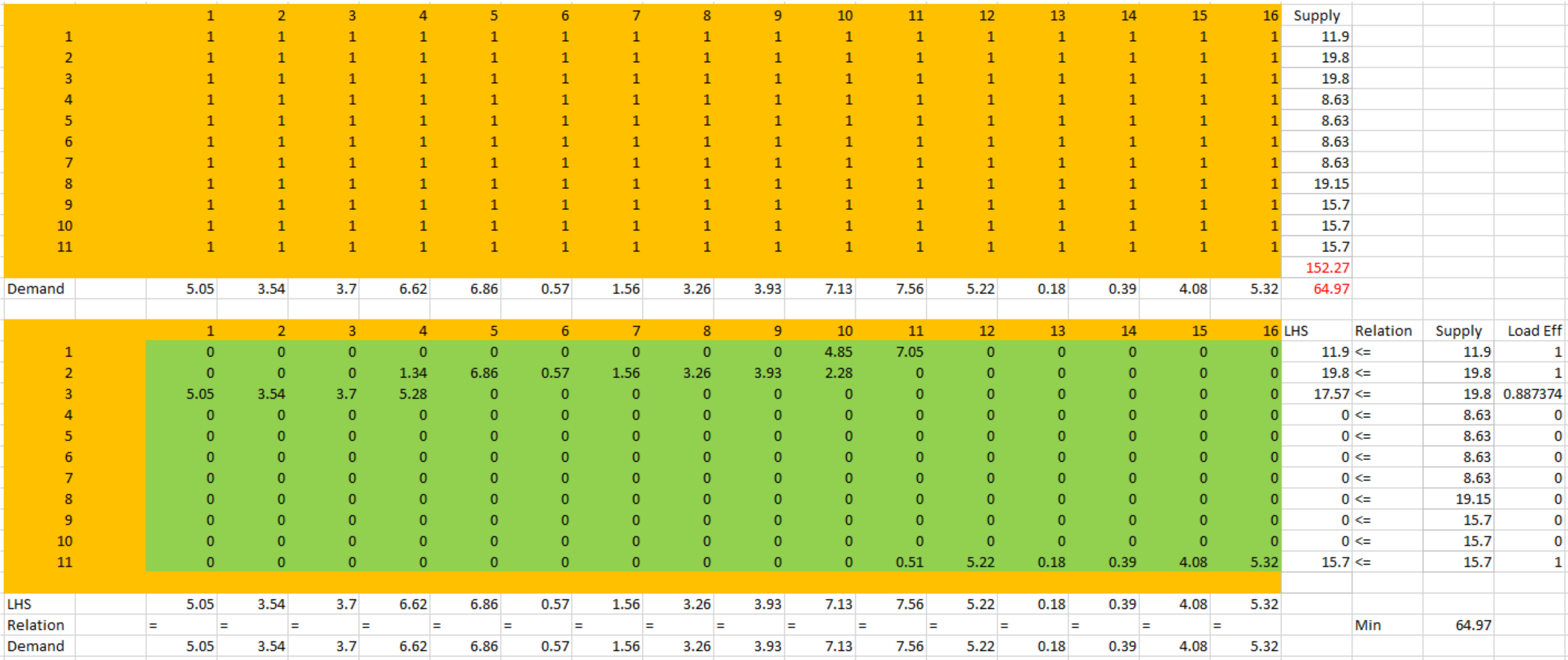
o) 21 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
2		1	1	1	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	1	1	1	19.8
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
5		1	1	1	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	1	1	1	8.63
7		1	1	1	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	1	1	1	15.7
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																	142.4
Demand		5.25	4.33	4.45	4.5	6.49	7.74	0.58	2.12	3.88	4.42	6.09	0.06	0.39	2.26	14.26	66.82

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	5.05	0.06	0.39	0.82	0	6.32	<=	6.32	1
2		0	0	0	0	0.02	7.74	0.58	2.12	3.88	4.42	1.04	0	0	0	0	19.8	<=	19.8	1
3		0.05	4.33	4.45	4.5	6.47	0	0	0	0	0	0	0	0	0	0	19.8	<=	19.8	1
4		5.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.2	<=	19.8	0.26263
5		0	0	0	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	0	0	0	<=	8.63	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	1.44	14.26	15.7	<=	15.7	1
LHS		5.25	4.33	4.45	4.5	6.49	7.74	0.58	2.12	3.88	4.42	6.09	0.06	0.39	2.26	14.26				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	66.82	
Demand		5.25	4.33	4.45	4.5	6.49	7.74	0.58	2.12	3.88	4.42	6.09	0.06	0.39	2.26	14.26				

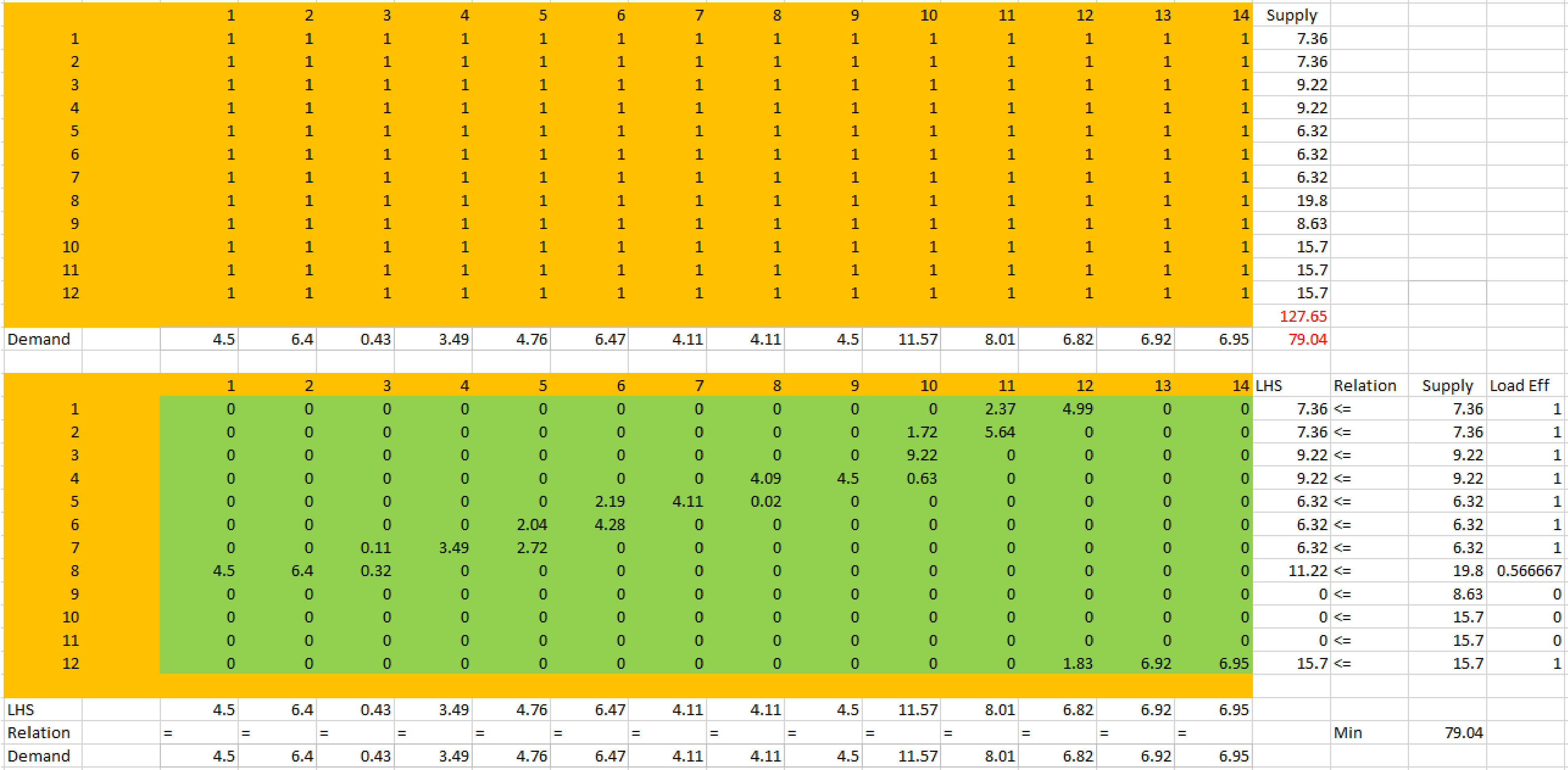
p) 22 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	11.9			
2		1	1	1	1	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	1	1	1	1	19.8			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63			
6		1	1	1	1	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	1	1	1	1	8.63			
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.15			
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7			
10		1	1	1	1	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	1	1	1	1	15.7			
																		152.27			
Demand		5.05	3.54	3.7	6.62	6.86	0.57	1.56	3.26	3.93	7.13	7.56	5.22	0.18	0.39	4.08	5.32	64.97			

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	4.85	7.05	0	0	0	0	0	11.9	<=	11.9	1
2		0	0	0	1.34	6.86	0.57	1.56	3.26	3.93	2.28	0	0	0	0	0	0	19.8	<=	19.8	1
3		5.05	3.54	3.7	5.28	0	0	0	0	0	0	0	0	0	0	0	0	17.57	<=	19.8	0.887374
4		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
6		0	0	0	0	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	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.15	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
10		0	0	0	0	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	0.51	5.22	0.18	0.39	4.08	5.32	15.7	<=	15.7	1
LHS		5.05	3.54	3.7	6.62	6.86	0.57	1.56	3.26	3.93	7.13	7.56	5.22	0.18	0.39	4.08	5.32				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	64.97	
Demand		5.05	3.54	3.7	6.62	6.86	0.57	1.56	3.26	3.93	7.13	7.56	5.22	0.18	0.39	4.08	5.32				

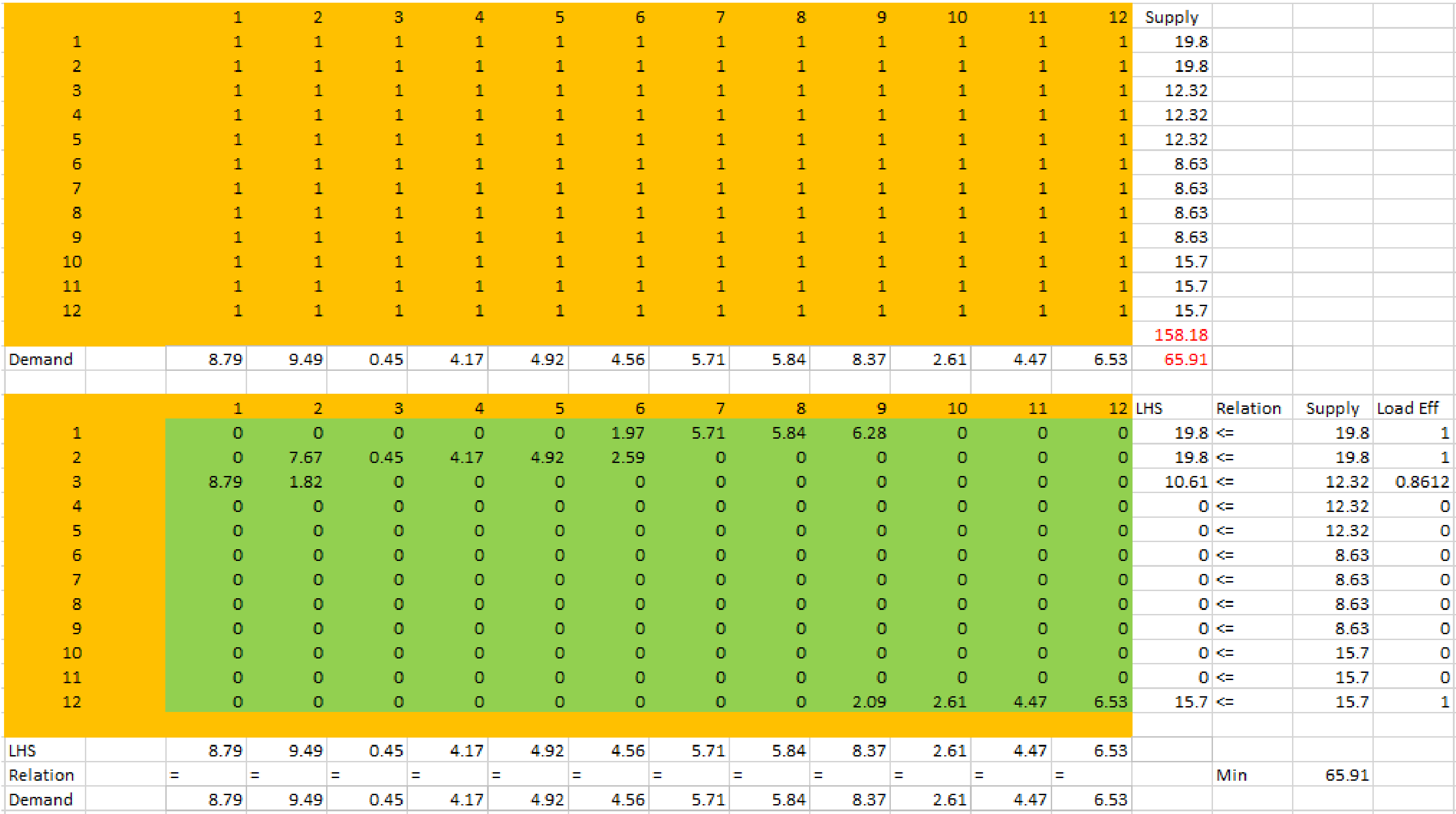
q) 23 October 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.36			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.36			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
9		1	1	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	1	1	15.7			
11		1	1	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	1	1	15.7			
																127.65			
Demand		4.5	6.4	0.43	3.49	4.76	6.47	4.11	4.11	4.5	11.57	8.01	6.82	6.92	6.95	79.04			

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	2.37	4.99	0	0	7.36	<=	7.36	1
2		0	0	0	0	0	0	0	0	0	1.72	5.64	0	0	0	7.36	<=	7.36	1
3		0	0	0	0	0	0	0	0	0	9.22	0	0	0	0	9.22	<=	9.22	1
4		0	0	0	0	0	0	0	4.09	4.5	0.63	0	0	0	0	9.22	<=	9.22	1
5		0	0	0	0	0	2.19	4.11	0.02	0	0	0	0	0	0	6.32	<=	6.32	1
6		0	0	0	0	2.04	4.28	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
7		0	0	0.11	3.49	2.72	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
8		4.5	6.4	0.32	0	0	0	0	0	0	0	0	0	0	0	11.22	<=	19.8	0.566667
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	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	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	0	0	1.83	6.92	6.95	15.7	<=	15.7	1
LHS		4.5	6.4	0.43	3.49	4.76	6.47	4.11	4.11	4.5	11.57	8.01	6.82	6.92	6.95				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	79.04	
Demand		4.5	6.4	0.43	3.49	4.76	6.47	4.11	4.11	4.5	11.57	8.01	6.82	6.92	6.95				

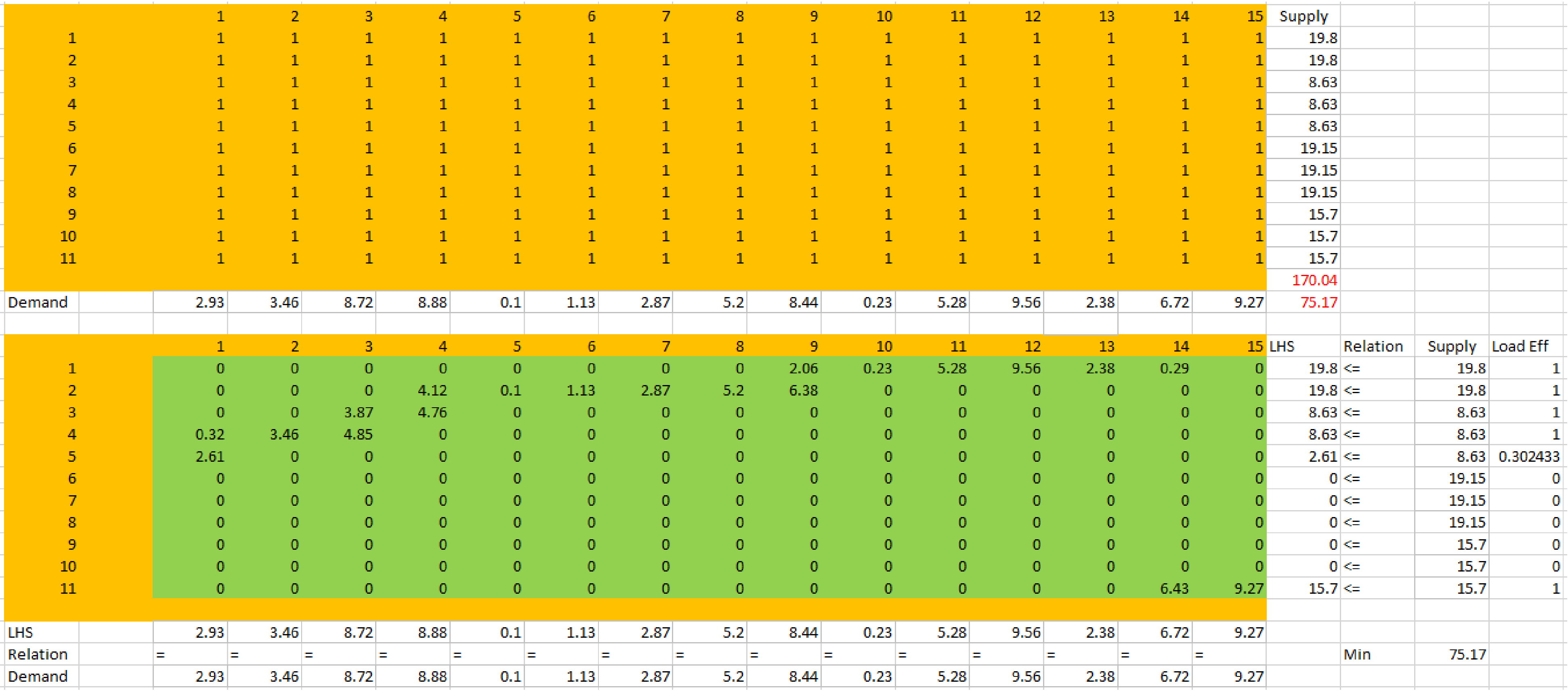
r) 27 October 2020



	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	1.97	5.71	5.84	6.28	0	0	0	19.8	<=	19.8	1
2	0	7.67	0.45	4.17	4.92	2.59	0	0	0	0	0	0	19.8	<=	19.8	1
3	8.79	1.82	0	0	0	0	0	0	0	0	0	0	10.61	<=	12.32	0.8612
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	0	0	0	0	<=	8.63	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
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	0	0	2.09	2.61	4.47	6.53	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				

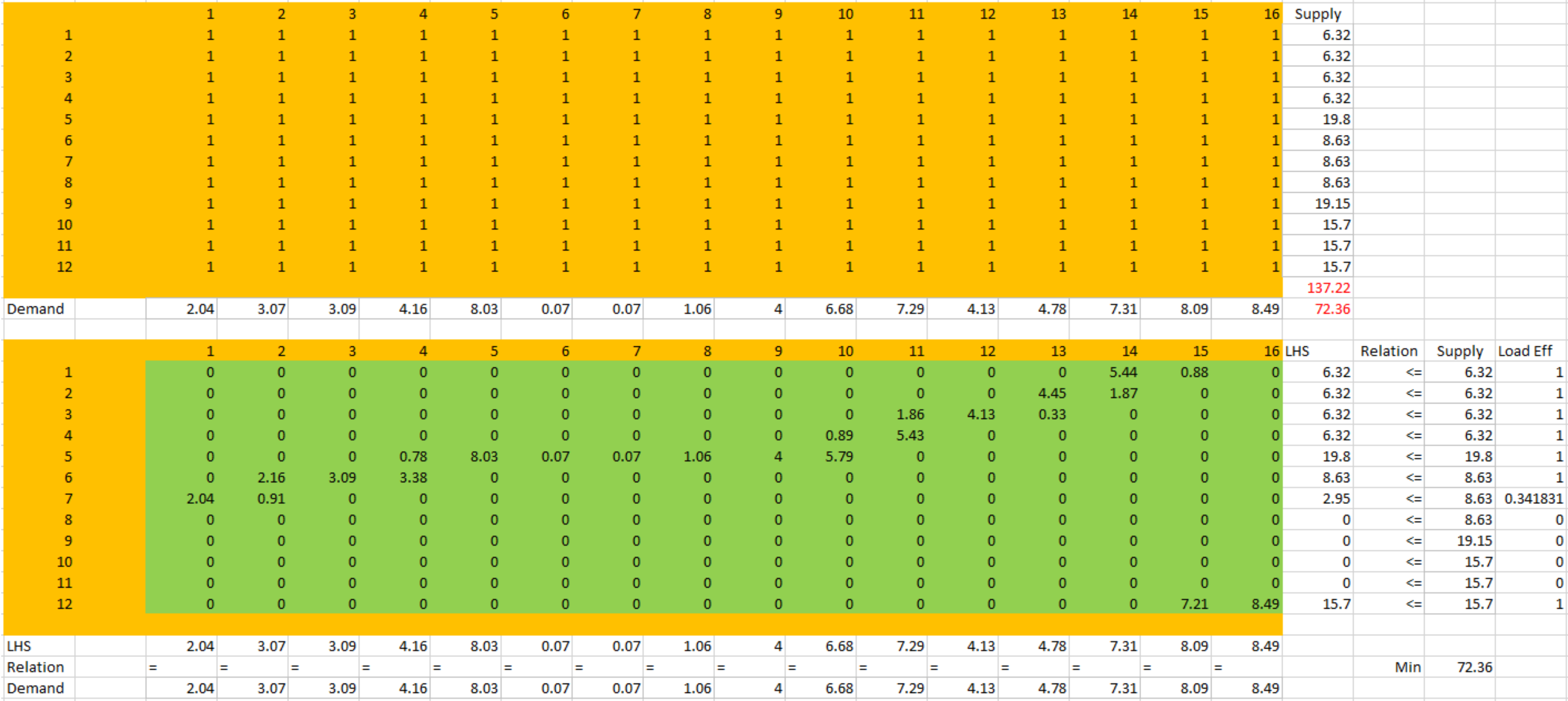
s) 28 October 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1	1	1	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	1	1	1	19.8
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.15
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.15
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.15
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
10	1	1	1	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	1	1	1	15.7
																170.04
Demand	2.93	3.46	8.72	8.88	0.1	1.13	2.87	5.2	8.44	0.23	5.28	9.56	2.38	6.72	9.27	75.17

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	2.06	0.23	5.28	9.56	2.38	0.29	0	19.8	<=	19.8	1
2	0	0	0	4.12	0.1	1.13	2.87	5.2	6.38	0	0	0	0	0	0	19.8	<=	19.8	1
3	0	0	3.87	4.76	0	0	0	0	0	0	0	0	0	0	0	8.63	<=	8.63	1
4	0.32	3.46	4.85	0	0	0	0	0	0	0	0	0	0	0	0	8.63	<=	8.63	1
5	2.61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.61	<=	8.63	0.302433
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.15	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.15	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.15	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
10	0	0	0	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	6.43	9.27	15.7	<=	15.7	1
LHS	2.93	3.46	8.72	8.88	0.1	1.13	2.87	5.2	8.44	0.23	5.28	9.56	2.38	6.72	9.27				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	75.17	
Demand	2.93	3.46	8.72	8.88	0.1	1.13	2.87	5.2	8.44	0.23	5.28	9.56	2.38	6.72	9.27				

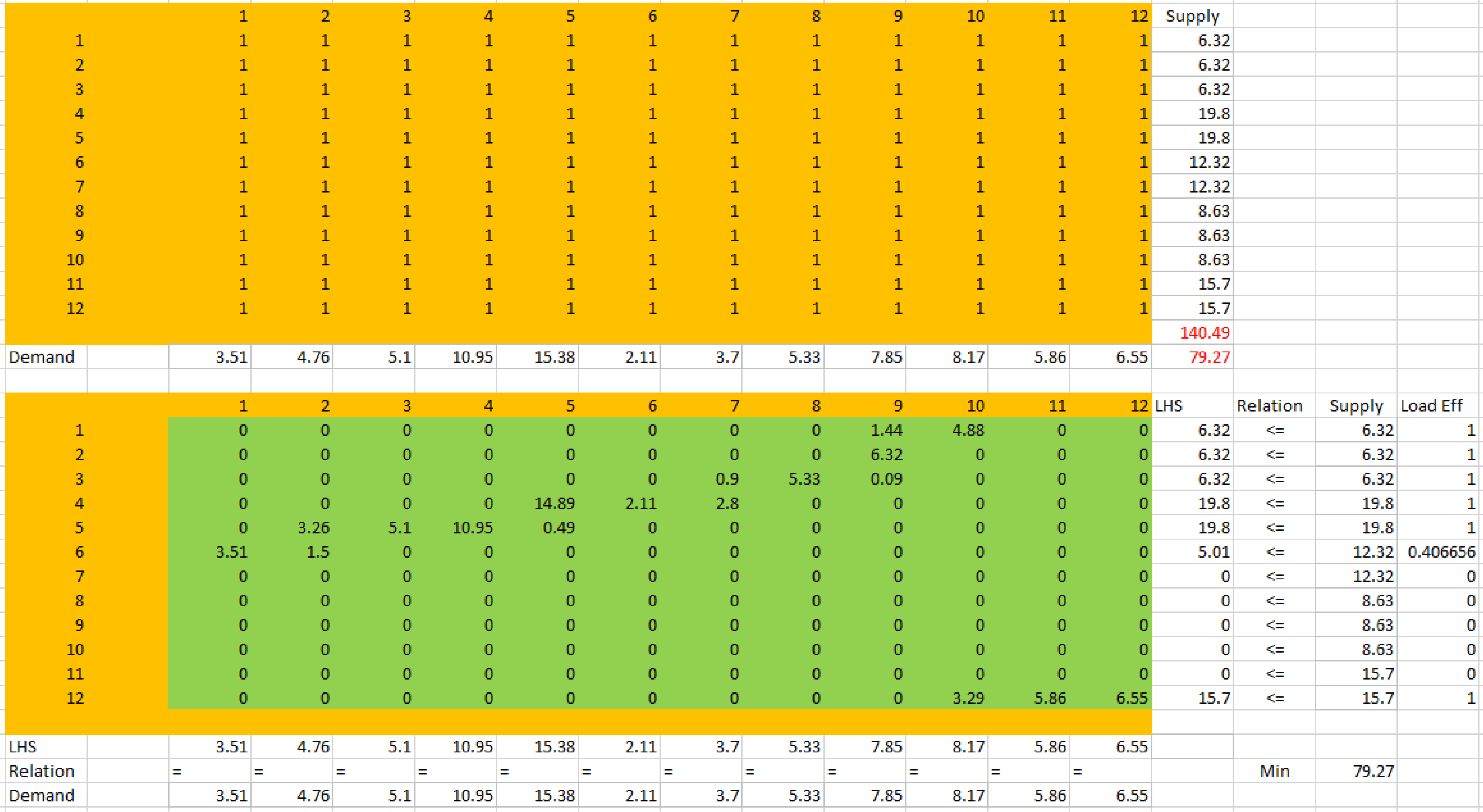
t) 29 October 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
6	1	1	1	1	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	1	1	1	1	8.63
8	1	1	1	1	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	1	1	1	1	19.15
10	1	1	1	1	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	1	1	1	1	15.7
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																	137.22
Demand	2.04	3.07	3.09	4.16	8.03	0.07	0.07	1.06	4	6.68	7.29	4.13	4.78	7.31	8.09	8.49	72.36

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	0	0	0	0	5.44	0.88	0	6.32	<=	6.32	1
2	0	0	0	0	0	0	0	0	0	0	0	0	4.45	1.87	0	0	6.32	<=	6.32	1
3	0	0	0	0	0	0	0	0	0	0	1.86	4.13	0.33	0	0	0	6.32	<=	6.32	1
4	0	0	0	0	0	0	0	0	0	0.89	5.43	0	0	0	0	0	6.32	<=	6.32	1
5	0	0	0	0.78	8.03	0.07	0.07	1.06	4	5.79	0	0	0	0	0	0	19.8	<=	19.8	1
6	0	2.16	3.09	3.38	0	0	0	0	0	0	0	0	0	0	0	0	8.63	<=	8.63	1
7	2.04	0.91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.95	<=	8.63	0.341831
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.15	0
10	0	0	0	0	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	0	0	0	0	<=	15.7	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.21	8.49	15.7	<=	15.7	1
LHS	2.04	3.07	3.09	4.16	8.03	0.07	0.07	1.06	4	6.68	7.29	4.13	4.78	7.31	8.09	8.49				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	72.36	
Demand	2.04	3.07	3.09	4.16	8.03	0.07	0.07	1.06	4	6.68	7.29	4.13	4.78	7.31	8.09	8.49				

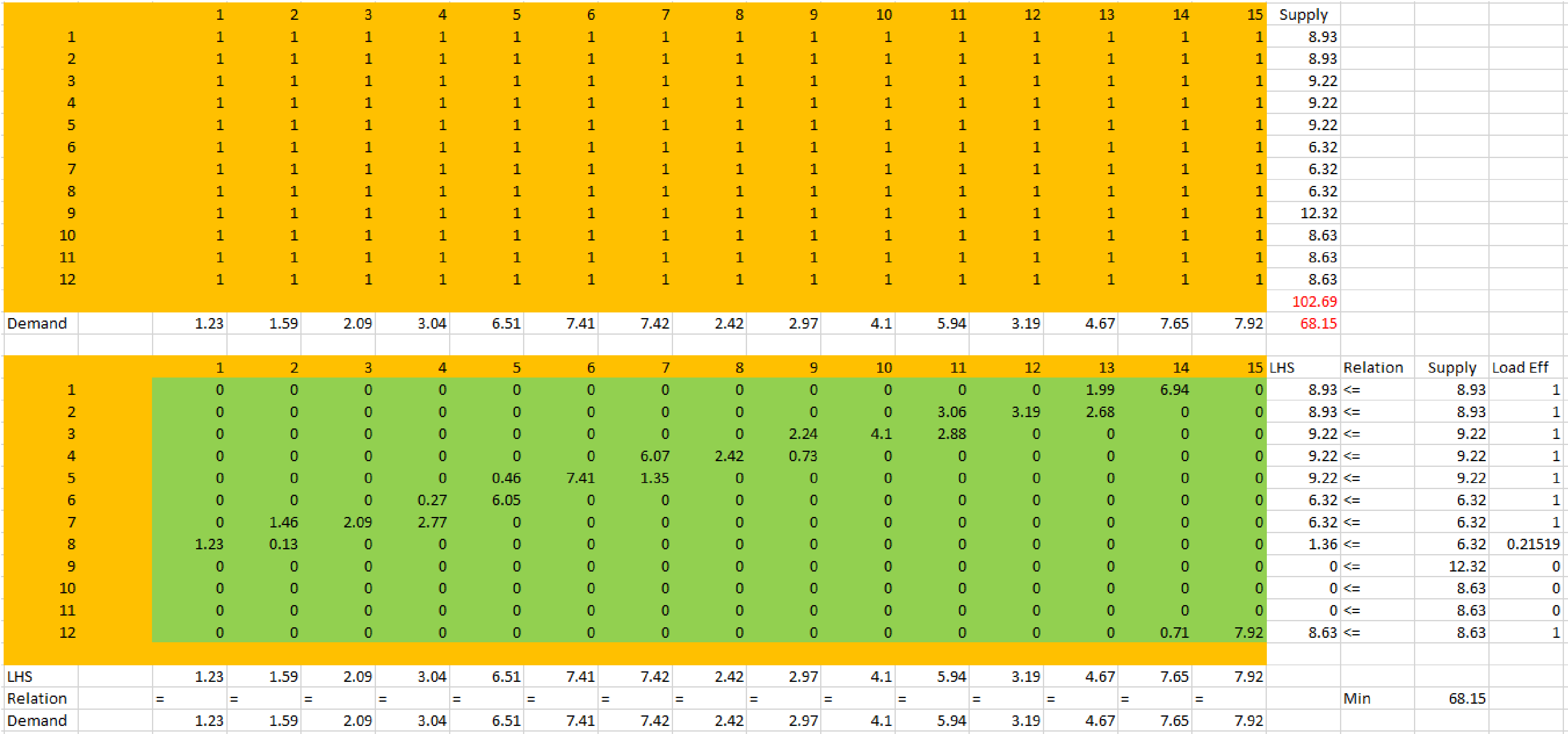
u) 30 October 2020



		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	6.32			
2		1	1	1	1	1	1	1	1	1	1	1	1	6.32			
3		1	1	1	1	1	1	1	1	1	1	1	1	6.32			
4		1	1	1	1	1	1	1	1	1	1	1	1	19.8			
5		1	1	1	1	1	1	1	1	1	1	1	1	19.8			
6		1	1	1	1	1	1	1	1	1	1	1	1	12.32			
7		1	1	1	1	1	1	1	1	1	1	1	1	12.32			
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	8.63			
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			
														140.49			
Demand		3.51	4.76	5.1	10.95	15.38	2.11	3.7	5.33	7.85	8.17	5.86	6.55	79.27			

		1	2	3	4	5	6	7	8	9	10	11	12	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	1.44	4.88	0	0	6.32	<=	6.32	1
2		0	0	0	0	0	0	0	0	6.32	0	0	0	6.32	<=	6.32	1
3		0	0	0	0	0	0	0.9	5.33	0.09	0	0	0	6.32	<=	6.32	1
4		0	0	0	0	14.89	2.11	2.8	0	0	0	0	0	19.8	<=	19.8	1
5		0	3.26	5.1	10.95	0.49	0	0	0	0	0	0	0	19.8	<=	19.8	1
6		3.51	1.5	0	0	0	0	0	0	0	0	0	0	5.01	<=	12.32	0.406656
7		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	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	0	0	0	3.29	5.86	6.55	15.7	<=	15.7	1
LHS		3.51	4.76	5.1	10.95	15.38	2.11	3.7	5.33	7.85	8.17	5.86	6.55				
Relation		=	=	=	=	=	=	=	=	=	=	=	=		Min	79.27	
Demand		3.51	4.76	5.1	10.95	15.38	2.11	3.7	5.33	7.85	8.17	5.86	6.55				

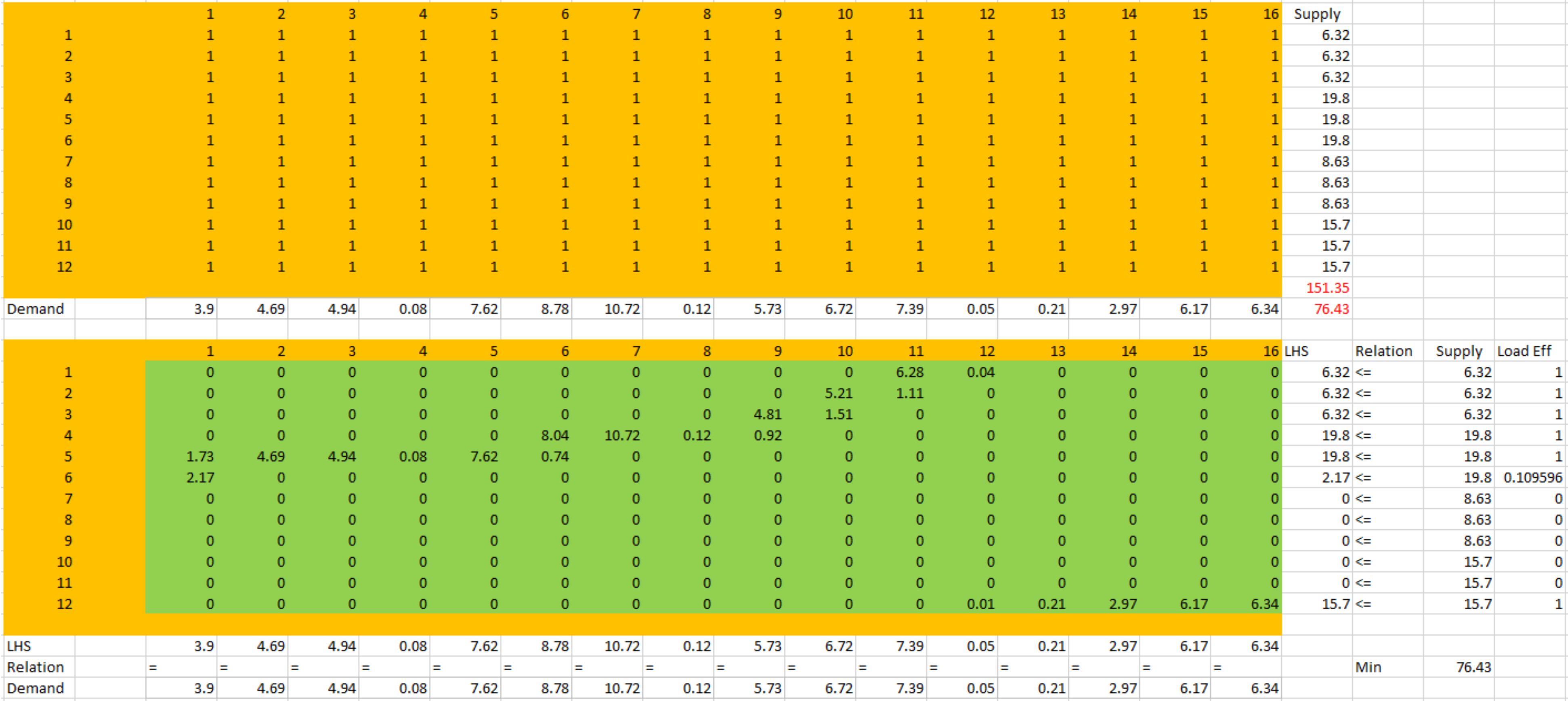
v) 02 November 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
																102.69
Demand	1.23	1.59	2.09	3.04	6.51	7.41	7.42	2.42	2.97	4.1	5.94	3.19	4.67	7.65	7.92	68.15

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	0	0	0	1.99	6.94	0	8.93	<=	8.93	1
2	0	0	0	0	0	0	0	0	0	0	3.06	3.19	2.68	0	0	8.93	<=	8.93	1
3	0	0	0	0	0	0	0	0	2.24	4.1	2.88	0	0	0	0	9.22	<=	9.22	1
4	0	0	0	0	0	0	6.07	2.42	0.73	0	0	0	0	0	0	9.22	<=	9.22	1
5	0	0	0	0	0.46	7.41	1.35	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
6	0	0	0	0.27	6.05	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
7	0	1.46	2.09	2.77	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
8	1.23	0.13	0	0	0	0	0	0	0	0	0	0	0	0	0	1.36	<=	6.32	0.21519
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0.71	7.92	8.63	<=	8.63	1
LHS	1.23	1.59	2.09	3.04	6.51	7.41	7.42	2.42	2.97	4.1	5.94	3.19	4.67	7.65	7.92				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	68.15	
Demand	1.23	1.59	2.09	3.04	6.51	7.41	7.42	2.42	2.97	4.1	5.94	3.19	4.67	7.65	7.92				

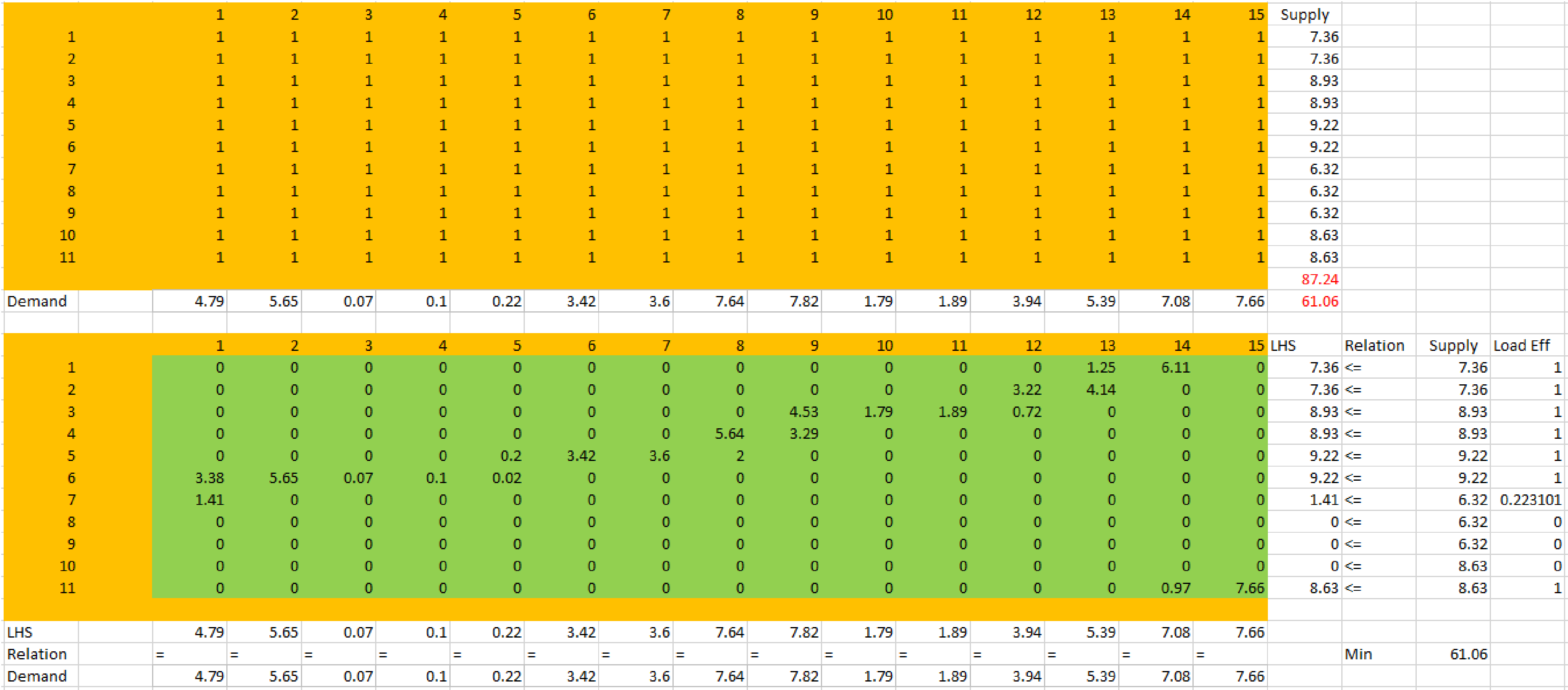
w) 04 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
7		1	1	1	1	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	1	1	1	1	8.63			
9		1	1	1	1	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	1	1	1	1	15.7			
11		1	1	1	1	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	1	1	1	1	15.7			
																		151.35			
Demand		3.9	4.69	4.94	0.08	7.62	8.78	10.72	0.12	5.73	6.72	7.39	0.05	0.21	2.97	6.17	6.34	76.43			

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	6.28	0.04	0	0	0	0	6.32	<=	6.32	1
2		0	0	0	0	0	0	0	0	0	5.21	1.11	0	0	0	0	0	6.32	<=	6.32	1
3		0	0	0	0	0	0	0	0	4.81	1.51	0	0	0	0	0	0	6.32	<=	6.32	1
4		0	0	0	0	0	8.04	10.72	0.12	0.92	0	0	0	0	0	0	0	19.8	<=	19.8	1
5		1.73	4.69	4.94	0.08	7.62	0.74	0	0	0	0	0	0	0	0	0	0	19.8	<=	19.8	1
6		2.17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.17	<=	19.8	0.109596
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	0	0	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	0	0	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	0	0	0.01	0.21	2.97	6.17	6.34	15.7	<=	15.7	1
LHS		3.9	4.69	4.94	0.08	7.62	8.78	10.72	0.12	5.73	6.72	7.39	0.05	0.21	2.97	6.17	6.34				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	76.43	
Demand		3.9	4.69	4.94	0.08	7.62	8.78	10.72	0.12	5.73	6.72	7.39	0.05	0.21	2.97	6.17	6.34				

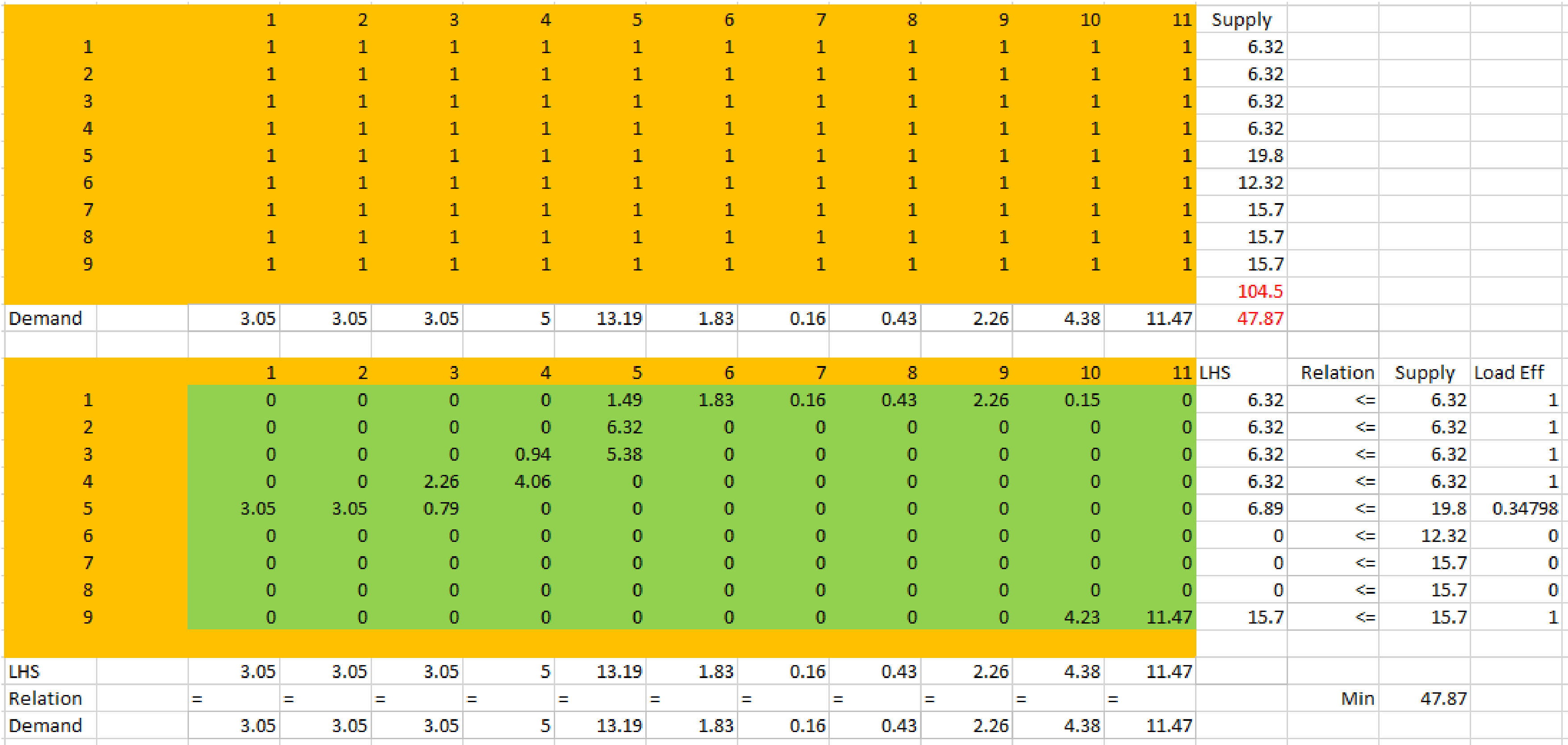
x) 05 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.36			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.36			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22			
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63			
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63			
																	87.24			
Demand		4.79	5.65	0.07	0.1	0.22	3.42	3.6	7.64	7.82	1.79	1.89	3.94	5.39	7.08	7.66	61.06			

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	0	1.25	6.11	0	7.36	<=	7.36	1
2		0	0	0	0	0	0	0	0	0	0	0	3.22	4.14	0	0	7.36	<=	7.36	1
3		0	0	0	0	0	0	0	0	4.53	1.79	1.89	0.72	0	0	0	8.93	<=	8.93	1
4		0	0	0	0	0	0	0	5.64	3.29	0	0	0	0	0	0	8.93	<=	8.93	1
5		0	0	0	0	0.2	3.42	3.6	2	0	0	0	0	0	0	0	9.22	<=	9.22	1
6		3.38	5.65	0.07	0.1	0.02	0	0	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
7		1.41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.41	<=	6.32	0.223101
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0.97	7.66	8.63	<=	8.63	1
LHS		4.79	5.65	0.07	0.1	0.22	3.42	3.6	7.64	7.82	1.79	1.89	3.94	5.39	7.08	7.66				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	61.06	
Demand		4.79	5.65	0.07	0.1	0.22	3.42	3.6	7.64	7.82	1.79	1.89	3.94	5.39	7.08	7.66				

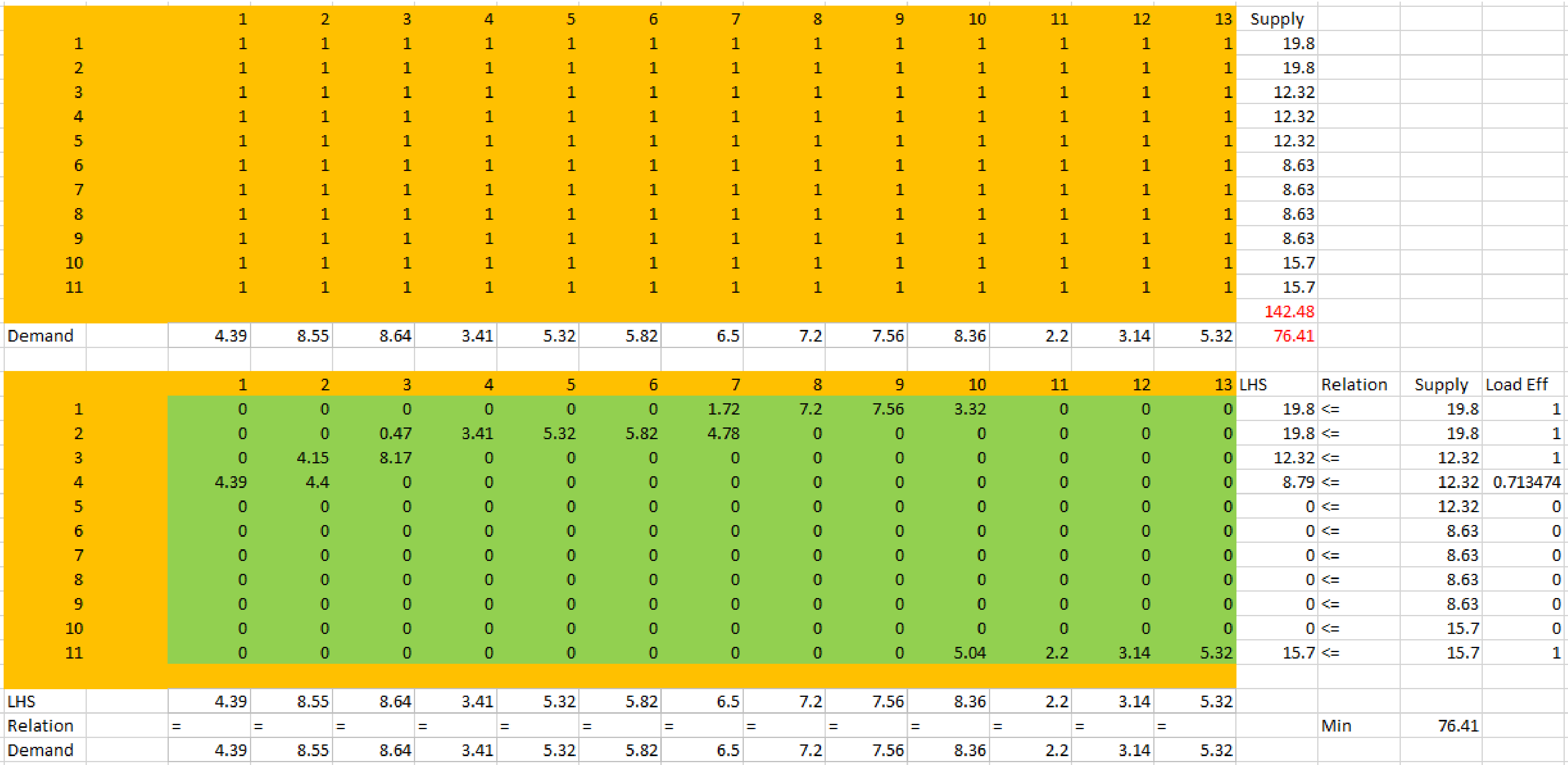
y) 06 November 2020



		1	2	3	4	5	6	7	8	9	10	11	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	6.32			
2		1	1	1	1	1	1	1	1	1	1	1	6.32			
3		1	1	1	1	1	1	1	1	1	1	1	6.32			
4		1	1	1	1	1	1	1	1	1	1	1	6.32			
5		1	1	1	1	1	1	1	1	1	1	1	19.8			
6		1	1	1	1	1	1	1	1	1	1	1	12.32			
7		1	1	1	1	1	1	1	1	1	1	1	15.7			
8		1	1	1	1	1	1	1	1	1	1	1	15.7			
9		1	1	1	1	1	1	1	1	1	1	1	15.7			
													104.5			
Demand		3.05	3.05	3.05	5	13.19	1.83	0.16	0.43	2.26	4.38	11.47	47.87			

		1	2	3	4	5	6	7	8	9	10	11	LHS	Relation	Supply	Load Eff
1		0	0	0	0	1.49	1.83	0.16	0.43	2.26	0.15	0	6.32	<=	6.32	1
2		0	0	0	0	6.32	0	0	0	0	0	0	6.32	<=	6.32	1
3		0	0	0	0.94	5.38	0	0	0	0	0	0	6.32	<=	6.32	1
4		0	0	2.26	4.06	0	0	0	0	0	0	0	6.32	<=	6.32	1
5		3.05	3.05	0.79	0	0	0	0	0	0	0	0	6.89	<=	19.8	0.34798
6		0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
7		0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
8		0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
9		0	0	0	0	0	0	0	0	0	4.23	11.47	15.7	<=	15.7	1
LHS		3.05	3.05	3.05	5	13.19	1.83	0.16	0.43	2.26	4.38	11.47				
Relation		=	=	=	=	=	=	=	=	=	=	=		Min	47.87	
Demand		3.05	3.05	3.05	5	13.19	1.83	0.16	0.43	2.26	4.38	11.47				

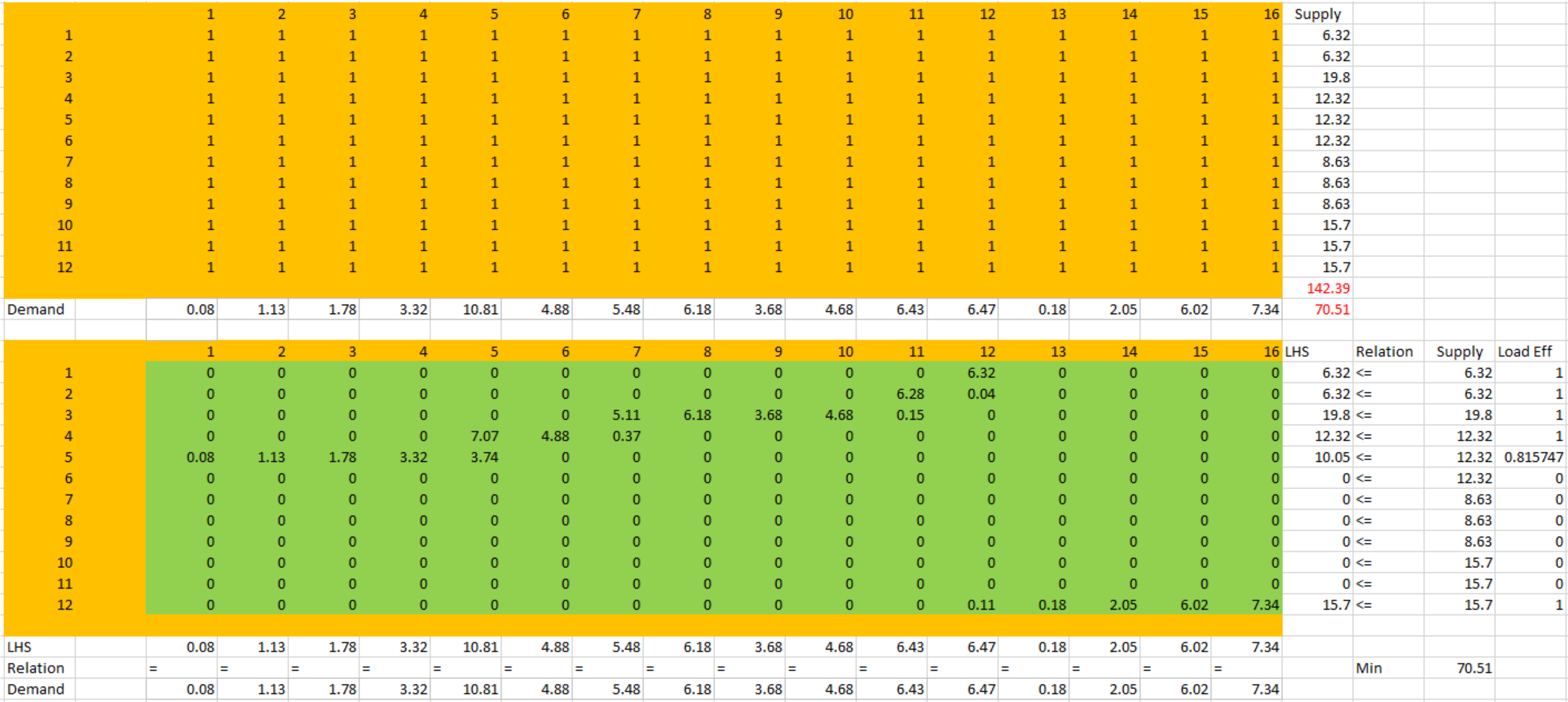
z) 09 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	Supply
1		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	1	19.8
3		1	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	1	12.32
5		1	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	1	8.63
7		1	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	1	8.63
9		1	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	1	15.7
11		1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
															142.48
Demand		4.39	8.55	8.64	3.41	5.32	5.82	6.5	7.2	7.56	8.36	2.2	3.14	5.32	76.41

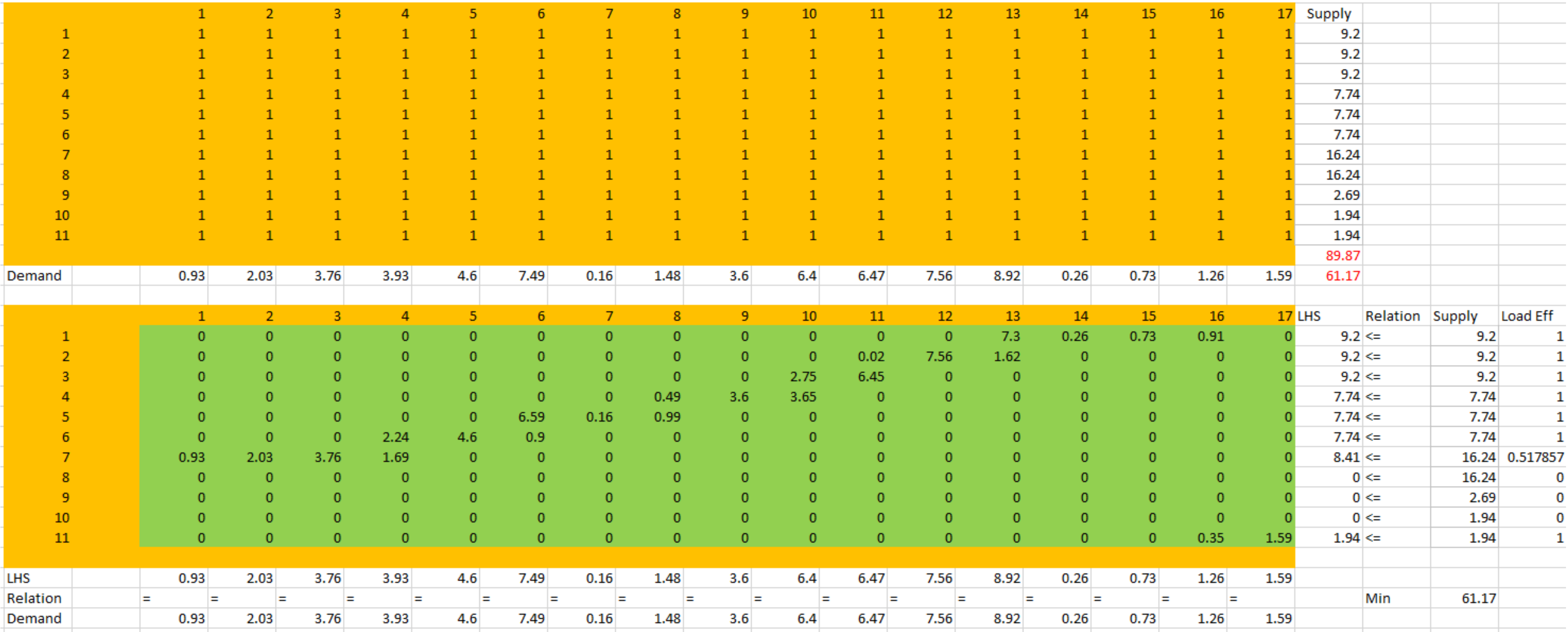
		1	2	3	4	5	6	7	8	9	10	11	12	13	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	1.72	7.2	7.56	3.32	0	0	0	19.8	<=	19.8	1
2		0	0	0.47	3.41	5.32	5.82	4.78	0	0	0	0	0	0	19.8	<=	19.8	1
3		0	4.15	8.17	0	0	0	0	0	0	0	0	0	0	12.32	<=	12.32	1
4		4.39	4.4	0	0	0	0	0	0	0	0	0	0	0	8.79	<=	12.32	0.713474
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	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	5.04	2.2	3.14	5.32	15.7	<=	15.7	1
LHS		4.39	8.55	8.64	3.41	5.32	5.82	6.5	7.2	7.56	8.36	2.2	3.14	5.32				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=		Min	76.41	
Demand		4.39	8.55	8.64	3.41	5.32	5.82	6.5	7.2	7.56	8.36	2.2	3.14	5.32				

aa) 10 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
4		1	1	1	1	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	1	1	1	1	12.32			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32			
7		1	1	1	1	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	1	1	1	1	8.63			
9		1	1	1	1	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	1	1	1	1	15.7			
11		1	1	1	1	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	1	1	1	1	15.7			
																		142.39			
Demand		0.08	1.13	1.78	3.32	10.81	4.88	5.48	6.18	3.68	4.68	6.43	6.47	0.18	2.05	6.02	7.34	70.51			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	6.32	0	0	0	0	6.32	<=	6.32	1
2		0	0	0	0	0	0	0	0	0	0	6.28	0.04	0	0	0	0	6.32	<=	6.32	1
3		0	0	0	0	0	0	5.11	6.18	3.68	4.68	0.15	0	0	0	0	0	19.8	<=	19.8	1
4		0	0	0	0	7.07	4.88	0.37	0	0	0	0	0	0	0	0	0	12.32	<=	12.32	1
5		0.08	1.13	1.78	3.32	3.74	0	0	0	0	0	0	0	0	0	0	0	10.05	<=	12.32	0.815747
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	0	0	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	0	0	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	0	0	0.11	0.18	2.05	6.02	7.34	15.7	<=	15.7	1
LHS		0.08	1.13	1.78	3.32	10.81	4.88	5.48	6.18	3.68	4.68	6.43	6.47	0.18	2.05	6.02	7.34				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	70.51	
Demand		0.08	1.13	1.78	3.32	10.81	4.88	5.48	6.18	3.68	4.68	6.43	6.47	0.18	2.05	6.02	7.34				

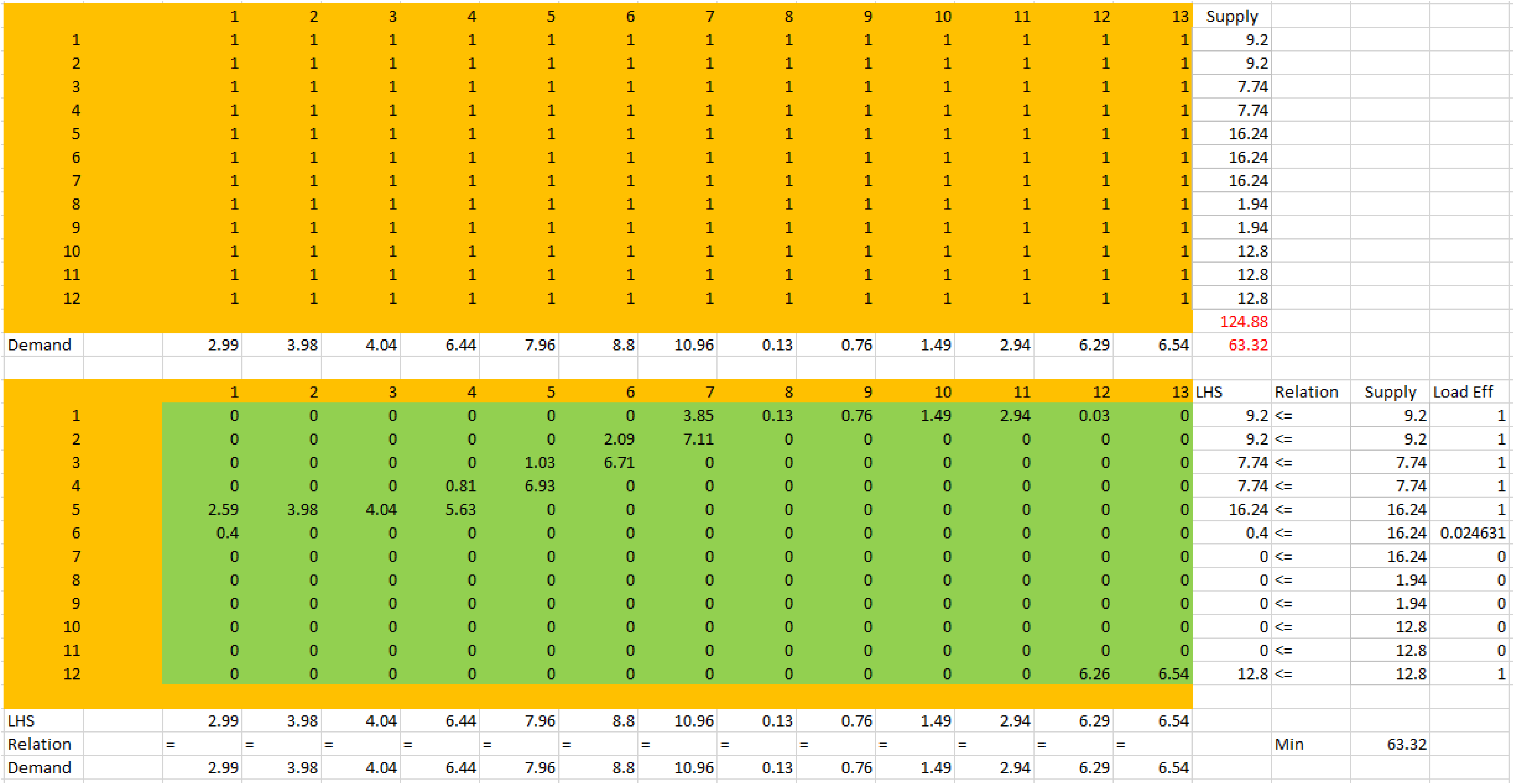
ab) 11 November 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2.69
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
																		89.87
Demand	0.93	2.03	3.76	3.93	4.6	7.49	0.16	1.48	3.6	6.4	6.47	7.56	8.92	0.26	0.73	1.26	1.59	61.17

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	0	0	0	7.3	0.26	0.73	0.91	0	9.2	<=	9.2	1
2	0	0	0	0	0	0	0	0	0	0	0.02	7.56	1.62	0	0	0	0	9.2	<=	9.2	1
3	0	0	0	0	0	0	0	0	0	2.75	6.45	0	0	0	0	0	0	9.2	<=	9.2	1
4	0	0	0	0	0	0	0	0.49	3.6	3.65	0	0	0	0	0	0	0	7.74	<=	7.74	1
5	0	0	0	0	0	6.59	0.16	0.99	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
6	0	0	0	2.24	4.6	0.9	0	0	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
7	0.93	2.03	3.76	1.69	0	0	0	0	0	0	0	0	0	0	0	0	0	8.41	<=	16.24	0.517857
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	2.69	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.35	1.59	1.94	<=	1.94	1
LHS	0.93	2.03	3.76	3.93	4.6	7.49	0.16	1.48	3.6	6.4	6.47	7.56	8.92	0.26	0.73	1.26	1.59				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	61.17	
Demand	0.93	2.03	3.76	3.93	4.6	7.49	0.16	1.48	3.6	6.4	6.47	7.56	8.92	0.26	0.73	1.26	1.59				

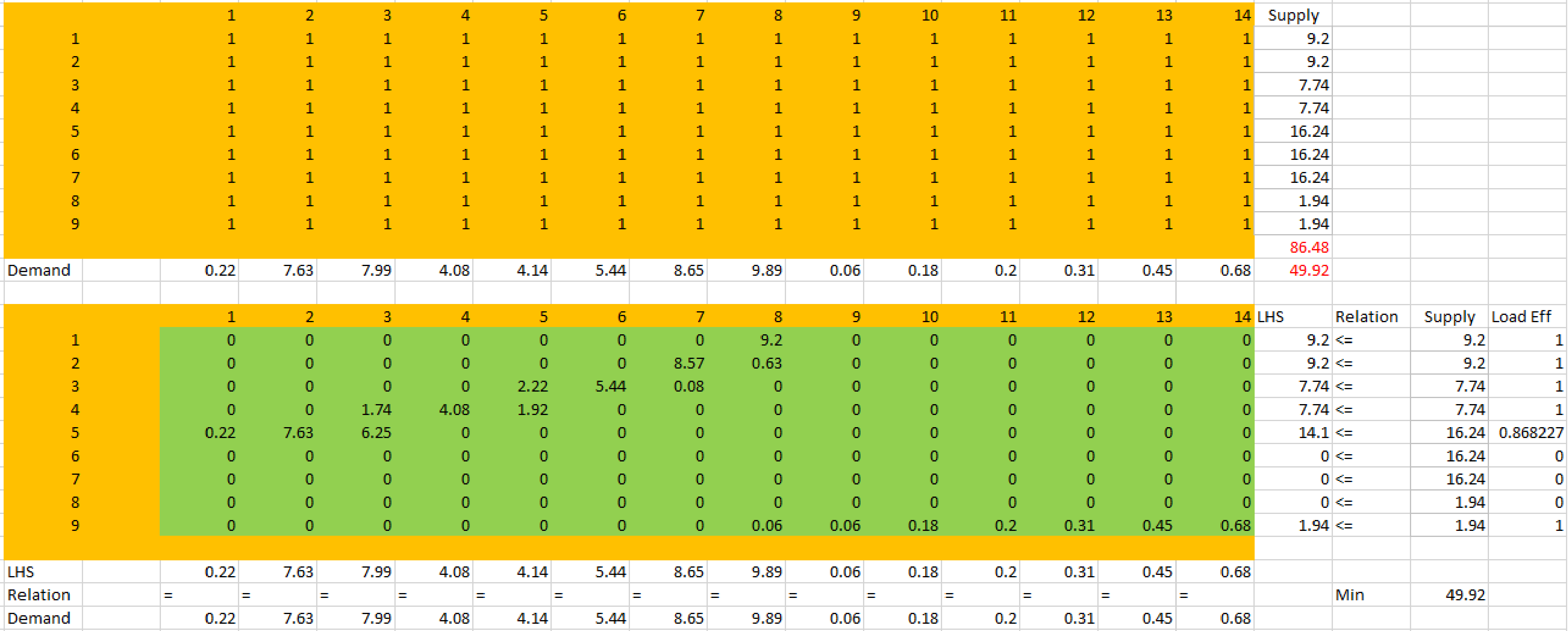
ac) 12 November 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
4	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
5	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
6	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
7	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
10	1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
11	1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
12	1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
														124.88
Demand	2.99	3.98	4.04	6.44	7.96	8.8	10.96	0.13	0.76	1.49	2.94	6.29	6.54	63.32

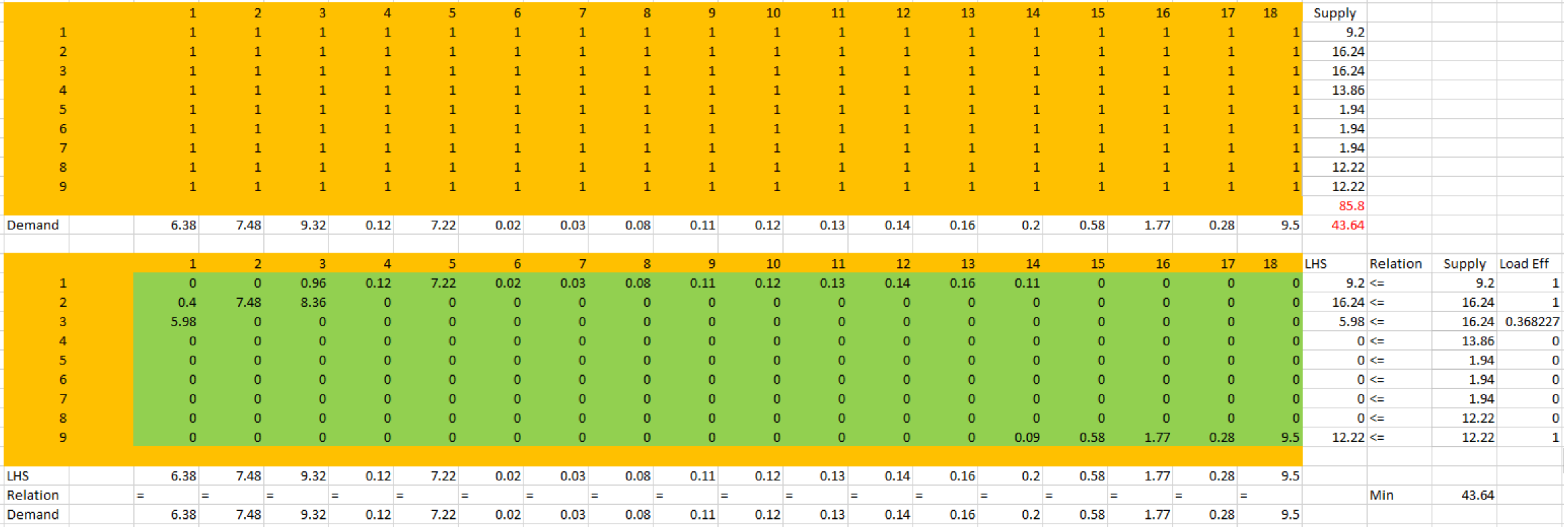
	1	2	3	4	5	6	7	8	9	10	11	12	13	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	3.85	0.13	0.76	1.49	2.94	0.03	0	9.2	<=	9.2	1
2	0	0	0	0	0	2.09	7.11	0	0	0	0	0	0	9.2	<=	9.2	1
3	0	0	0	0	1.03	6.71	0	0	0	0	0	0	0	7.74	<=	7.74	1
4	0	0	0	0.81	6.93	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
5	2.59	3.98	4.04	5.63	0	0	0	0	0	0	0	0	0	16.24	<=	16.24	1
6	0.4	0	0	0	0	0	0	0	0	0	0	0	0	0.4	<=	16.24	0.024631
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.8	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.8	0
12	0	0	0	0	0	0	0	0	0	0	0	6.26	6.54	12.8	<=	12.8	1
LHS	2.99	3.98	4.04	6.44	7.96	8.8	10.96	0.13	0.76	1.49	2.94	6.29	6.54				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	63.32	
Demand	2.99	3.98	4.04	6.44	7.96	8.8	10.96	0.13	0.76	1.49	2.94	6.29	6.54				

ad) 13 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24			
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24			
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94			
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94			
																86.48			
Demand		0.22	7.63	7.99	4.08	4.14	5.44	8.65	9.89	0.06	0.18	0.2	0.31	0.45	0.68	49.92			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	9.2	0	0	0	0	0	0	9.2	<=	9.2	1
2		0	0	0	0	0	0	8.57	0.63	0	0	0	0	0	0	9.2	<=	9.2	1
3		0	0	0	0	2.22	5.44	0.08	0	0	0	0	0	0	0	7.74	<=	7.74	1
4		0	0	1.74	4.08	1.92	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
5		0.22	7.63	6.25	0	0	0	0	0	0	0	0	0	0	0	14.1	<=	16.24	0.868227
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
9		0	0	0	0	0	0	0	0.06	0.06	0.18	0.2	0.31	0.45	0.68	1.94	<=	1.94	1
LHS		0.22	7.63	7.99	4.08	4.14	5.44	8.65	9.89	0.06	0.18	0.2	0.31	0.45	0.68				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	49.92	
Demand		0.22	7.63	7.99	4.08	4.14	5.44	8.65	9.89	0.06	0.18	0.2	0.31	0.45	0.68				

ae) 16 November 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Supply
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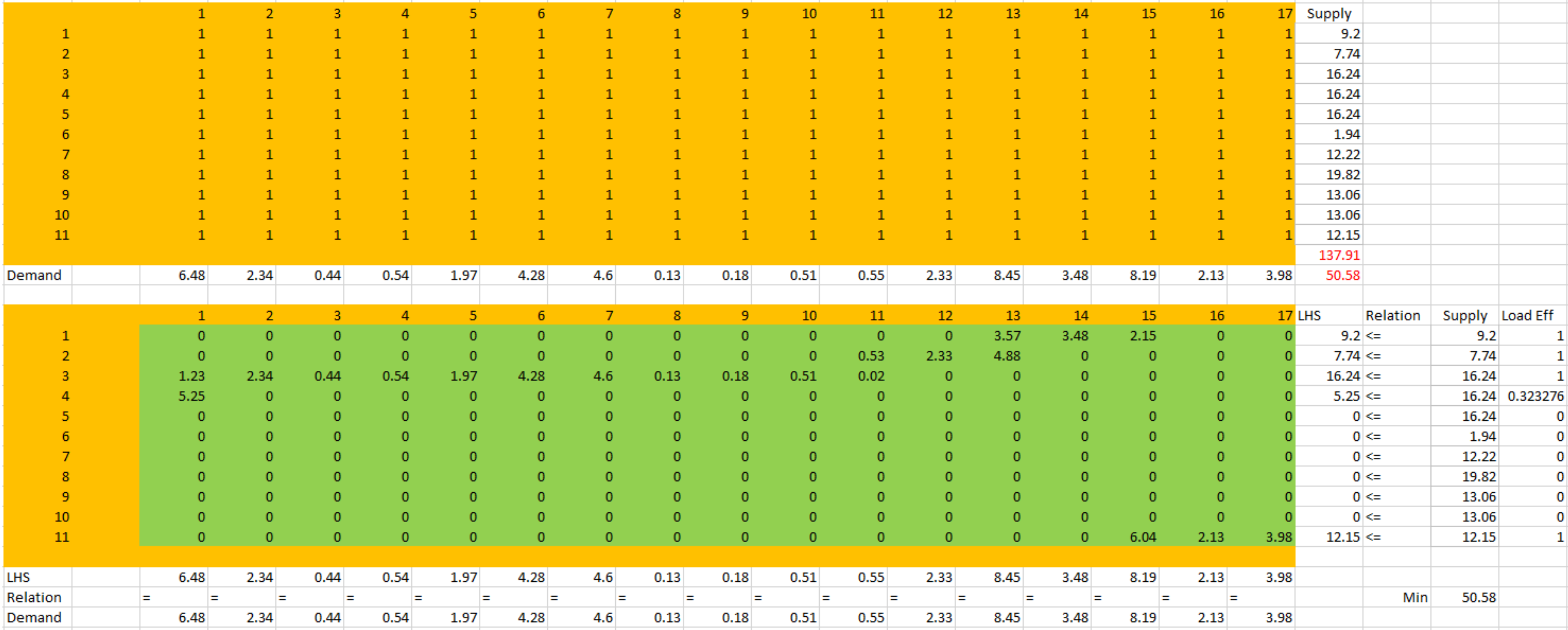
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.22
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.22
																			85.8
Demand	6.38	7.48	9.32	0.12	7.22	0.02	0.03	0.08	0.11	0.12	0.13	0.14	0.16	0.2	0.58	1.77	0.28	9.5	43.64

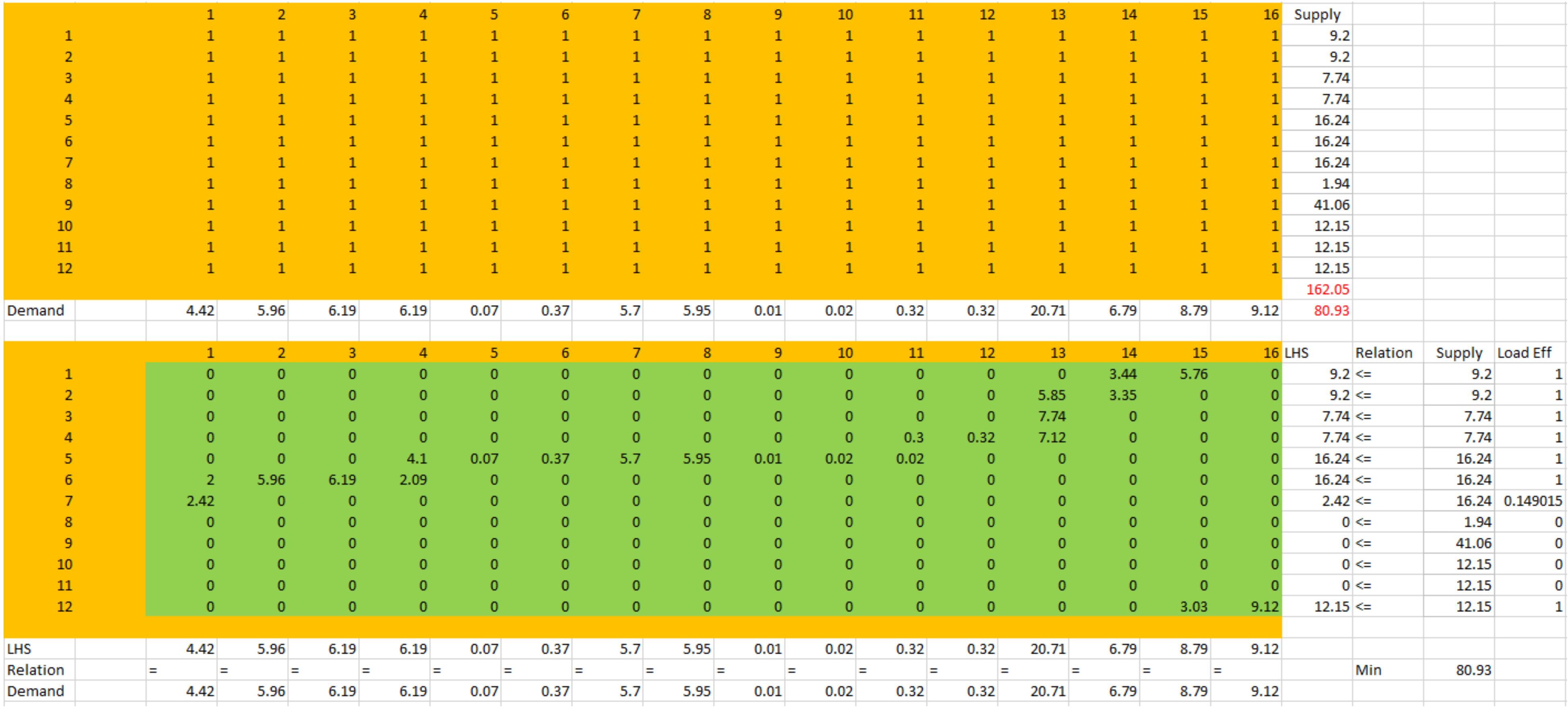
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	LHS	Relation	Supply	Load Eff
1	0	0	0.96	0.12	7.22	0.02	0.03	0.08	0.11	0.12	0.13	0.14	0.16	0.11	0	0	0	0	9.2	<=	9.2	1
2	0.4	7.48	8.36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16.24	<=	16.24	1
3	5.98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.98	<=	16.24	0.368227
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.22	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09	0.58	1.77	0.28	9.5	12.22	<=	12.22	1
LHS	6.38	7.48	9.32	0.12	7.22	0.02	0.03	0.08	0.11	0.12	0.13	0.14	0.16	0.2	0.58	1.77	0.28	9.5				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	43.64	
Demand	6.38	7.48	9.32	0.12	7.22	0.02	0.03	0.08	0.11	0.12	0.13	0.14	0.16	0.2	0.58	1.77	0.28	9.5				

af) 17 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94			
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.22			
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.82			
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.06			
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.06			
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.15			
																			137.91			
Demand		6.48	2.34	0.44	0.54	1.97	4.28	4.6	0.13	0.18	0.51	0.55	2.33	8.45	3.48	8.19	2.13	3.98	50.58			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	0	3.57	3.48	2.15	0	0	9.2	<=	9.2	1
2		0	0	0	0	0	0	0	0	0	0	0.53	2.33	4.88	0	0	0	0	7.74	<=	7.74	1
3		1.23	2.34	0.44	0.54	1.97	4.28	4.6	0.13	0.18	0.51	0.02	0	0	0	0	0	0	16.24	<=	16.24	1
4		5.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.25	<=	16.24	0.323276
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.22	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.82	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.06	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.06	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.04	2.13	3.98	12.15	<=	12.15	1
LHS		6.48	2.34	0.44	0.54	1.97	4.28	4.6	0.13	0.18	0.51	0.55	2.33	8.45	3.48	8.19	2.13	3.98				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	50.58	
Demand		6.48	2.34	0.44	0.54	1.97	4.28	4.6	0.13	0.18	0.51	0.55	2.33	8.45	3.48	8.19	2.13	3.98				

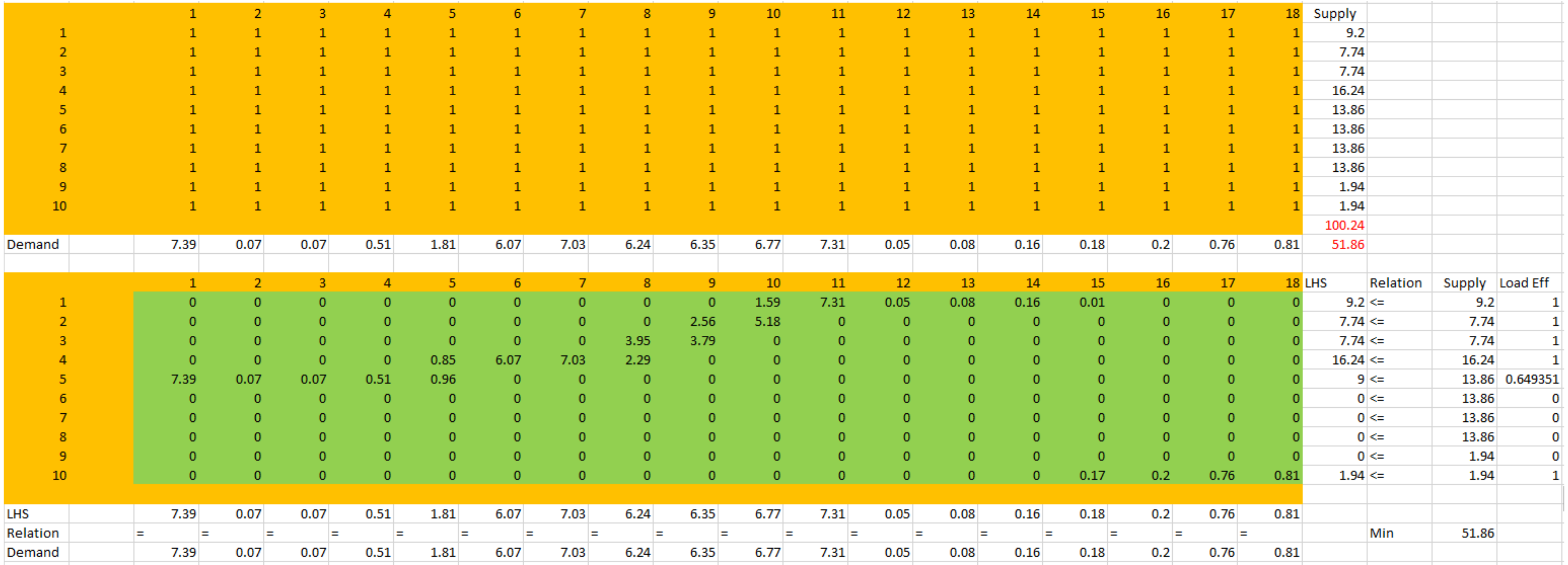
ag) 18 November 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	41.06
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.15
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.15
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.15
																	162.05
Demand	4.42	5.96	6.19	6.19	0.07	0.37	5.7	5.95	0.01	0.02	0.32	0.32	20.71	6.79	8.79	9.12	80.93

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	0	0	0	0	3.44	5.76	0	9.2	<=	9.2	1
2	0	0	0	0	0	0	0	0	0	0	0	0	5.85	3.35	0	0	9.2	<=	9.2	1
3	0	0	0	0	0	0	0	0	0	0	0	0	7.74	0	0	0	7.74	<=	7.74	1
4	0	0	0	0	0	0	0	0	0	0	0.3	0.32	7.12	0	0	0	7.74	<=	7.74	1
5	0	0	0	4.1	0.07	0.37	5.7	5.95	0.01	0.02	0.02	0	0	0	0	0	16.24	<=	16.24	1
6	2	5.96	6.19	2.09	0	0	0	0	0	0	0	0	0	0	0	0	16.24	<=	16.24	1
7	2.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.42	<=	16.24	0.149015
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	41.06	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.15	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.15	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.03	9.12	12.15	<=	12.15	1
LHS	4.42	5.96	6.19	6.19	0.07	0.37	5.7	5.95	0.01	0.02	0.32	0.32	20.71	6.79	8.79	9.12				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	80.93	
Demand	4.42	5.96	6.19	6.19	0.07	0.37	5.7	5.95	0.01	0.02	0.32	0.32	20.71	6.79	8.79	9.12				

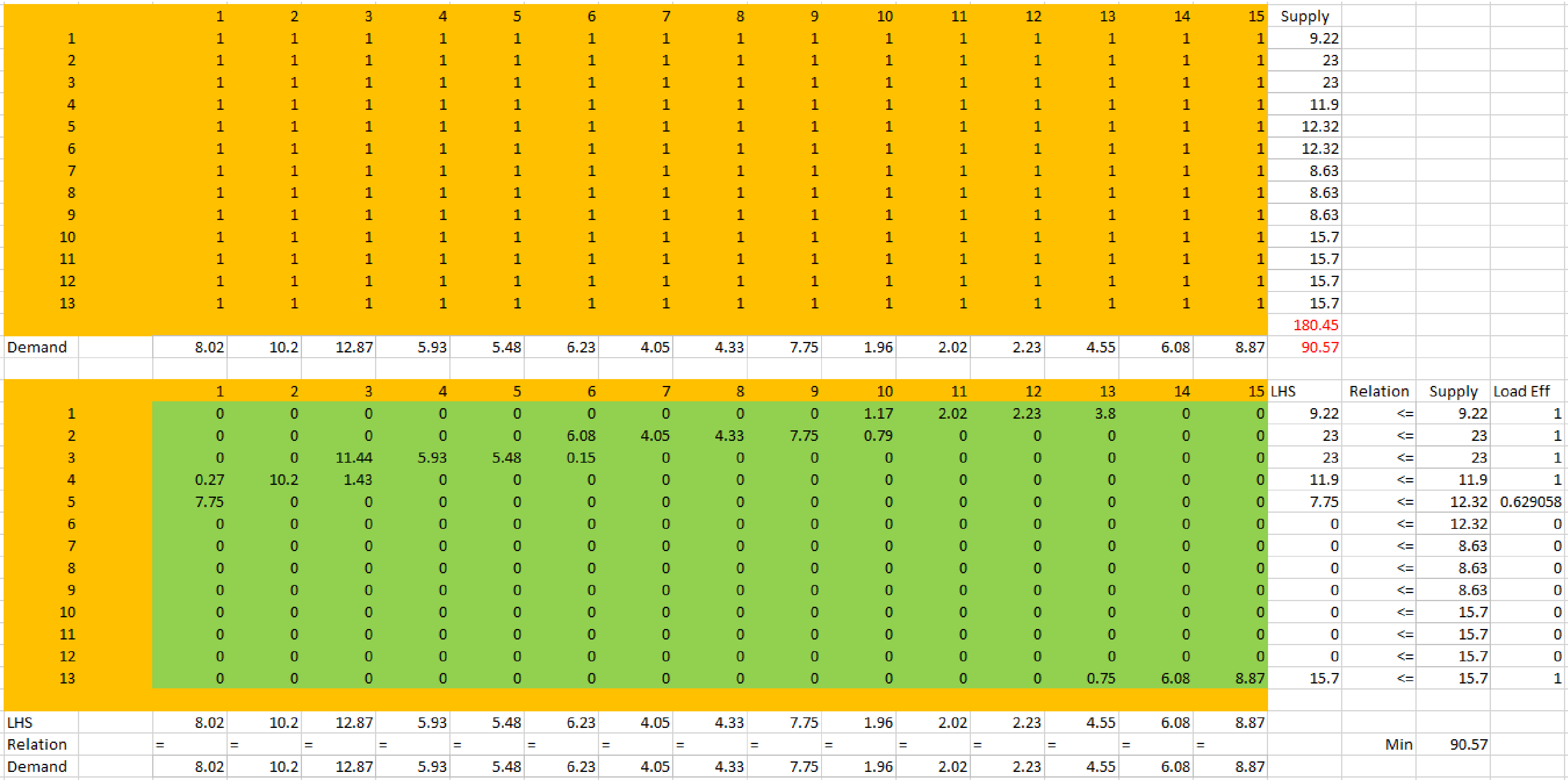
ah) 19 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86			
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86			
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86			
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94			
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94			
																				100.24			
Demand		7.39	0.07	0.07	0.51	1.81	6.07	7.03	6.24	6.35	6.77	7.31	0.05	0.08	0.16	0.18	0.2	0.76	0.81	51.86			

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	1.59	7.31	0.05	0.08	0.16	0.01	0	0	0	9.2	<=	9.2	1
2		0	0	0	0	0	0	0	0	2.56	5.18	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
3		0	0	0	0	0	0	0	3.95	3.79	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
4		0	0	0	0	0.85	6.07	7.03	2.29	0	0	0	0	0	0	0	0	0	0	16.24	<=	16.24	1
5		7.39	0.07	0.07	0.51	0.96	0	0	0	0	0	0	0	0	0	0	0	0	0	9	<=	13.86	0.649351
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.17	0.2	0.76	0.81	1.94	<=	1.94	1
LHS		7.39	0.07	0.07	0.51	1.81	6.07	7.03	6.24	6.35	6.77	7.31	0.05	0.08	0.16	0.18	0.2	0.76	0.81				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	51.86	
Demand		7.39	0.07	0.07	0.51	1.81	6.07	7.03	6.24	6.35	6.77	7.31	0.05	0.08	0.16	0.18	0.2	0.76	0.81				

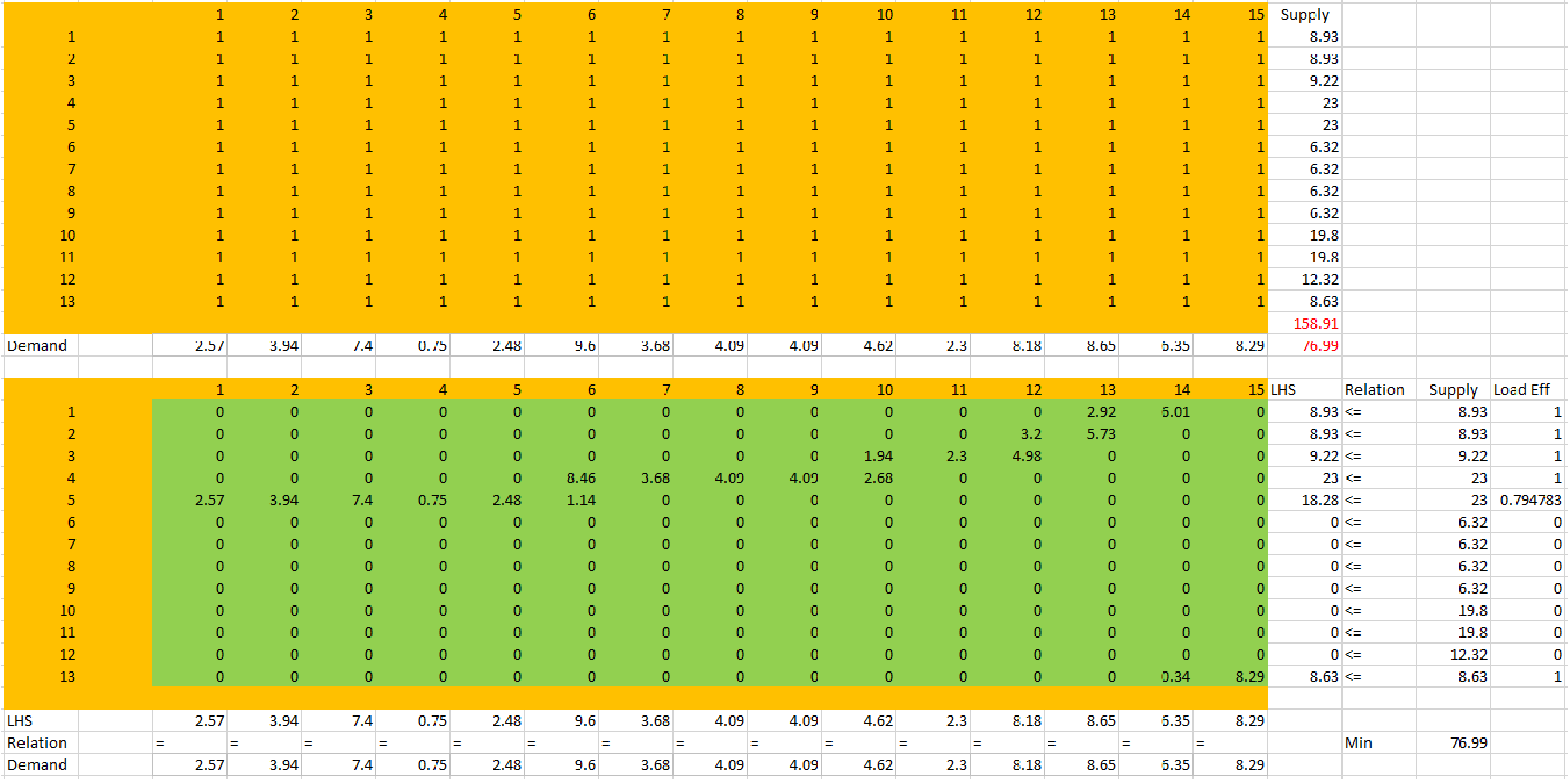
ai) 20 November 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	11.9
5	1	1	1	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	1	1	1	12.32
7	1	1	1	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	1	1	1	8.63
9	1	1	1	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	1	1	1	15.7
11	1	1	1	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	1	1	1	15.7
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																180.45
Demand	8.02	10.2	12.87	5.93	5.48	6.23	4.05	4.33	7.75	1.96	2.02	2.23	4.55	6.08	8.87	90.57

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	1.17	2.02	2.23	3.8	0	0	9.22	<=	9.22	1
2	0	0	0	0	0	6.08	4.05	4.33	7.75	0.79	0	0	0	0	0	23	<=	23	1
3	0	0	11.44	5.93	5.48	0.15	0	0	0	0	0	0	0	0	0	23	<=	23	1
4	0.27	10.2	1.43	0	0	0	0	0	0	0	0	0	0	0	0	11.9	<=	11.9	1
5	7.75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.75	<=	12.32	0.629058
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10	0	0	0	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	0	0	0	<=	15.7	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0.75	6.08	8.87	15.7	<=	15.7	1
LHS	8.02	10.2	12.87	5.93	5.48	6.23	4.05	4.33	7.75	1.96	2.02	2.23	4.55	6.08	8.87				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	90.57	
Demand	8.02	10.2	12.87	5.93	5.48	6.23	4.05	4.33	7.75	1.96	2.02	2.23	4.55	6.08	8.87				

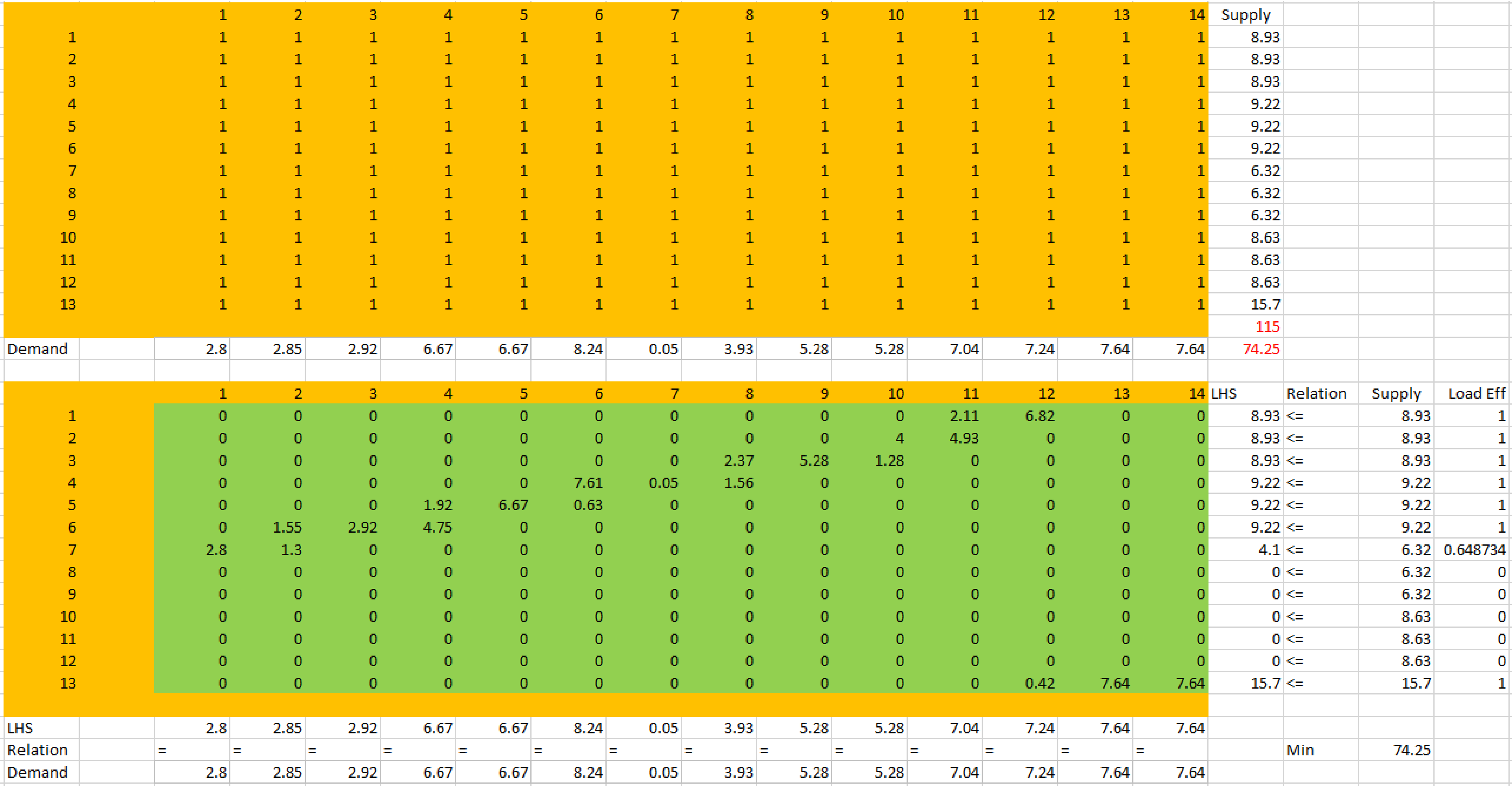
aj) 23 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
12		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
13		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
																	158.91
Demand		2.57	3.94	7.4	0.75	2.48	9.6	3.68	4.09	4.09	4.62	2.3	8.18	8.65	6.35	8.29	76.99

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	0	2.92	6.01	0	8.93	<=	8.93	1
2		0	0	0	0	0	0	0	0	0	0	0	3.2	5.73	0	0	8.93	<=	8.93	1
3		0	0	0	0	0	0	0	0	0	1.94	2.3	4.98	0	0	0	9.22	<=	9.22	1
4		0	0	0	0	0	8.46	3.68	4.09	4.09	2.68	0	0	0	0	0	23	<=	23	1
5		2.57	3.94	7.4	0.75	2.48	1.14	0	0	0	0	0	0	0	0	0	18.28	<=	23	0.794783
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
13		0	0	0	0	0	0	0	0	0	0	0	0	0	0.34	8.29	8.63	<=	8.63	1
LHS		2.57	3.94	7.4	0.75	2.48	9.6	3.68	4.09	4.09	4.62	2.3	8.18	8.65	6.35	8.29				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	76.99	
Demand		2.57	3.94	7.4	0.75	2.48	9.6	3.68	4.09	4.09	4.62	2.3	8.18	8.65	6.35	8.29				

ak) 24 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
12		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
13		1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																115
Demand		2.8	2.85	2.92	6.67	6.67	8.24	0.05	3.93	5.28	5.28	7.04	7.24	7.64	7.64	74.25

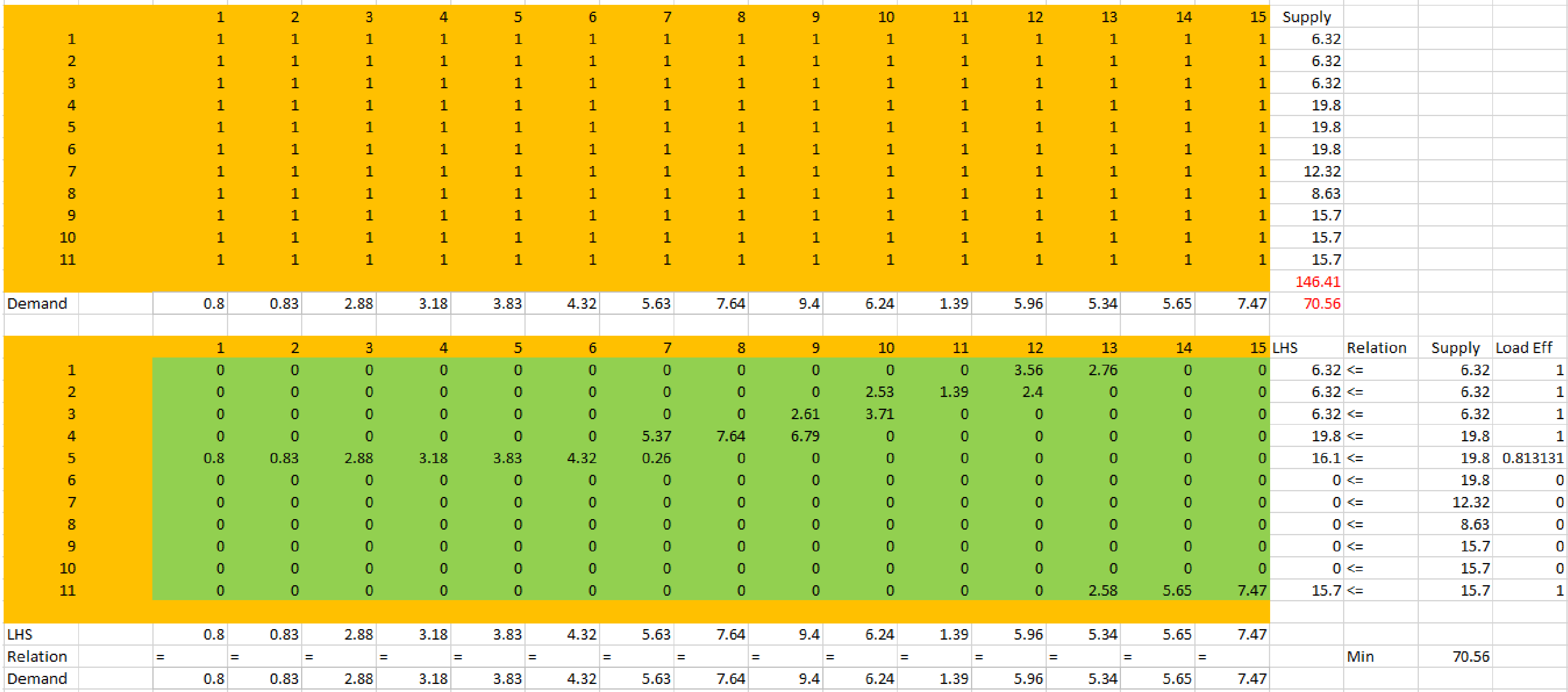
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	2.11	6.82	0	0	8.93	<=	8.93	1
2		0	0	0	0	0	0	0	0	0	4	4.93	0	0	0	8.93	<=	8.93	1
3		0	0	0	0	0	0	0	2.37	5.28	1.28	0	0	0	0	8.93	<=	8.93	1
4		0	0	0	0	0	7.61	0.05	1.56	0	0	0	0	0	0	9.22	<=	9.22	1
5		0	0	0	1.92	6.67	0.63	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
6		0	1.55	2.92	4.75	0	0	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
7		2.8	1.3	0	0	0	0	0	0	0	0	0	0	0	0	4.1	<=	6.32	0.648734
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
13		0	0	0	0	0	0	0	0	0	0	0	0.42	7.64	7.64	15.7	<=	15.7	1
LHS		2.8	2.85	2.92	6.67	6.67	8.24	0.05	3.93	5.28	5.28	7.04	7.24	7.64	7.64				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	74.25	
Demand		2.8	2.85	2.92	6.67	6.67	8.24	0.05	3.93	5.28	5.28	7.04	7.24	7.64	7.64				

al) 25 November 2020

		1	2	3	4	5	6	7	8	9	10	11	12	13	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	23
2		1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
3		1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
4		1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
5		1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
6		1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
7		1	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	1	15.7
9		1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
10		1	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	1	15.7
															132.03
Demand		2.39	4.2	5.8	5.85	5.85	5.33	7.9	0.59	2.03	4.62	6.04	6.6	9.18	66.38

		1	2	3	4	5	6	7	8	9	10	11	12	13	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	1.74	7.9	0.59	2.03	4.62	6.04	0.08	0	23	<=	23	1
2		0	0	0	0	2.73	3.59	0	0	0	0	0	0	0	6.32	<=	6.32	1
3		0	0	0	3.2	3.12	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
4		0	0	3.67	2.65	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
5		0	4.19	2.13	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
6		2.39	0.01	0	0	0	0	0	0	0	0	0	0	0	2.4	<=	12.32	0.194805
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
10		0	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	6.52	9.18	15.7	<=	15.7	1
LHS		2.39	4.2	5.8	5.85	5.85	5.33	7.9	0.59	2.03	4.62	6.04	6.6	9.18				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=		Min	66.38	
Demand		2.39	4.2	5.8	5.85	5.85	5.33	7.9	0.59	2.03	4.62	6.04	6.6	9.18				

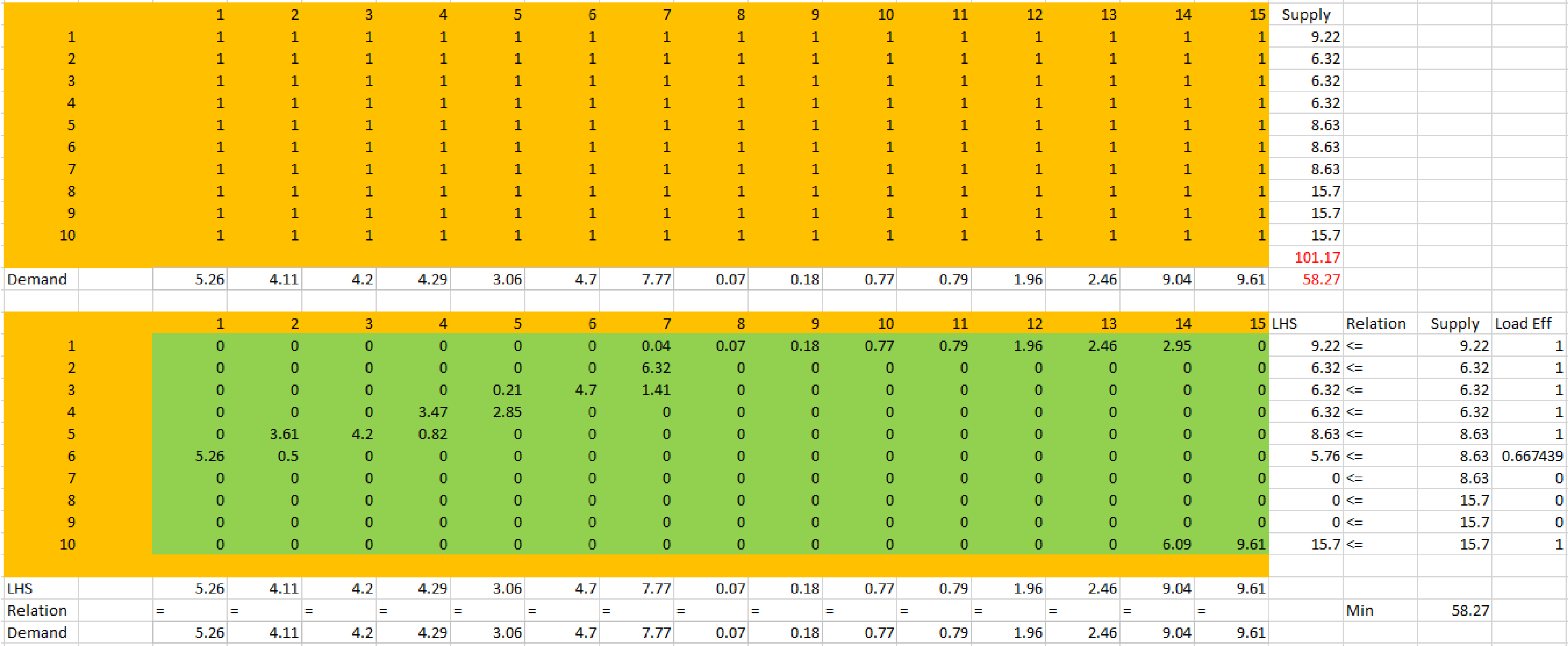
am) 26 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
8		1	1	1	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	1	1	1	15.7
10		1	1	1	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	1	1	1	15.7
																	146.41
Demand		0.8	0.83	2.88	3.18	3.83	4.32	5.63	7.64	9.4	6.24	1.39	5.96	5.34	5.65	7.47	70.56

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	3.56	2.76	0	0	6.32	<=	6.32	1
2		0	0	0	0	0	0	0	0	0	2.53	1.39	2.4	0	0	0	6.32	<=	6.32	1
3		0	0	0	0	0	0	0	0	2.61	3.71	0	0	0	0	0	6.32	<=	6.32	1
4		0	0	0	0	0	0	5.37	7.64	6.79	0	0	0	0	0	0	19.8	<=	19.8	1
5		0.8	0.83	2.88	3.18	3.83	4.32	0.26	0	0	0	0	0	0	0	0	16.1	<=	19.8	0.813131
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
10		0	0	0	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	2.58	5.65	7.47	15.7	<=	15.7	1
LHS		0.8	0.83	2.88	3.18	3.83	4.32	5.63	7.64	9.4	6.24	1.39	5.96	5.34	5.65	7.47				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	70.56	
Demand		0.8	0.83	2.88	3.18	3.83	4.32	5.63	7.64	9.4	6.24	1.39	5.96	5.34	5.65	7.47				

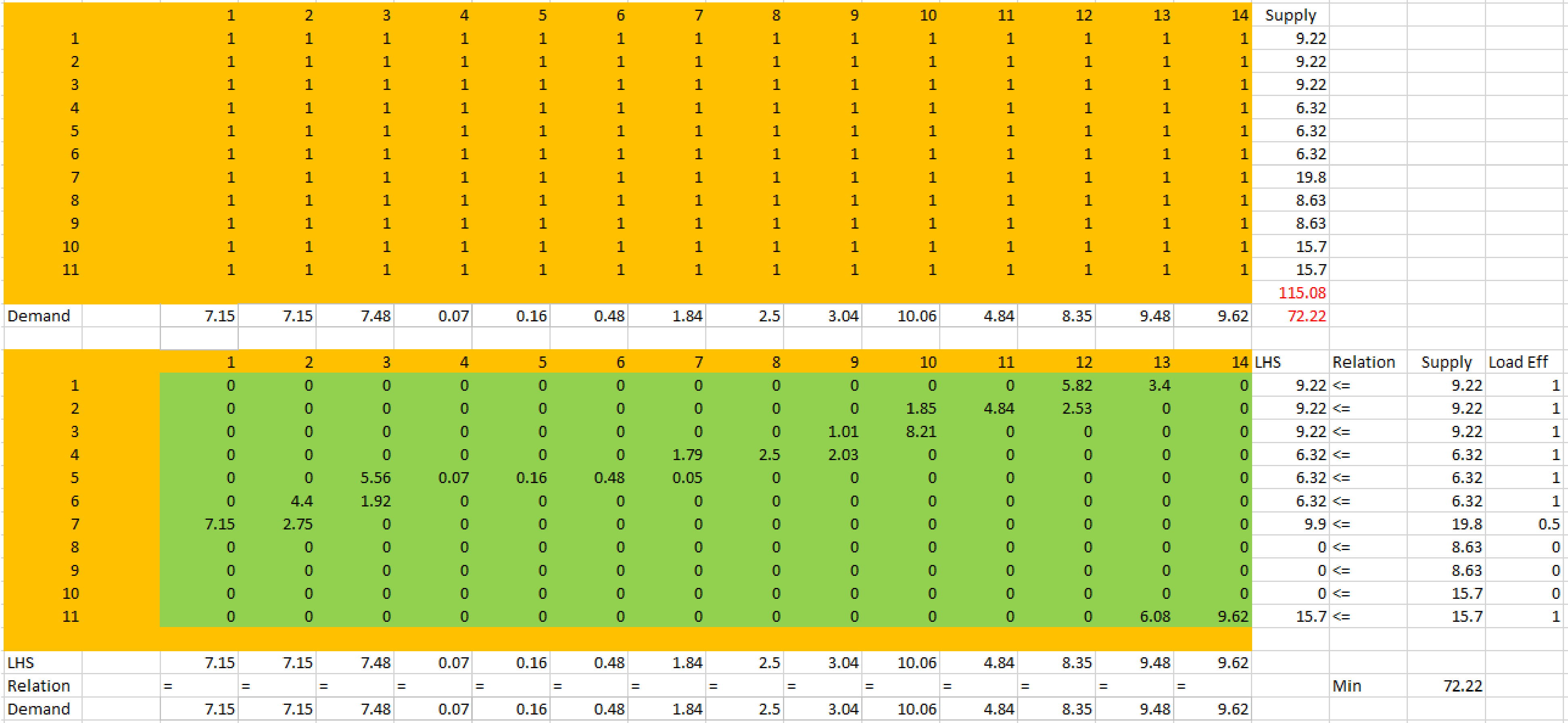
an) 27 November 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63			
6		1	1	1	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	1	1	1	8.63			
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7			
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7			
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7			
																	101.17			
Demand		5.26	4.11	4.2	4.29	3.06	4.7	7.77	0.07	0.18	0.77	0.79	1.96	2.46	9.04	9.61	58.27			

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0.04	0.07	0.18	0.77	0.79	1.96	2.46	2.95	0	9.22	<=	9.22	1
2		0	0	0	0	0	0	6.32	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
3		0	0	0	0	0.21	4.7	1.41	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
4		0	0	0	3.47	2.85	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
5		0	3.61	4.2	0.82	0	0	0	0	0	0	0	0	0	0	0	8.63	<=	8.63	1
6		5.26	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	5.76	<=	8.63	0.667439
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	6.09	9.61	15.7	<=	15.7	1
LHS		5.26	4.11	4.2	4.29	3.06	4.7	7.77	0.07	0.18	0.77	0.79	1.96	2.46	9.04	9.61				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	58.27	
Demand		5.26	4.11	4.2	4.29	3.06	4.7	7.77	0.07	0.18	0.77	0.79	1.96	2.46	9.04	9.61				

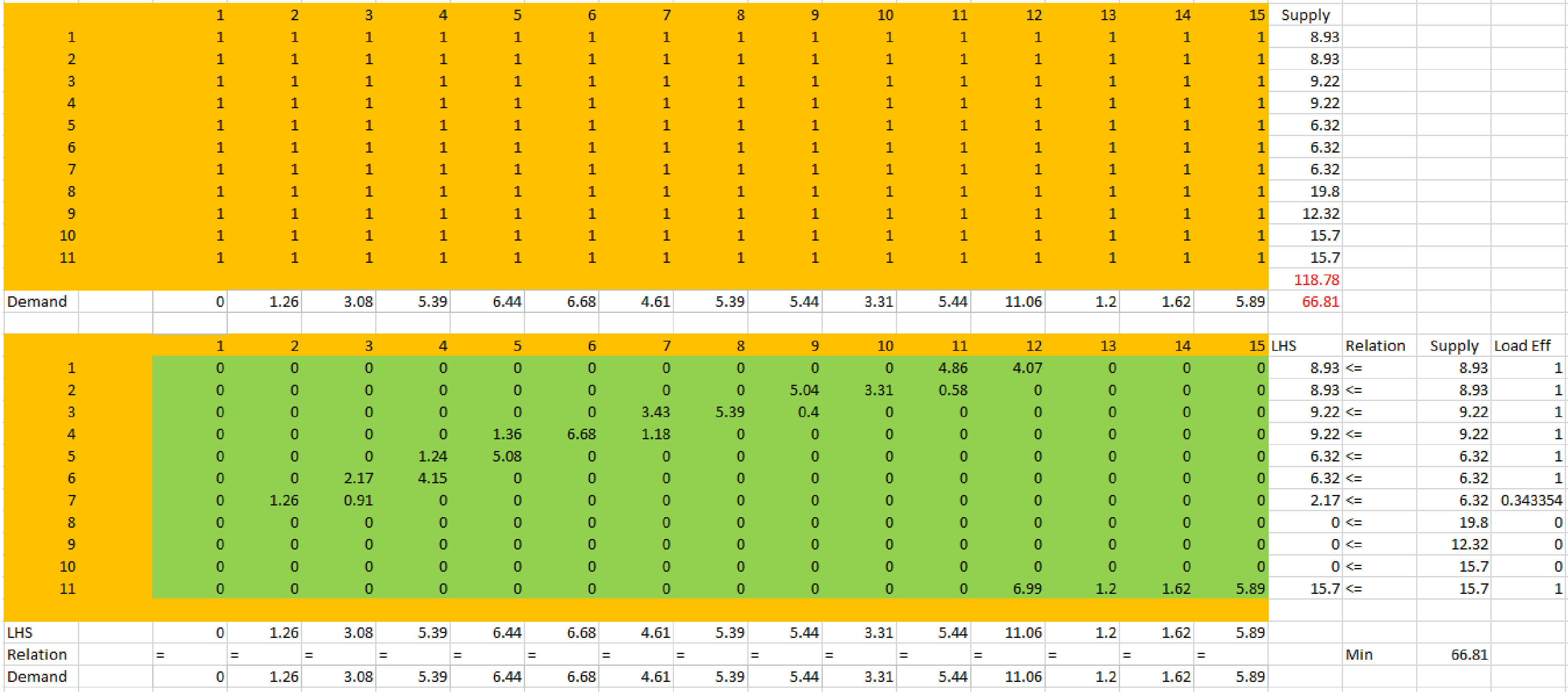
ao) 30 November 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
8	1	1	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	1	1	8.63
10	1	1	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	1	1	15.7
															115.08
Demand	7.15	7.15	7.48	0.07	0.16	0.48	1.84	2.5	3.04	10.06	4.84	8.35	9.48	9.62	72.22

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	0	0	5.82	3.4	0	9.22	<=	9.22	1
2	0	0	0	0	0	0	0	0	0	1.85	4.84	2.53	0	0	9.22	<=	9.22	1
3	0	0	0	0	0	0	0	0	1.01	8.21	0	0	0	0	9.22	<=	9.22	1
4	0	0	0	0	0	0	1.79	2.5	2.03	0	0	0	0	0	6.32	<=	6.32	1
5	0	0	5.56	0.07	0.16	0.48	0.05	0	0	0	0	0	0	0	6.32	<=	6.32	1
6	0	4.4	1.92	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
7	7.15	2.75	0	0	0	0	0	0	0	0	0	0	0	0	9.9	<=	19.8	0.5
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10	0	0	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	6.08	9.62	15.7	<=	15.7	1
LHS	7.15	7.15	7.48	0.07	0.16	0.48	1.84	2.5	3.04	10.06	4.84	8.35	9.48	9.62				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	72.22	
Demand	7.15	7.15	7.48	0.07	0.16	0.48	1.84	2.5	3.04	10.06	4.84	8.35	9.48	9.62				

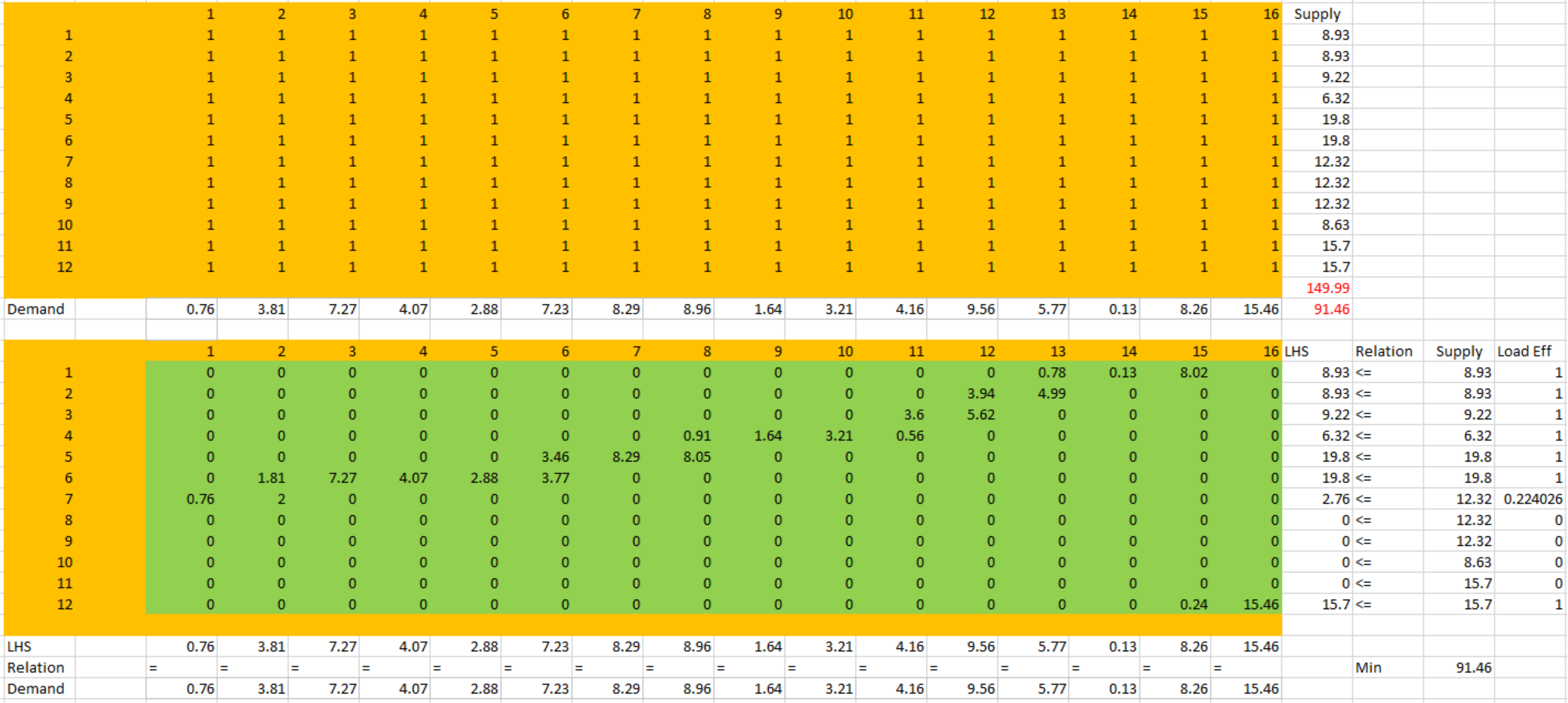
ap) 01 December 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
10	1	1	1	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	1	1	1	15.7
																118.78
Demand	0	1.26	3.08	5.39	6.44	6.68	4.61	5.39	5.44	3.31	5.44	11.06	1.2	1.62	5.89	66.81

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	0	0	4.86	4.07	0	0	0	8.93	<=	8.93	1
2	0	0	0	0	0	0	0	0	5.04	3.31	0.58	0	0	0	0	8.93	<=	8.93	1
3	0	0	0	0	0	0	3.43	5.39	0.4	0	0	0	0	0	0	9.22	<=	9.22	1
4	0	0	0	0	1.36	6.68	1.18	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
5	0	0	0	1.24	5.08	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
6	0	0	2.17	4.15	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
7	0	1.26	0.91	0	0	0	0	0	0	0	0	0	0	0	0	2.17	<=	6.32	0.343354
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
10	0	0	0	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	6.99	1.2	1.62	5.89	15.7	<=	15.7	1
LHS	0	1.26	3.08	5.39	6.44	6.68	4.61	5.39	5.44	3.31	5.44	11.06	1.2	1.62	5.89				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	66.81	
Demand	0	1.26	3.08	5.39	6.44	6.68	4.61	5.39	5.44	3.31	5.44	11.06	1.2	1.62	5.89				

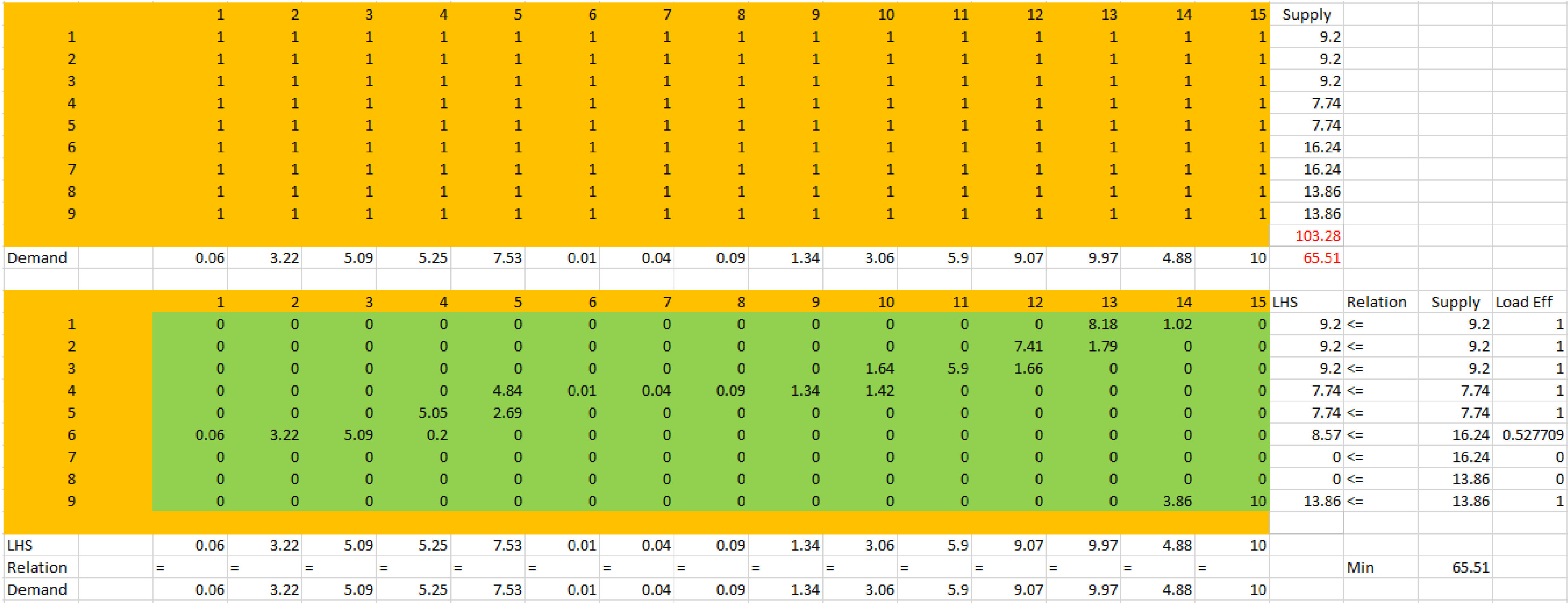
aq) 02 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
11		1	1	1	1	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	1	1	1	1	15.7
																		149.99
Demand		0.76	3.81	7.27	4.07	2.88	7.23	8.29	8.96	1.64	3.21	4.16	9.56	5.77	0.13	8.26	15.46	91.46

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	0	0.78	0.13	8.02	0	8.93	<=	8.93	1
2		0	0	0	0	0	0	0	0	0	0	0	3.94	4.99	0	0	0	8.93	<=	8.93	1
3		0	0	0	0	0	0	0	0	0	0	3.6	5.62	0	0	0	0	9.22	<=	9.22	1
4		0	0	0	0	0	0	0	0.91	1.64	3.21	0.56	0	0	0	0	0	6.32	<=	6.32	1
5		0	0	0	0	0	3.46	8.29	8.05	0	0	0	0	0	0	0	0	19.8	<=	19.8	1
6		0	1.81	7.27	4.07	2.88	3.77	0	0	0	0	0	0	0	0	0	0	19.8	<=	19.8	1
7		0.76	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.76	<=	12.32	0.224026
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.24	15.46	15.7	<=	15.7	1
LHS		0.76	3.81	7.27	4.07	2.88	7.23	8.29	8.96	1.64	3.21	4.16	9.56	5.77	0.13	8.26	15.46				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	91.46	
Demand		0.76	3.81	7.27	4.07	2.88	7.23	8.29	8.96	1.64	3.21	4.16	9.56	5.77	0.13	8.26	15.46				

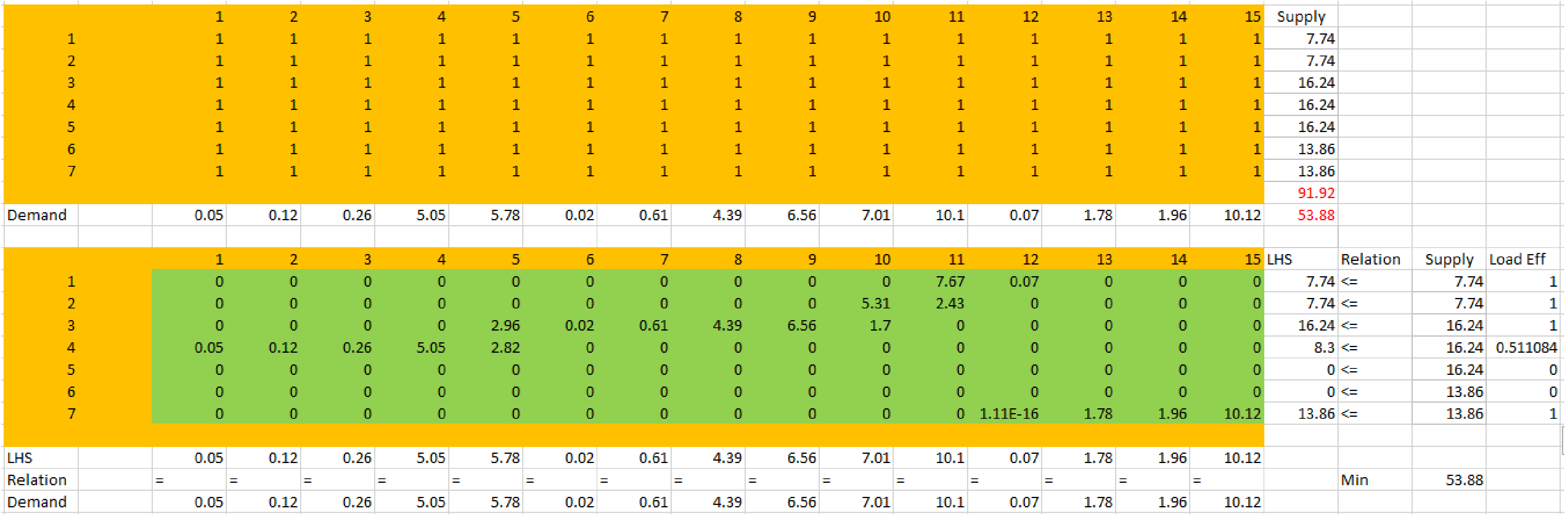
ar) 03 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
																	103.28
Demand		0.06	3.22	5.09	5.25	7.53	0.01	0.04	0.09	1.34	3.06	5.9	9.07	9.97	4.88	10	65.51

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	0	8.18	1.02	0	9.2	<=	9.2	1
2		0	0	0	0	0	0	0	0	0	0	0	7.41	1.79	0	0	9.2	<=	9.2	1
3		0	0	0	0	0	0	0	0	0	1.64	5.9	1.66	0	0	0	9.2	<=	9.2	1
4		0	0	0	0	4.84	0.01	0.04	0.09	1.34	1.42	0	0	0	0	0	7.74	<=	7.74	1
5		0	0	0	5.05	2.69	0	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
6		0.06	3.22	5.09	0.2	0	0	0	0	0	0	0	0	0	0	0	8.57	<=	16.24	0.527709
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	3.86	10	13.86	<=	13.86	1
LHS		0.06	3.22	5.09	5.25	7.53	0.01	0.04	0.09	1.34	3.06	5.9	9.07	9.97	4.88	10				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	65.51	
Demand		0.06	3.22	5.09	5.25	7.53	0.01	0.04	0.09	1.34	3.06	5.9	9.07	9.97	4.88	10				

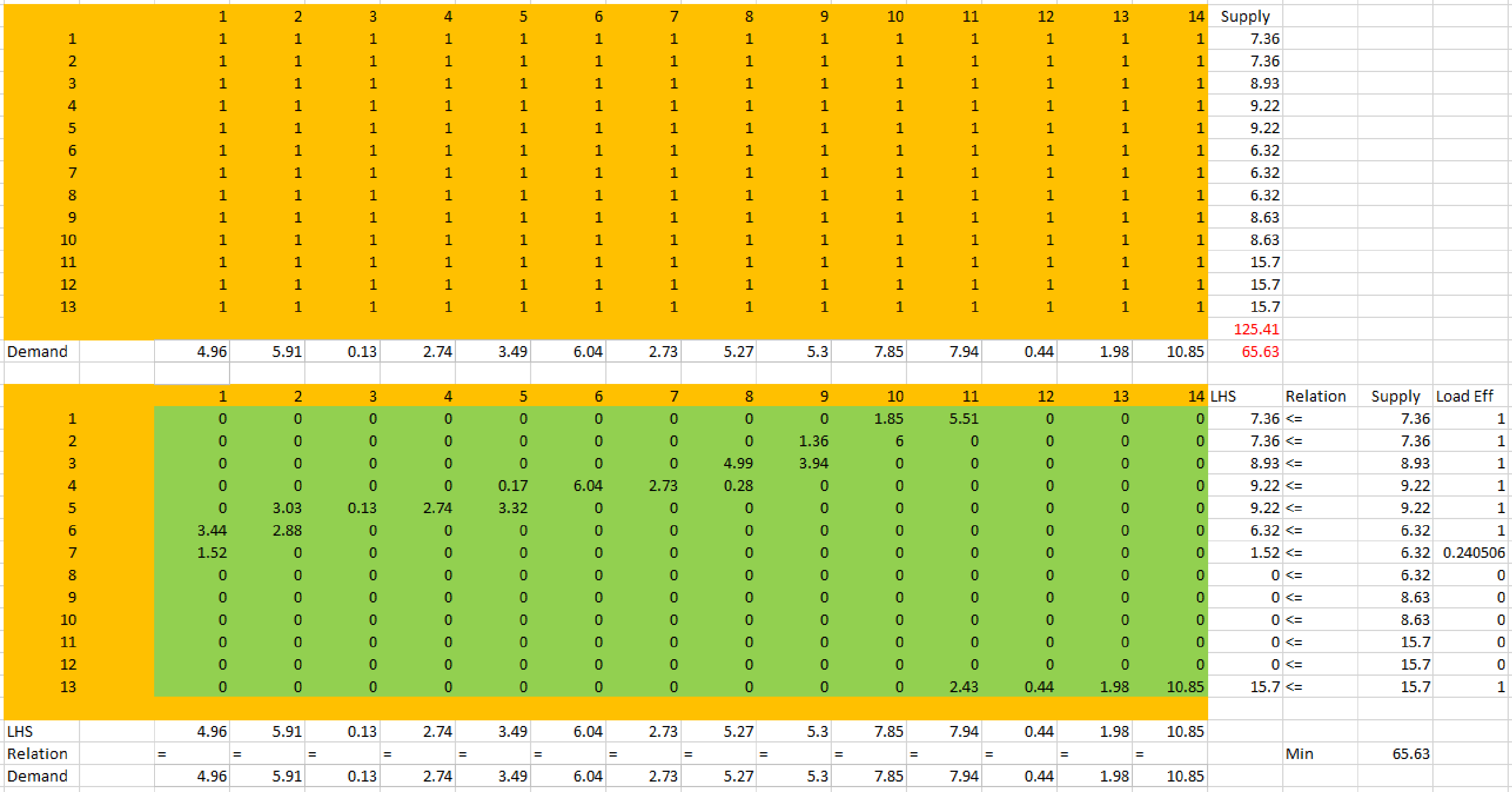
as) 04 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
																	91.92
Demand		0.05	0.12	0.26	5.05	5.78	0.02	0.61	4.39	6.56	7.01	10.1	0.07	1.78	1.96	10.12	53.88

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	7.67	0.07	0	0	0	7.74	<=	7.74	1
2		0	0	0	0	0	0	0	0	0	5.31	2.43	0	0	0	0	7.74	<=	7.74	1
3		0	0	0	0	2.96	0.02	0.61	4.39	6.56	1.7	0	0	0	0	0	16.24	<=	16.24	1
4		0.05	0.12	0.26	5.05	2.82	0	0	0	0	0	0	0	0	0	0	8.3	<=	16.24	0.511084
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
7		0	0	0	0	0	0	0	0	0	0	0	1.11E-16	1.78	1.96	10.12	13.86	<=	13.86	1
LHS		0.05	0.12	0.26	5.05	5.78	0.02	0.61	4.39	6.56	7.01	10.1	0.07	1.78	1.96	10.12				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	53.88	
Demand		0.05	0.12	0.26	5.05	5.78	0.02	0.61	4.39	6.56	7.01	10.1	0.07	1.78	1.96	10.12				

at) 07 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Supply
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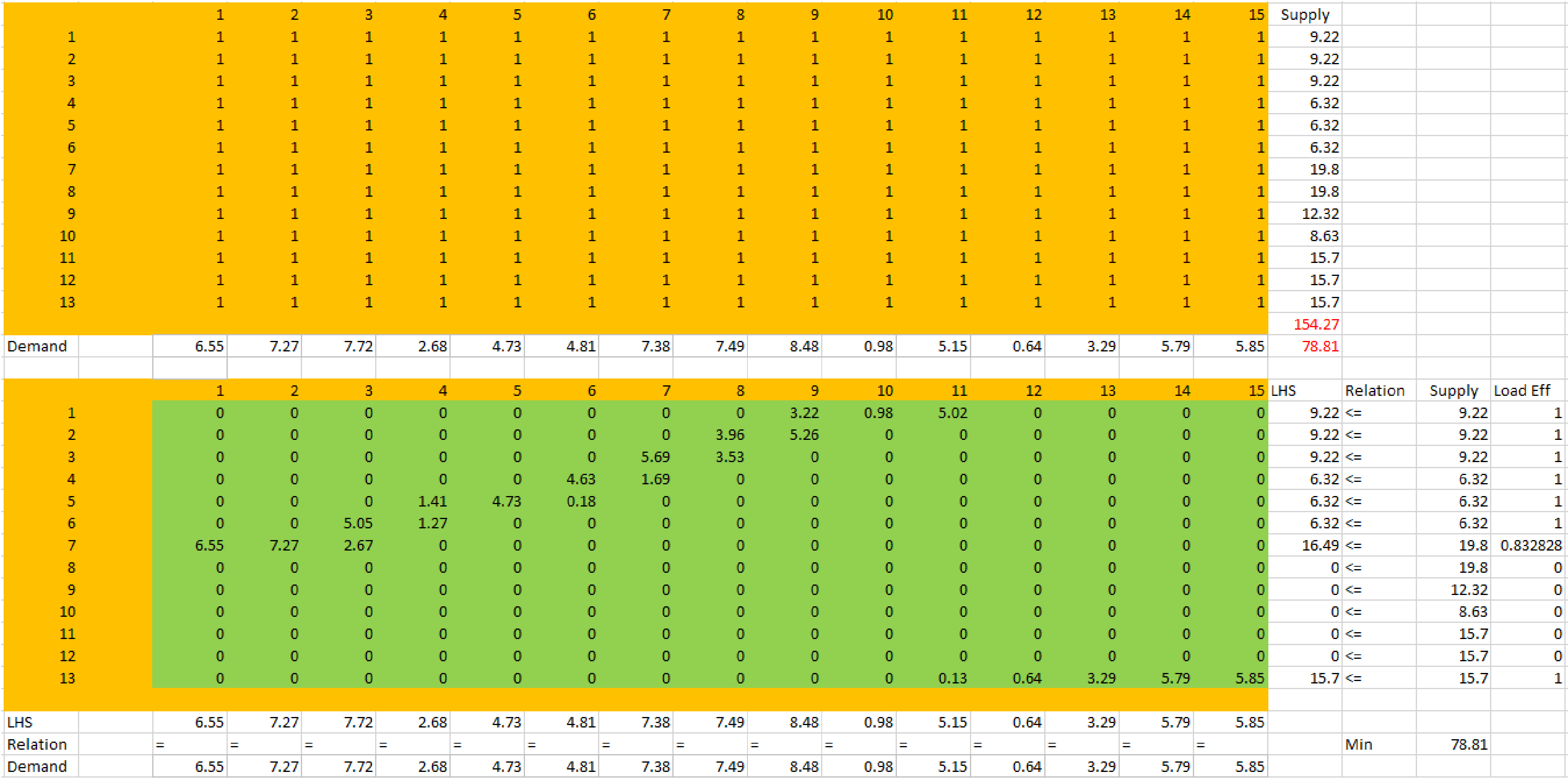
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.36
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
11		1	1	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	1	1	15.7
13		1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																125.41
Demand		4.96	5.91	0.13	2.74	3.49	6.04	2.73	5.27	5.3	7.85	7.94	0.44	1.98	10.85	65.63

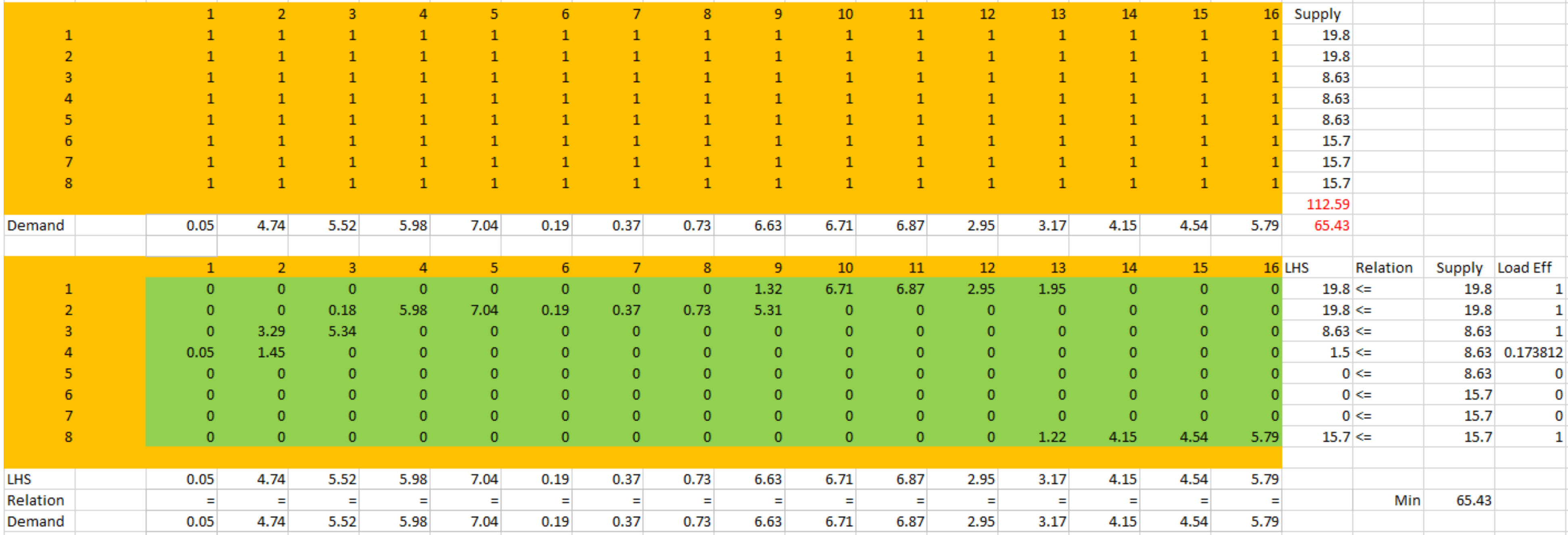
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	1.85	5.51	0	0	0	7.36	<=	7.36	1
2		0	0	0	0	0	0	0	0	1.36	6	0	0	0	0	7.36	<=	7.36	1
3		0	0	0	0	0	0	0	4.99	3.94	0	0	0	0	0	8.93	<=	8.93	1
4		0	0	0	0	0.17	6.04	2.73	0.28	0	0	0	0	0	0	9.22	<=	9.22	1
5		0	3.03	0.13	2.74	3.32	0	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
6		3.44	2.88	0	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
7		1.52	0	0	0	0	0	0	0	0	0	0	0	0	0	1.52	<=	6.32	0.240506
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
13		0	0	0	0	0	0	0	0	0	0	2.43	0.44	1.98	10.85	15.7	<=	15.7	1
LHS		4.96	5.91	0.13	2.74	3.49	6.04	2.73	5.27	5.3	7.85	7.94	0.44	1.98	10.85				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	65.63	
Demand		4.96	5.91	0.13	2.74	3.49	6.04	2.73	5.27	5.3	7.85	7.94	0.44	1.98	10.85				

au) 08 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22			
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22			
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22			
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32			
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8			
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32			
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63			
11		1	1	1	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	1	1	1	15.7			
13		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7			
																	154.27			
Demand		6.55	7.27	7.72	2.68	4.73	4.81	7.38	7.49	8.48	0.98	5.15	0.64	3.29	5.79	5.85	78.81			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	3.22	0.98	5.02	0	0	0	0	9.22	<=	9.22	1
2		0	0	0	0	0	0	0	3.96	5.26	0	0	0	0	0	0	9.22	<=	9.22	1
3		0	0	0	0	0	0	5.69	3.53	0	0	0	0	0	0	0	9.22	<=	9.22	1
4		0	0	0	0	0	4.63	1.69	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
5		0	0	0	1.41	4.73	0.18	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
6		0	0	5.05	1.27	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
7		6.55	7.27	2.67	0	0	0	0	0	0	0	0	0	0	0	0	16.49	<=	19.8	0.832828
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.8	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
13		0	0	0	0	0	0	0	0	0	0	0.13	0.64	3.29	5.79	5.85	15.7	<=	15.7	1
LHS		6.55	7.27	7.72	2.68	4.73	4.81	7.38	7.49	8.48	0.98	5.15	0.64	3.29	5.79	5.85				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	78.81	
Demand		6.55	7.27	7.72	2.68	4.73	4.81	7.38	7.49	8.48	0.98	5.15	0.64	3.29	5.79	5.85				

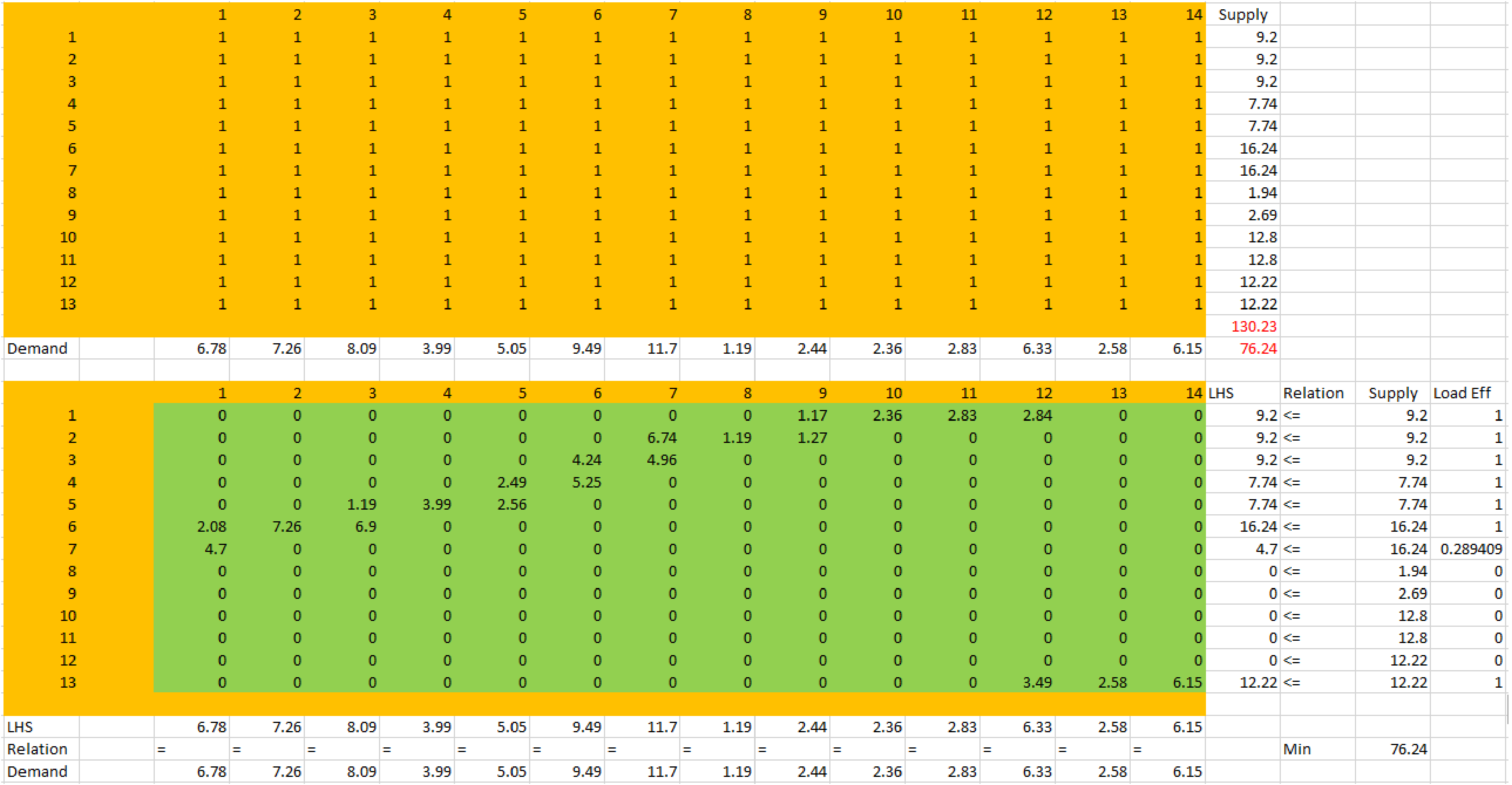
av) 09 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply
1		1	1	1	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	1	1	1	1	19.8
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																		112.59
Demand		0.05	4.74	5.52	5.98	7.04	0.19	0.37	0.73	6.63	6.71	6.87	2.95	3.17	4.15	4.54	5.79	65.43

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	1.32	6.71	6.87	2.95	1.95	0	0	0	19.8	<=	19.8	1
2		0	0	0.18	5.98	7.04	0.19	0.37	0.73	5.31	0	0	0	0	0	0	0	19.8	<=	19.8	1
3		0	3.29	5.34	0	0	0	0	0	0	0	0	0	0	0	0	0	8.63	<=	8.63	1
4		0.05	1.45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.5	<=	8.63	0.173812
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	15.7	0
8		0	0	0	0	0	0	0	0	0	0	0	0	1.22	4.15	4.54	5.79	15.7	<=	15.7	1
LHS		0.05	4.74	5.52	5.98	7.04	0.19	0.37	0.73	6.63	6.71	6.87	2.95	3.17	4.15	4.54	5.79				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	65.43	
Demand		0.05	4.74	5.52	5.98	7.04	0.19	0.37	0.73	6.63	6.71	6.87	2.95	3.17	4.15	4.54	5.79				

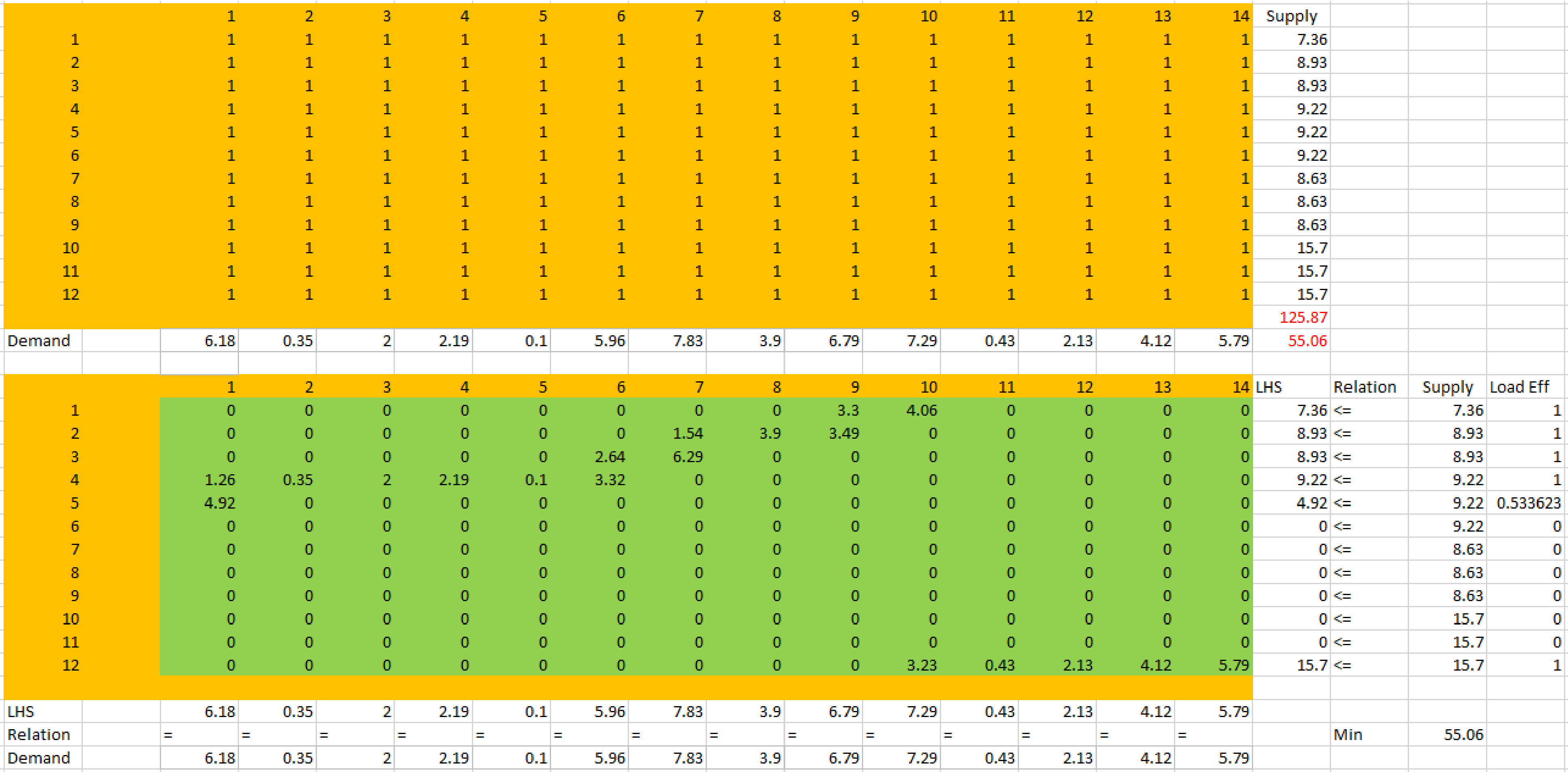
aw) 10 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	2.69
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
12		1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.22
13		1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.22
																130.23
Demand		6.78	7.26	8.09	3.99	5.05	9.49	11.7	1.19	2.44	2.36	2.83	6.33	2.58	6.15	76.24

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	1.17	2.36	2.83	2.84	0	0	9.2	<=	9.2	1
2		0	0	0	0	0	0	6.74	1.19	1.27	0	0	0	0	0	9.2	<=	9.2	1
3		0	0	0	0	0	4.24	4.96	0	0	0	0	0	0	0	9.2	<=	9.2	1
4		0	0	0	0	2.49	5.25	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
5		0	0	1.19	3.99	2.56	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
6		2.08	7.26	6.9	0	0	0	0	0	0	0	0	0	0	0	16.24	<=	16.24	1
7		4.7	0	0	0	0	0	0	0	0	0	0	0	0	0	4.7	<=	16.24	0.289409
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	2.69	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.8	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.8	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.22	0
13		0	0	0	0	0	0	0	0	0	0	0	3.49	2.58	6.15	12.22	<=	12.22	1
LHS		6.78	7.26	8.09	3.99	5.05	9.49	11.7	1.19	2.44	2.36	2.83	6.33	2.58	6.15				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	76.24	
Demand		6.78	7.26	8.09	3.99	5.05	9.49	11.7	1.19	2.44	2.36	2.83	6.33	2.58	6.15				

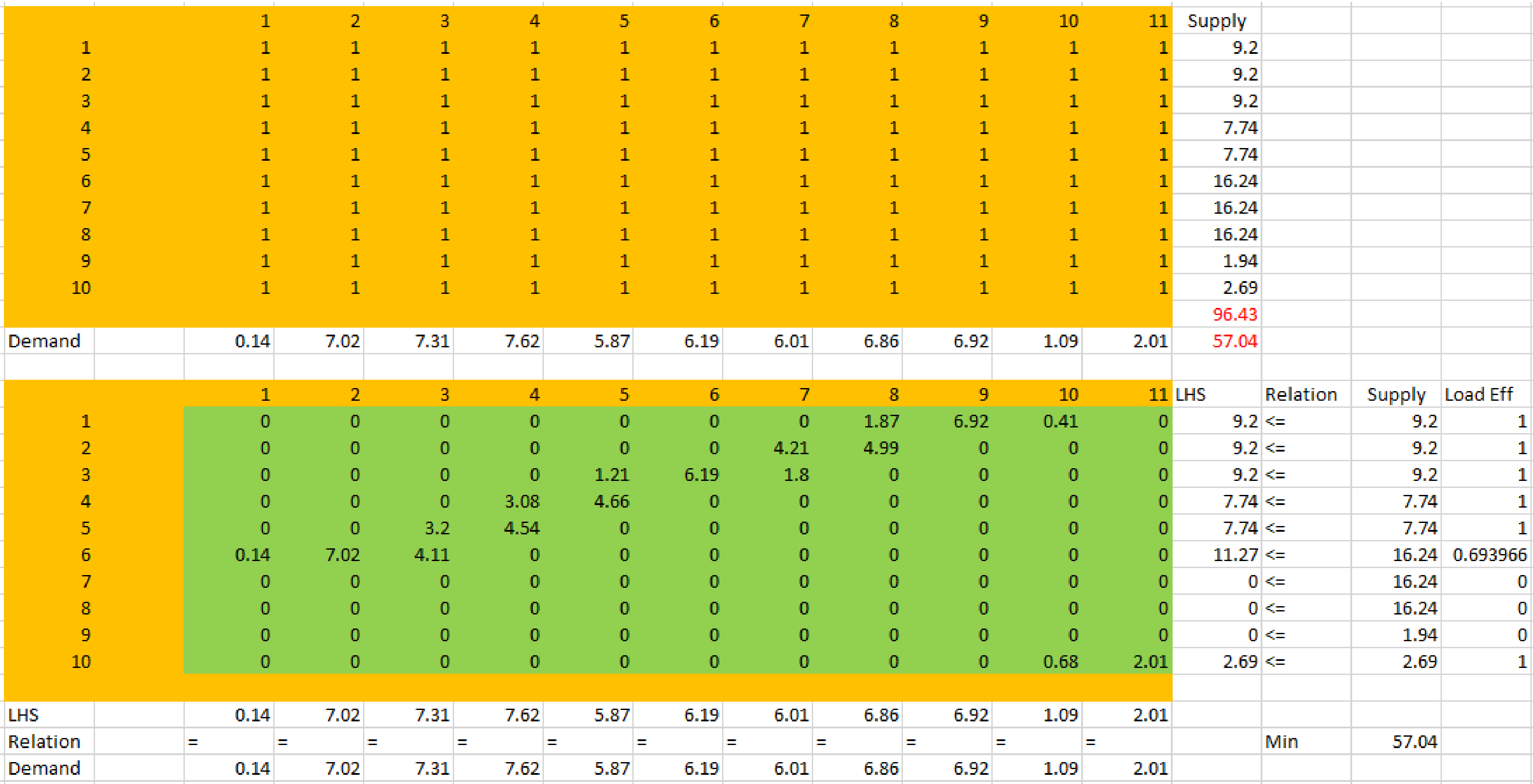
ax) 11 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.36
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
7		1	1	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	1	1	8.63
9		1	1	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	1	1	15.7
11		1	1	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	1	1	15.7
																125.87
Demand		6.18	0.35	2	2.19	0.1	5.96	7.83	3.9	6.79	7.29	0.43	2.13	4.12	5.79	55.06

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	3.3	4.06	0	0	0	0	7.36	<=	7.36	1
2		0	0	0	0	0	0	1.54	3.9	3.49	0	0	0	0	0	8.93	<=	8.93	1
3		0	0	0	0	0	2.64	6.29	0	0	0	0	0	0	0	8.93	<=	8.93	1
4		1.26	0.35	2	2.19	0.1	3.32	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
5		4.92	0	0	0	0	0	0	0	0	0	0	0	0	0	4.92	<=	9.22	0.533623
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	9.22	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	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	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	3.23	0.43	2.13	4.12	5.79	15.7	<=	15.7	1
LHS		6.18	0.35	2	2.19	0.1	5.96	7.83	3.9	6.79	7.29	0.43	2.13	4.12	5.79				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	55.06	
Demand		6.18	0.35	2	2.19	0.1	5.96	7.83	3.9	6.79	7.29	0.43	2.13	4.12	5.79				

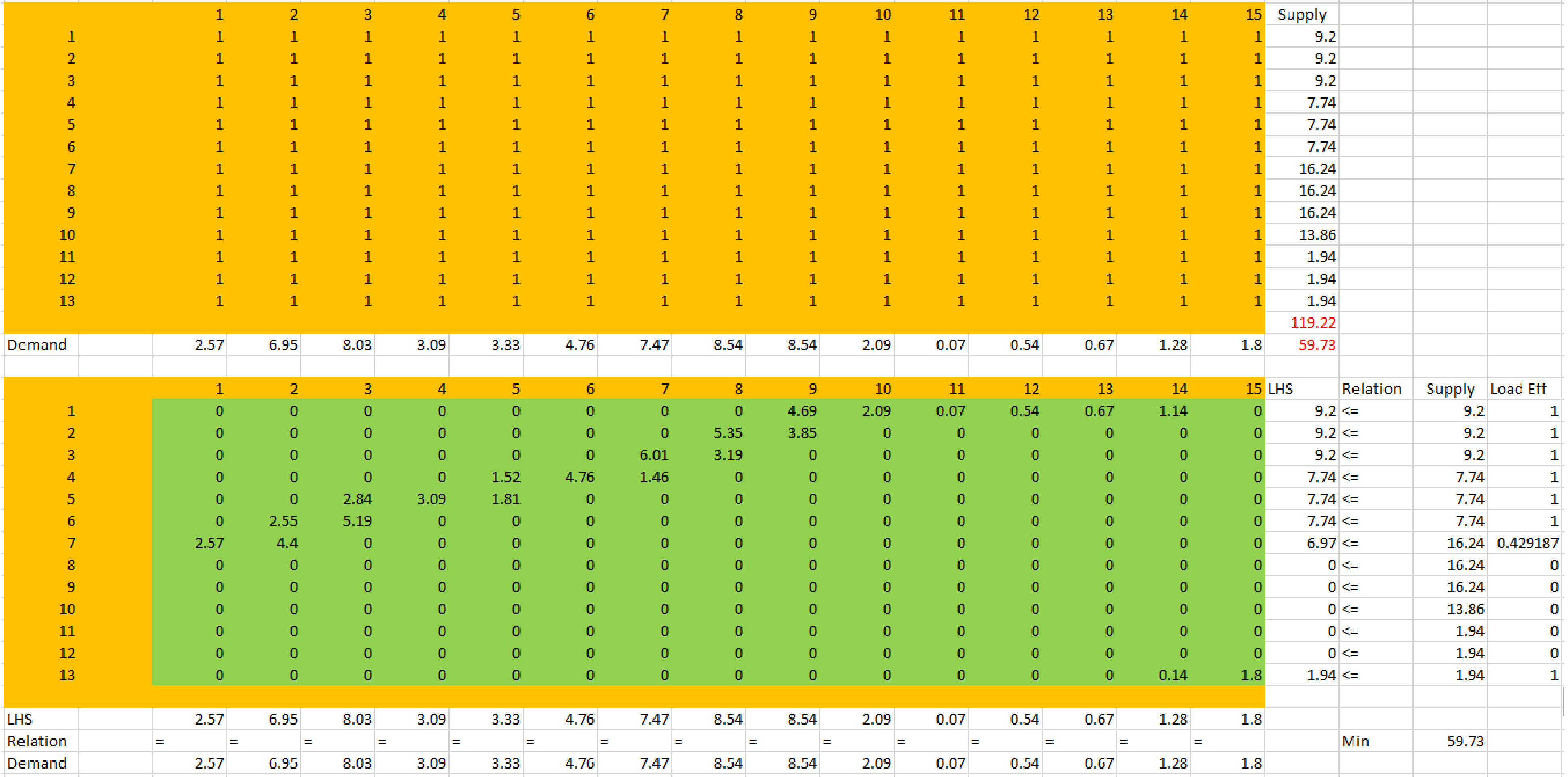
ay) 14 December 2020



		1	2	3	4	5	6	7	8	9	10	11	Supply			
1		1	1	1	1	1	1	1	1	1	1	1	9.2			
2		1	1	1	1	1	1	1	1	1	1	1	9.2			
3		1	1	1	1	1	1	1	1	1	1	1	9.2			
4		1	1	1	1	1	1	1	1	1	1	1	7.74			
5		1	1	1	1	1	1	1	1	1	1	1	7.74			
6		1	1	1	1	1	1	1	1	1	1	1	16.24			
7		1	1	1	1	1	1	1	1	1	1	1	16.24			
8		1	1	1	1	1	1	1	1	1	1	1	16.24			
9		1	1	1	1	1	1	1	1	1	1	1	1.94			
10		1	1	1	1	1	1	1	1	1	1	1	2.69			
													96.43			
Demand		0.14	7.02	7.31	7.62	5.87	6.19	6.01	6.86	6.92	1.09	2.01	57.04			

		1	2	3	4	5	6	7	8	9	10	11	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	1.87	6.92	0.41	0	9.2	<=	9.2	1
2		0	0	0	0	0	0	4.21	4.99	0	0	0	9.2	<=	9.2	1
3		0	0	0	0	1.21	6.19	1.8	0	0	0	0	9.2	<=	9.2	1
4		0	0	0	3.08	4.66	0	0	0	0	0	0	7.74	<=	7.74	1
5		0	0	3.2	4.54	0	0	0	0	0	0	0	7.74	<=	7.74	1
6		0.14	7.02	4.11	0	0	0	0	0	0	0	0	11.27	<=	16.24	0.693966
7		0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
8		0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
9		0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
10		0	0	0	0	0	0	0	0	0	0.68	2.01	2.69	<=	2.69	1
LHS		0.14	7.02	7.31	7.62	5.87	6.19	6.01	6.86	6.92	1.09	2.01				
Relation		=	=	=	=	=	=	=	=	=	=	=		Min	57.04	
Demand		0.14	7.02	7.31	7.62	5.87	6.19	6.01	6.86	6.92	1.09	2.01				

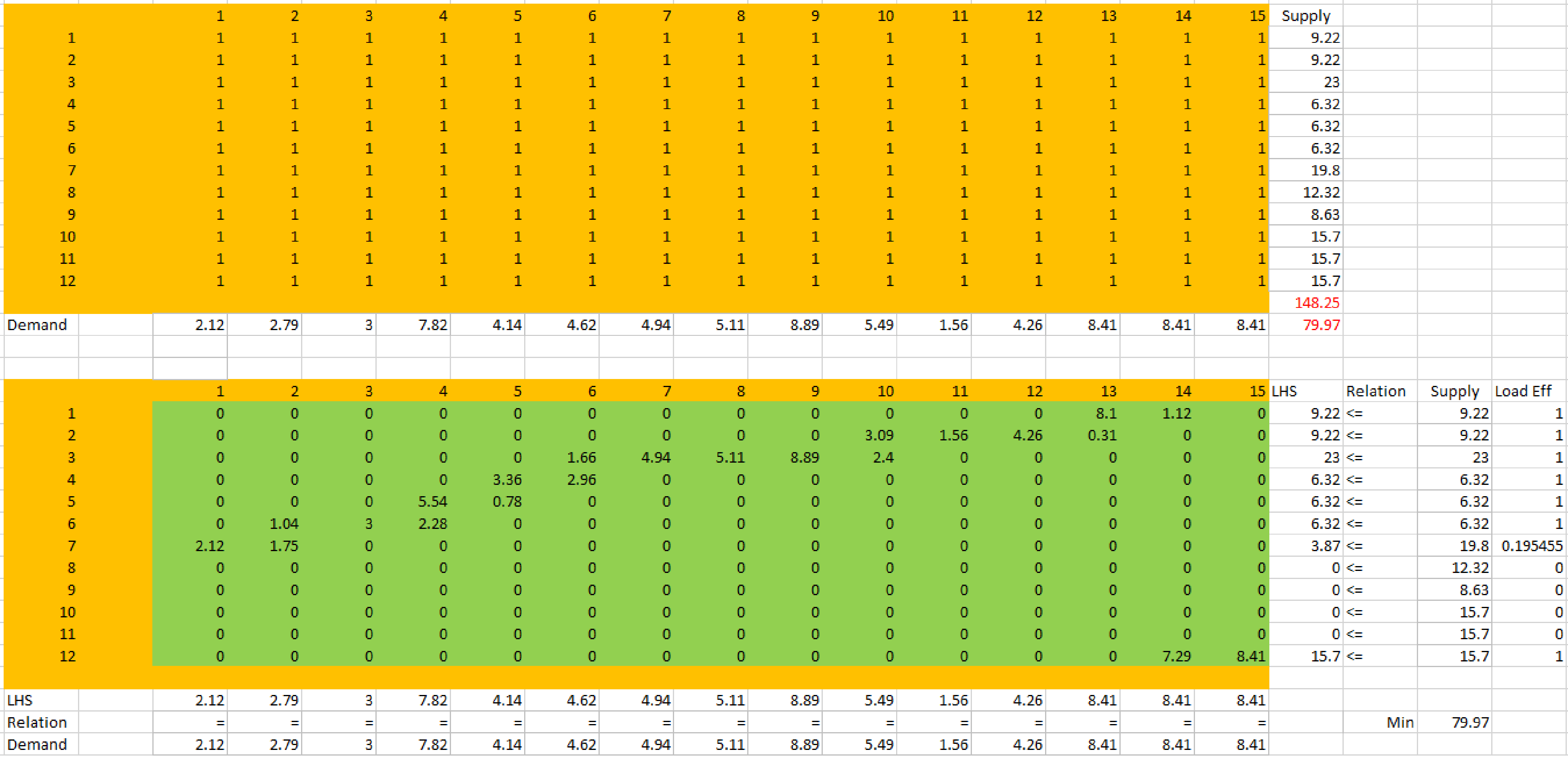
az) 15 December 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.2
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	13.86
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
																119.22
Demand	2.57	6.95	8.03	3.09	3.33	4.76	7.47	8.54	8.54	2.09	0.07	0.54	0.67	1.28	1.8	59.73

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0	0	4.69	2.09	0.07	0.54	0.67	1.14	0	9.2	<=	9.2	1
2	0	0	0	0	0	0	0	5.35	3.85	0	0	0	0	0	0	9.2	<=	9.2	1
3	0	0	0	0	0	0	6.01	3.19	0	0	0	0	0	0	0	9.2	<=	9.2	1
4	0	0	0	0	1.52	4.76	1.46	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
5	0	0	2.84	3.09	1.81	0	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
6	0	2.55	5.19	0	0	0	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
7	2.57	4.4	0	0	0	0	0	0	0	0	0	0	0	0	0	6.97	<=	16.24	0.429187
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.86	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0.14	1.8	1.94	<=	1.94	1
LHS	2.57	6.95	8.03	3.09	3.33	4.76	7.47	8.54	8.54	2.09	0.07	0.54	0.67	1.28	1.8				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	59.73	
Demand	2.57	6.95	8.03	3.09	3.33	4.76	7.47	8.54	8.54	2.09	0.07	0.54	0.67	1.28	1.8				

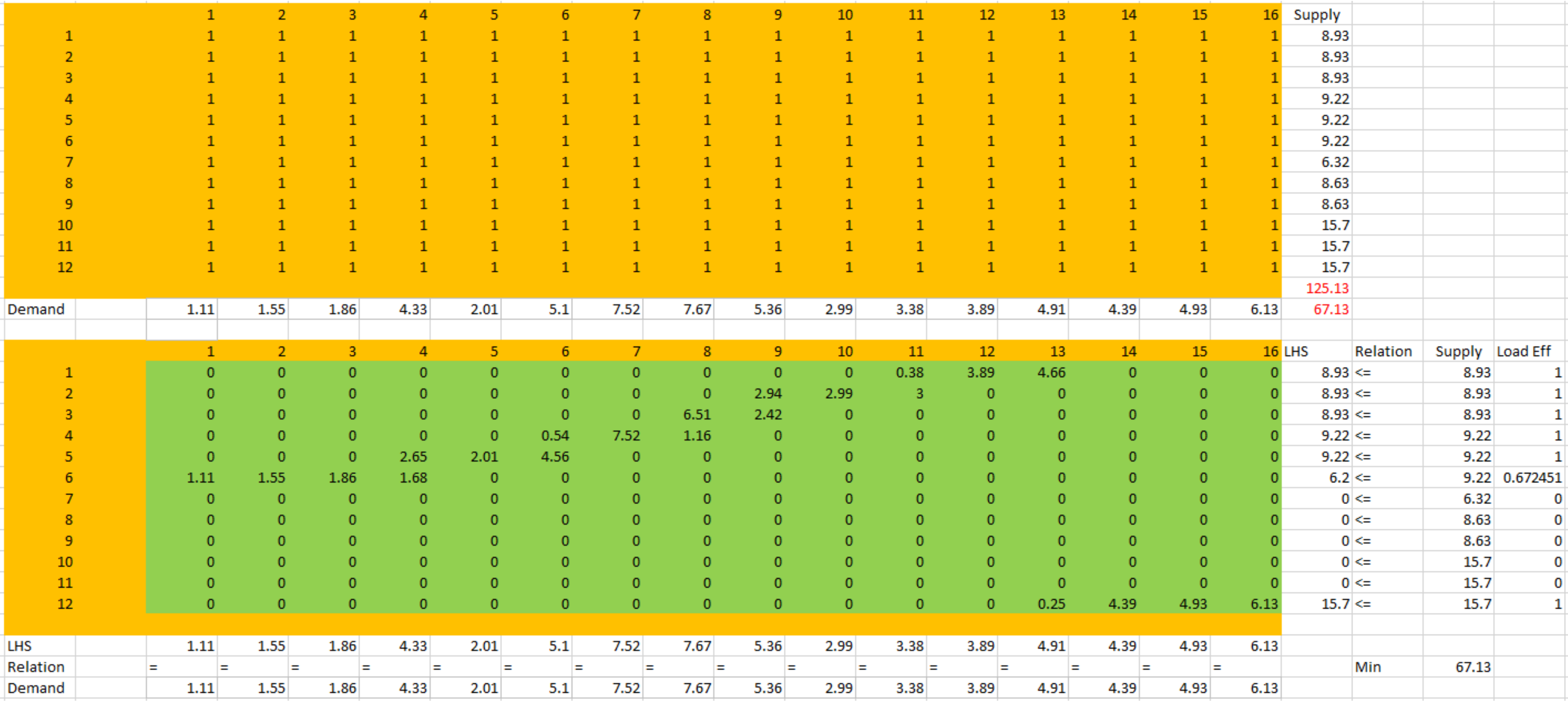
ba) 16 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.32
9		1	1	1	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	1	1	1	15.7
11		1	1	1	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	1	1	1	15.7
																	148.25
Demand		2.12	2.79	3	7.82	4.14	4.62	4.94	5.11	8.89	5.49	1.56	4.26	8.41	8.41	8.41	79.97

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	0	0	8.1	1.12	0	9.22	<=	9.22	1
2		0	0	0	0	0	0	0	0	0	3.09	1.56	4.26	0.31	0	0	9.22	<=	9.22	1
3		0	0	0	0	0	1.66	4.94	5.11	8.89	2.4	0	0	0	0	0	23	<=	23	1
4		0	0	0	0	3.36	2.96	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
5		0	0	0	5.54	0.78	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
6		0	1.04	3	2.28	0	0	0	0	0	0	0	0	0	0	0	6.32	<=	6.32	1
7		2.12	1.75	0	0	0	0	0	0	0	0	0	0	0	0	0	3.87	<=	19.8	0.195455
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.32	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
10		0	0	0	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	0	0	0	<=	15.7	0
12		0	0	0	0	0	0	0	0	0	0	0	0	0	7.29	8.41	15.7	<=	15.7	1
LHS		2.12	2.79	3	7.82	4.14	4.62	4.94	5.11	8.89	5.49	1.56	4.26	8.41	8.41	8.41				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	79.97	
Demand		2.12	2.79	3	7.82	4.14	4.62	4.94	5.11	8.89	5.49	1.56	4.26	8.41	8.41	8.41				

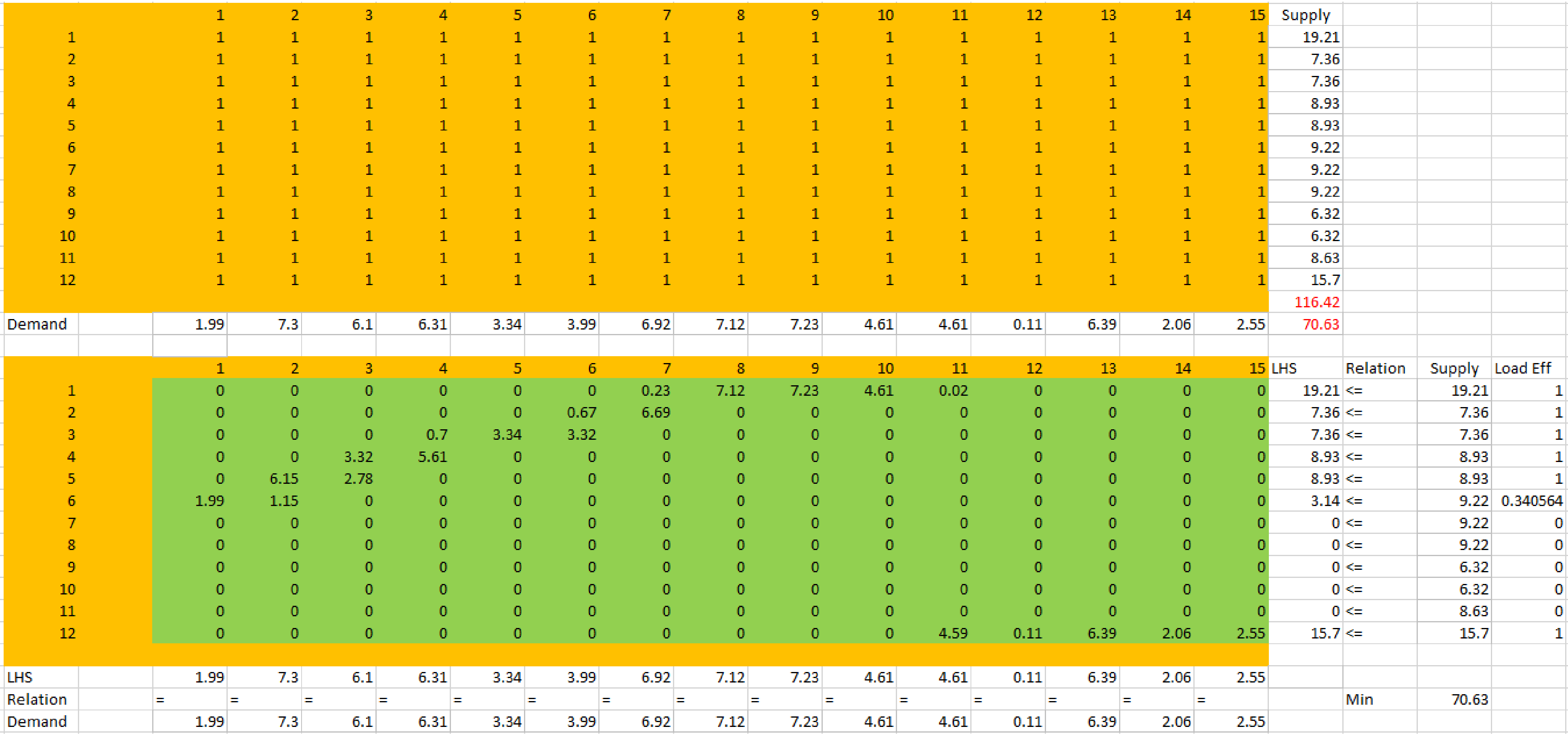
bb) 17 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Supply
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
	4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
	5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
	6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
	7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
	8	1	1	1	1	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	1	1	1	1	8.63
	10	1	1	1	1	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	1	1	1	1	15.7
	12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																		125.13
Demand		1.11	1.55	1.86	4.33	2.01	5.1	7.52	7.67	5.36	2.99	3.38	3.89	4.91	4.39	4.93	6.13	67.13

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	LHS	Relation	Supply	Load Eff
	1	0	0	0	0	0	0	0	0	0	0	0.38	3.89	4.66	0	0	0	8.93	<=	8.93	1
	2	0	0	0	0	0	0	0	0	2.94	2.99	3	0	0	0	0	0	8.93	<=	8.93	1
	3	0	0	0	0	0	0	0	6.51	2.42	0	0	0	0	0	0	0	8.93	<=	8.93	1
	4	0	0	0	0	0	0.54	7.52	1.16	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
	5	0	0	0	2.65	2.01	4.56	0	0	0	0	0	0	0	0	0	0	9.22	<=	9.22	1
	6	1.11	1.55	1.86	1.68	0	0	0	0	0	0	0	0	0	0	0	0	6.2	<=	9.22	0.672451
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
	10	0	0	0	0	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	0	0	0	0	<=	15.7	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0.25	4.39	4.93	6.13	15.7	<=	15.7	1
LHS		1.11	1.55	1.86	4.33	2.01	5.1	7.52	7.67	5.36	2.99	3.38	3.89	4.91	4.39	4.93	6.13				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	67.13	
Demand		1.11	1.55	1.86	4.33	2.01	5.1	7.52	7.67	5.36	2.99	3.38	3.89	4.91	4.39	4.93	6.13				

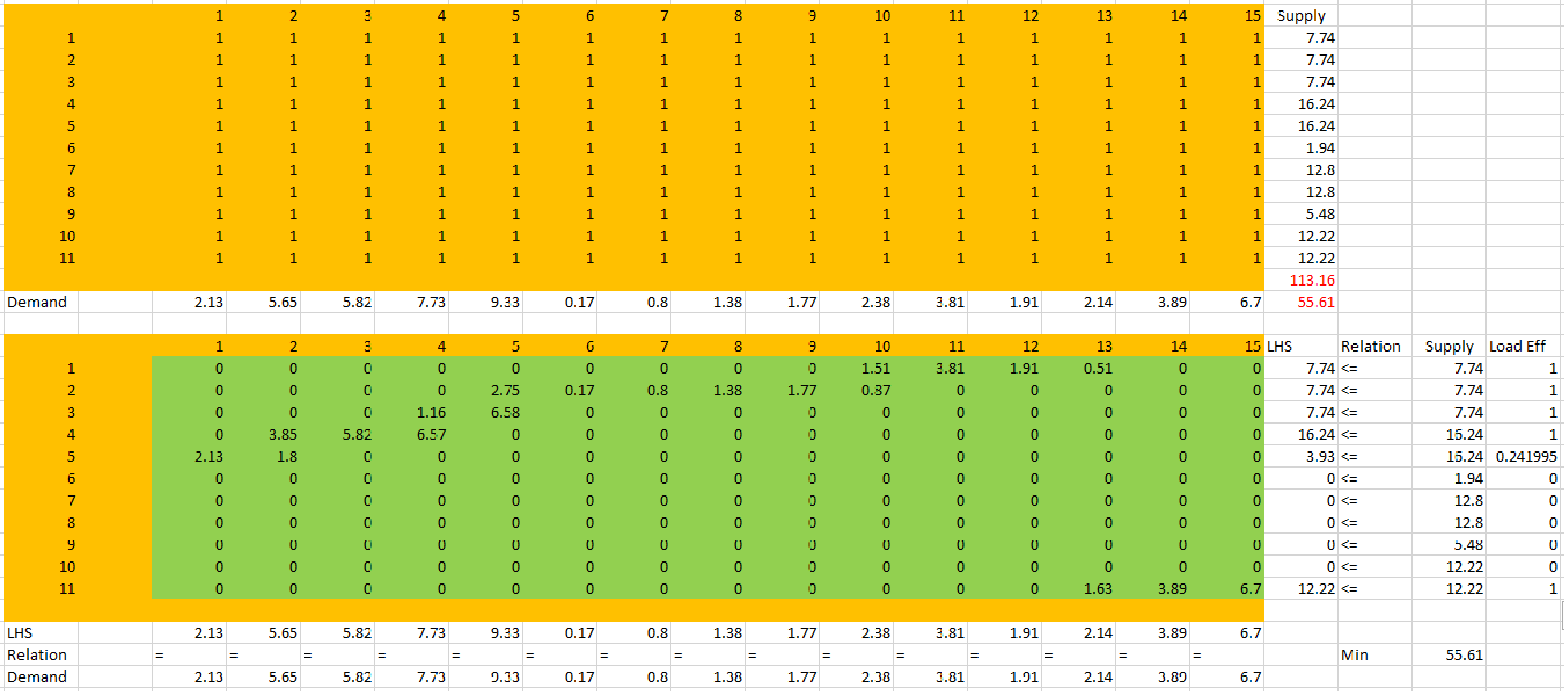
bc) 18 December 2020



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.21
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.36
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.36
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.93
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	9.22
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	6.32
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	8.63
12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.7
																116.42
Demand	1.99	7.3	6.1	6.31	3.34	3.99	6.92	7.12	7.23	4.61	4.61	0.11	6.39	2.06	2.55	70.63

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1	0	0	0	0	0	0	0.23	7.12	7.23	4.61	0.02	0	0	0	0	19.21	<=	19.21	1
2	0	0	0	0	0	0.67	6.69	0	0	0	0	0	0	0	0	7.36	<=	7.36	1
3	0	0	0	0.7	3.34	3.32	0	0	0	0	0	0	0	0	0	7.36	<=	7.36	1
4	0	0	3.32	5.61	0	0	0	0	0	0	0	0	0	0	0	8.93	<=	8.93	1
5	0	6.15	2.78	0	0	0	0	0	0	0	0	0	0	0	0	8.93	<=	8.93	1
6	1.99	1.15	0	0	0	0	0	0	0	0	0	0	0	0	0	3.14	<=	9.22	0.340564
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	9.22	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	9.22	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	6.32	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	8.63	0
12	0	0	0	0	0	0	0	0	0	0	4.59	0.11	6.39	2.06	2.55	15.7	<=	15.7	1
LHS	1.99	7.3	6.1	6.31	3.34	3.99	6.92	7.12	7.23	4.61	4.61	0.11	6.39	2.06	2.55				
Relation	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	70.63	
Demand	1.99	7.3	6.1	6.31	3.34	3.99	6.92	7.12	7.23	4.61	4.61	0.11	6.39	2.06	2.55				

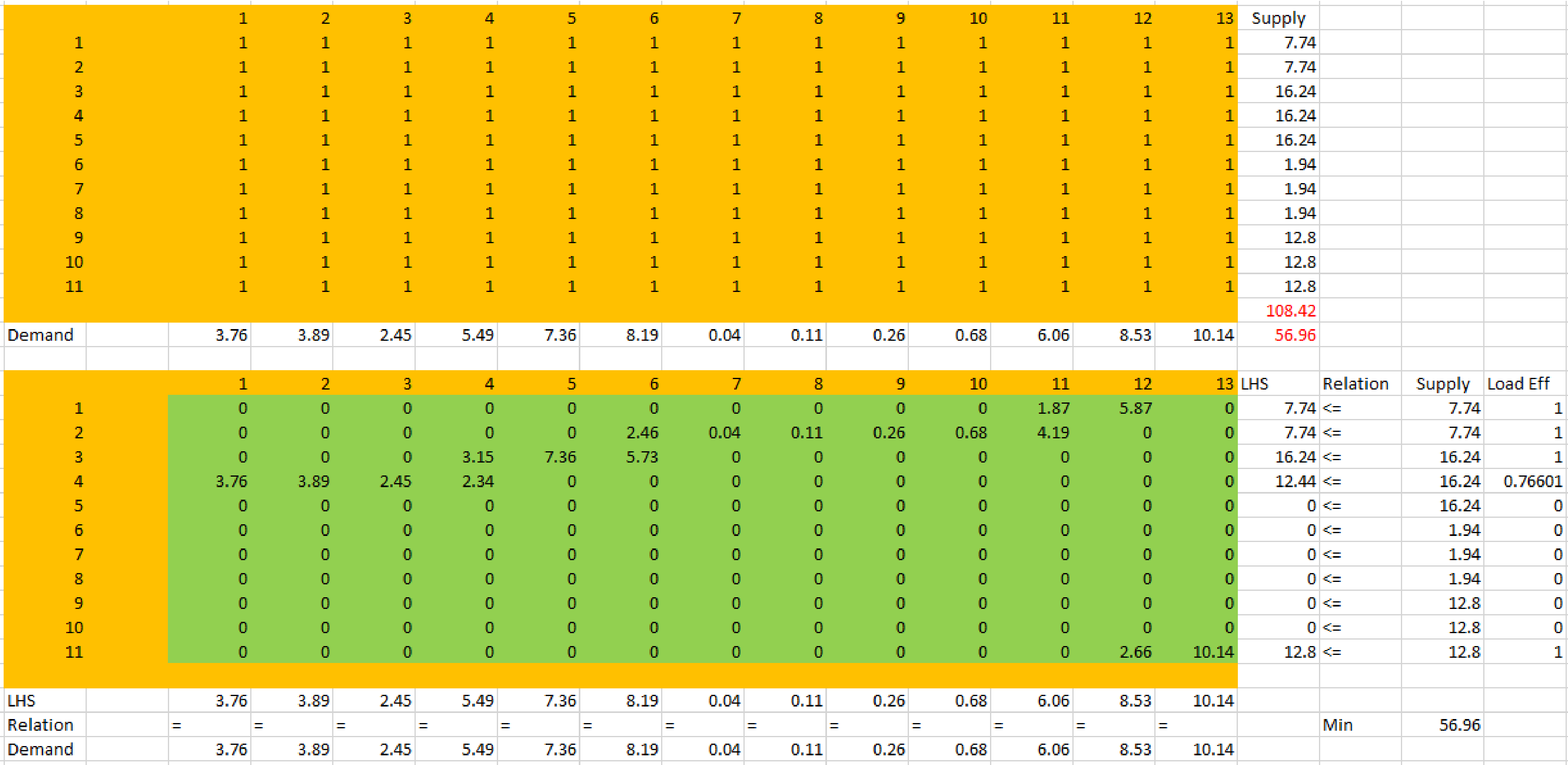
bd) 21 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
3		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
9		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5.48
10		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.22
11		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	12.22
																	113.16
Demand		2.13	5.65	5.82	7.73	9.33	0.17	0.8	1.38	1.77	2.38	3.81	1.91	2.14	3.89	6.7	55.61

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	1.51	3.81	1.91	0.51	0	0	7.74	<=	7.74	1
2		0	0	0	0	2.75	0.17	0.8	1.38	1.77	0.87	0	0	0	0	0	7.74	<=	7.74	1
3		0	0	0	1.16	6.58	0	0	0	0	0	0	0	0	0	0	7.74	<=	7.74	1
4		0	3.85	5.82	6.57	0	0	0	0	0	0	0	0	0	0	0	16.24	<=	16.24	1
5		2.13	1.8	0	0	0	0	0	0	0	0	0	0	0	0	0	3.93	<=	16.24	0.241995
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.8	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.8	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	5.48	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.22	0
11		0	0	0	0	0	0	0	0	0	0	0	0	1.63	3.89	6.7	12.22	<=	12.22	1
LHS		2.13	5.65	5.82	7.73	9.33	0.17	0.8	1.38	1.77	2.38	3.81	1.91	2.14	3.89	6.7				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=	=	=		Min	55.61	
Demand		2.13	5.65	5.82	7.73	9.33	0.17	0.8	1.38	1.77	2.38	3.81	1.91	2.14	3.89	6.7				

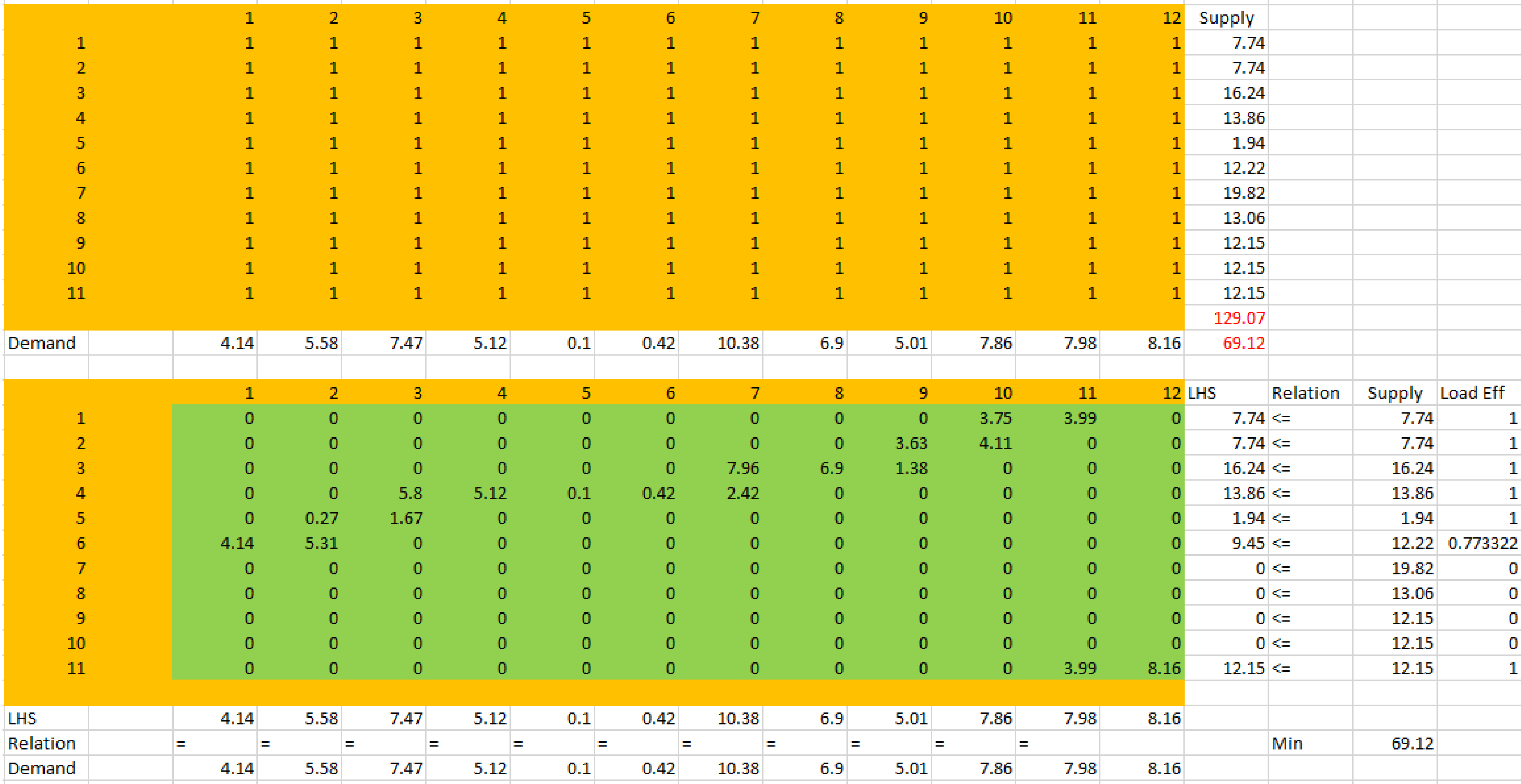
be) 22 December 2020



		1	2	3	4	5	6	7	8	9	10	11	12	13	Supply
1		1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
2		1	1	1	1	1	1	1	1	1	1	1	1	1	7.74
3		1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
4		1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
5		1	1	1	1	1	1	1	1	1	1	1	1	1	16.24
6		1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
7		1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
8		1	1	1	1	1	1	1	1	1	1	1	1	1	1.94
9		1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
10		1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
11		1	1	1	1	1	1	1	1	1	1	1	1	1	12.8
															108.42
Demand		3.76	3.89	2.45	5.49	7.36	8.19	0.04	0.11	0.26	0.68	6.06	8.53	10.14	56.96

		1	2	3	4	5	6	7	8	9	10	11	12	13	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	0	1.87	5.87	0	7.74	<=	7.74	1
2		0	0	0	0	0	2.46	0.04	0.11	0.26	0.68	4.19	0	0	7.74	<=	7.74	1
3		0	0	0	3.15	7.36	5.73	0	0	0	0	0	0	0	16.24	<=	16.24	1
4		3.76	3.89	2.45	2.34	0	0	0	0	0	0	0	0	0	12.44	<=	16.24	0.76601
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	16.24	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
7		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	1.94	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.8	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.8	0
11		0	0	0	0	0	0	0	0	0	0	0	2.66	10.14	12.8	<=	12.8	1
LHS		3.76	3.89	2.45	5.49	7.36	8.19	0.04	0.11	0.26	0.68	6.06	8.53	10.14				
Relation		=	=	=	=	=	=	=	=	=	=	=	=	=		Min	56.96	
Demand		3.76	3.89	2.45	5.49	7.36	8.19	0.04	0.11	0.26	0.68	6.06	8.53	10.14				

bf) 23 December 2020



		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	7.74			
2		1	1	1	1	1	1	1	1	1	1	1	1	7.74			
3		1	1	1	1	1	1	1	1	1	1	1	1	16.24			
4		1	1	1	1	1	1	1	1	1	1	1	1	13.86			
5		1	1	1	1	1	1	1	1	1	1	1	1	1.94			
6		1	1	1	1	1	1	1	1	1	1	1	1	12.22			
7		1	1	1	1	1	1	1	1	1	1	1	1	19.82			
8		1	1	1	1	1	1	1	1	1	1	1	1	13.06			
9		1	1	1	1	1	1	1	1	1	1	1	1	12.15			
10		1	1	1	1	1	1	1	1	1	1	1	1	12.15			
11		1	1	1	1	1	1	1	1	1	1	1	1	12.15			
														129.07			
Demand		4.14	5.58	7.47	5.12	0.1	0.42	10.38	6.9	5.01	7.86	7.98	8.16	69.12			

		1	2	3	4	5	6	7	8	9	10	11	12	LHS	Relation	Supply	Load Eff
1		0	0	0	0	0	0	0	0	0	3.75	3.99	0	7.74	<=	7.74	1
2		0	0	0	0	0	0	0	0	3.63	4.11	0	0	7.74	<=	7.74	1
3		0	0	0	0	0	0	7.96	6.9	1.38	0	0	0	16.24	<=	16.24	1
4		0	0	5.8	5.12	0.1	0.42	2.42	0	0	0	0	0	13.86	<=	13.86	1
5		0	0.27	1.67	0	0	0	0	0	0	0	0	0	1.94	<=	1.94	1
6		4.14	5.31	0	0	0	0	0	0	0	0	0	0	9.45	<=	12.22	0.773322
7		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	19.82	0
8		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	13.06	0
9		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.15	0
10		0	0	0	0	0	0	0	0	0	0	0	0	0	<=	12.15	0
11		0	0	0	0	0	0	0	0	0	0	3.99	8.16	12.15	<=	12.15	1
LHS		4.14	5.58	7.47	5.12	0.1	0.42	10.38	6.9	5.01	7.86	7.98	8.16				
Relation		=	=	=	=	=	=	=	=	=	=	=			Min	69.12	
Demand		4.14	5.58	7.47	5.12	0.1	0.42	10.38	6.9	5.01	7.86	7.98	8.16				

Appendix F *Delivery zones, delivery areas, uptakes, and distances from selected zonal reference points in Auckland*

Zone	Delivery Area	Distance from Reference Point (km)	Bearing from Reference Point (Degrees)	Horizontal Component of Distance (H) (km)	Vertical Component of Distance (V) (km)	Uptake (Tonnes)	Weighted H (km)	Weighted V (km)
C	Avondale	8	325	6.5536	-4.5888	271	1776.0256	-1243.5648
C	Eden Terrace	1.5	290	0.513	-1.40955	0	0	0
C	Ellerslie	6.8	230	-4.37104	-5.2088	32	-139.87328	-166.6816
C	Epsom	4.8	259.5	-0.87456	-4.71984	106	-92.70336	-500.30304
C	Freemans Bay	1.2	351	1.18524	-0.18768	22	26.07528	-4.12896
C	Grafton	1	258	-0.2079	-0.9781	155	-32.2245	-151.6055
C	Greenlane	6	242.5	-2.7702	-5.322	148	-409.9896	-787.656
C	Herne Bay	3.2	12.5	3.12416	0.69248	31	96.84896	21.46688
C	Kingsland	2.8	306	1.64584	-2.2652	4	6.58336	-9.0608
C	Newmarket	2.5	244	-1.096	-2.247	6	-6.576	-13.482
C	One Tree Hill	6.5	249	-2.3296	-6.0684	1	-2.3296	-6.0684
C	Owairaka	6.2	309	3.90166	-4.81802	6	23.40996	-28.90812
C	Parnell	1.8	206	-1.61784	-0.78912	49	-79.27416	-38.66688
C	Penrose	9	237	-4.9014	-7.5483	19	-93.1266	-143.4177
C	Remuera	4.7	222	-3.49257	-3.14477	129	-450.54153	-405.67533
C	St Marys Bay	1.8	22.5	1.66302	0.68886	1	1.66302	0.68886
E	Beachlands	11.7	148	-9.9216	6.19983	188	-1865.2608	1165.56804

E	Botany	4.5	118	-2.11275	3.97305	55	-116.20125	218.51775
E	Buckland	7.3	101	-1.39284	7.16568	9	-12.53556	64.49112
E	Bucklands Beach	7.3	101	-1.39284	7.16568	119	-165.74796	852.71592
E	Cockle Bay	7	135	-4.9497	4.9497	53	-262.3341	262.3341
E	Dannemora	2.7	150	-2.3382	1.35	29	-67.8078	39.15
E	Eastern Beach	8	102	-1.6632	7.8248	10	-16.632	78.248
E	Farm Cove	5.4	83	0.65826	5.3595	9	5.92434	48.2355
E	Flat Bush	4	135	-2.8284	2.8284	1488	-4208.6592	4208.6592
E	Glen Innes	8.2	65	3.46532	7.43166	192	665.34144	1426.87872
E	Glendowie	9.5	78	1.97505	9.29195	49	96.77745	455.30555
E	Half Moon Bay	6.2	96	-0.6479	6.1659	102	-66.0858	628.9218
E	Highland Park	5	106	-1.378	4.8065	33	-45.474	158.6145
E	Howick	6.2	115	-2.62012	5.61906	121	-317.03452	679.90626
E	Kohimarama	10.8	64	4.73472	9.70704	25	118.368	242.676
E	Maraetai	15	152	-13.2435	7.0425	6	-79.461	42.255
E	Meadowbank	10.1	54	5.93678	8.1709	25	148.4195	204.2725
E	Mellons Bay	7.2	117	-3.2688	6.4152	29	-94.7952	186.0408
E	Mission Bay	11.6	60	5.8	10.0456	66	382.8	663.0096
E	Mt Wellington	6.2	37.3	4.9321	3.7572	283	1395.7843	1063.2876
E	Orakei	11	57	5.9906	9.2257	56	335.4736	516.6392
E	Pakuranga	4	57	2.1784	3.3548	112	243.9808	375.7376

E	Panmure	5.7	57	3.10422	4.78059	36	111.75192	172.10124
E	Point England	7	68	2.6222	6.4904	75	196.665	486.78
E	St Heliers	10.2	68	3.82092	9.45744	82	313.31544	775.51008
E	St Johns	9	60	4.5	7.794	80	360	623.52
E	Sunnyhills	5	84	0.5225	4.9725	29	15.1525	144.2025
E	Whitford	6.2	182	-6.19628	-0.21638	68	-421.34704	-14.71384
N	Bayswater	12	129	-7.5516	9.3252	12	-90.6192	111.9024
N	Beach Haven	7.2	277	0.87768	-7.146	65	57.0492	-464.49
N	Belmont	12.2	134	-8.47534	8.77546	16	-135.60544	140.40736
N	Birkdale	7.7	266	-0.53746	-7.68152	3	-1.61238	-23.04456
N	Birkenhead	9.3	256	-2.24967	-9.02379	26	-58.49142	-234.61854
N	Browns Bay	4.2	165	-4.05678	1.08696	102	-413.79156	110.86992
N	Campbells Bay	6.2	158	-5.74864	2.32252	20	-114.9728	46.4504
N	Castor Bay	6.8	146	-5.6372	3.80256	9	-50.7348	34.22304
N	Coatesville	5.75	11	5.6442	1.0971	104	586.9968	114.0984
N	Dairy Flat	7.8	55	4.47408	6.38976	45	201.3336	287.5392
N	Devonport	14.1	230	-9.06348	-10.8006	117	-1060.42716	-1263.6702
N	Fairview Heights	2.3	133	-1.5686	1.68222	23	-36.0778	38.69106
N	Forrest Hill	5.8	222	-4.30998	-3.88078	97	-418.06806	-376.43566
N	Glenfield	6.5	250	-2.223	-6.10805	99	-220.077	-604.69695
N	Greenhithe	5.25	286	1.4469	-5.046825	58	83.9202	-292.71585

N	Gulf Harbour	22.8	123	-12.41688	19.12236	89	-1105.10232	1701.89004
N	Helensville	20	15	19.318	5.176	28	540.904	144.928
N	Hillcrest	15.42	244	-6.760128	-13.859496	36	-243.364608	-498.941856
N	Hobsonville	8.9	300	4.45	-7.7074	931	4142.95	-7175.5894
N	Huapai	15	344	14.4195	-4.134	197	2840.6415	-814.398
N	Kaukapakapa	20	35	16.384	11.472	37	606.208	424.464
N	Kumeu	12.79	335	11.591577	-5.405054	123	1425.763971	-664.821642
N	Leigh	49	102	-10.1871	47.9269	18	-183.3678	862.6842
N	Long Bay	6.2	134	-4.30714	4.45966	83	-357.49262	370.15178
N	Mairangi Bay	6	194	-5.8218	-1.4514	50	-291.09	-72.57
N	Manly	22.8	120	-11.4	19.7448	22	-250.8	434.3856
N	Massey	1	240	-0.5	-0.866	257	-128.5	-222.562
N	Matakana	42.1	92	-1.46929	42.07474	20	-29.3858	841.4948
N	Milford	7	38	5.516	4.3099	114	628.824	491.3286
N	Milldale	13.6	74	3.74816	13.07368	254	952.03264	3320.71472
N	Millwater	13.8	81	2.15832	13.63026	85	183.4572	1158.5721
N	Muriwai	26	344	24.9938	-7.1656	13	324.9194	-93.1528
N	Murrays Bay	4.5	184	-4.4892	-0.3141	28	-125.6976	-8.7948
N	Narrow Neck	13.5	227	-9.207	-9.8739	38	-349.866	-375.2082
N	Northcote	9.5	244	-4.1648	-8.5386	121	-503.9408	-1033.1706
N	Northcross	3.5	145	-2.8672	2.0076	0	0	0

N	Okura	6	116	-2.6304	5.3928	8	-21.0432	43.1424
N	Omaha	50	279	7.82	-49.385	19	148.58	-938.315
N	Orewa	15.5	87	0.81065	15.4783	217	175.91105	3358.7911
N	Paremoremo	5.2	314	3.61244	-3.74036	0	0	0
N	Pinehill	2.5	191	-2.454	-0.477	101	-247.854	-48.177
N	Point Wells	46	95	-4.0112	45.8252	31	-124.3472	1420.5812
N	Puhoi	23.5	83	2.86465	23.32375	9	25.78185	209.91375
N	Red Beach	15.4	94	-1.07492	15.36304	135	-145.1142	2074.0104
N	Riverhead	10	339	9.336	-3.584	103	961.608	-369.152
N	Rosedale	3	251	-0.9768	-2.8365	4	-3.9072	-11.346
N	Rothesay Bay	4.8	174	-4.7736	0.5016	28	-133.6608	14.0448
N	Sandspit	42	93	-2.1966	41.9412	3	-6.5898	125.8236
N	Schnapper Rock	3.5	281.5	0.6979	-3.42965	24	16.7496	-82.3116
N	Silverdale	13.7	82	1.90704	13.56711	259	493.92336	3513.88149
N	Snells Beach	45.2	93.5	-2.7572	45.11412	51	-140.6172	2300.82012
N	South Head	38	27	33.858	17.252	14	474.012	241.528
N	Stanmore Bay	18	106	-4.9608	17.3034	46	-228.1968	795.9564
N	Stillwater	9.9	101	-1.88892	9.71784	2	-3.77784	19.43568
N	Sunnynook	4.8	221	-3.62256	-3.14928	69	-249.95664	-217.30032
N	Takapuna	9.5	226	-6.59965	-6.83335	249	-1643.31285	-1701.50415
N	Taupaki	17	323	13.5762	-10.2306	55	746.691	-562.683

N	Tawharanui	45	99	-7.038	44.4465	1	-7.038	44.4465
N	Tindalls Bay	25	120	-12.5	21.65	1	-12.5	21.65
N	Torbay	6	144	-4.854	3.5268	67	-325.218	236.2956
N	Unsworth Heights	4	242	-1.878	-3.5316	24	-45.072	-84.7584
N	Waiake	5.5	153	-4.9005	2.497	18	-88.209	44.946
N	Waimauku	13.2	341	12.4806	-4.29792	71	886.1226	-305.15232
N	Wainui	16.8	57	9.14928	14.09016	92	841.73376	1296.29472
N	Waitakere West	19.4	315	13.71774	-13.71774	7	96.02418	-96.02418
N	Waitoki	16.5	38	13.002	10.15905	14	182.028	142.2267
N	Waiwera	22.5	93	-1.17675	22.4685	3	-3.53025	67.4055
N	Warkworth	36.7	85	3.20024	36.56054	108	345.62592	3948.53832
N	Wellsford	50	72	15.45	47.555	13	200.85	618.215
N	West Harbour	12	300	6	-10.392	75	450	-779.4
N	Westgate	13	307	7.8234	-10.3818	147	1150.0398	-1526.1246
N	Whangaparaoa	20	108	-6.18	19.022	23	-142.14	437.506
N	Whenuapai	10.5	315	7.42455	-7.42455	181	1343.84355	-1343.84355
N	Woodhill	24.5	357	24.4657	-1.28135	6	146.7942	-7.6881
S	Ardmore	5.3	181	-5.29894	-0.09275	99	-524.59506	-9.18225
S	Awhitu	50	350	49.24	-8.68	3	147.72	-26.04
S	Bombay	17	251	-5.5352	-16.0735	26	-143.9152	-417.911
S	Clarks Beach	22.5	332	19.86525	-10.56375	28	556.227	-295.785

S	Clevedon	11	152	-9.7119	5.1645	31	-301.0689	160.0995
S	Clover Park	7	64	3.0688	6.2916	19	58.3072	119.5404
S	Drury	8	249	-2.8672	-7.4688	149	-427.2128	-1112.8512
S	Glen Murray	50	267	-2.615	-49.93	0	0	0
S	Glenbrook	24	310	15.4272	-18.384	29	447.3888	-533.136
S	Hunua	12	198	-11.4132	-3.708	26	-296.7432	-96.408
S	Karaka	9	308	5.5413	-7.092	404	2238.6852	-2865.168
S	Kawakawa Bay	23.5	155	-21.29805	9.9311	1	-21.29805	9.9311
S	Kingseat	15.5	320	11.873	-9.9634	15	178.095	-149.451
S	Mangatangi	31	215	-25.3952	-17.7816	6	-152.3712	-106.6896
S	Manukau	8	46	5.5576	5.7544	110	611.336	632.984
S	Manurewa	3.7	26	3.32556	1.62208	394	1310.27064	639.09952
S	Orere Point	27.3	347	26.60112	-6.13977	4	106.40448	-24.55908
S	Otahuhu	12	53	7.2216	9.5832	165	1191.564	1581.228
S	Otara	9.6	64.5	4.1328	8.66496	34	140.5152	294.60864
S	Otaua	34	298	15.963	-30.0186	6	95.778	-180.1116
S	Paerata	14.5	282	3.01455	-14.18245	46	138.6693	-652.3927
S	Papakura	3.2	236	-1.78944	-2.6528	761	-1361.76384	-2018.7808
S	Papatoetoe	10	53	6.018	7.986	454	2732.172	3625.644
S	Patumahoe	18.5	297	8.399	-16.4835	17	142.783	-280.2195
S	Pukekohe	18	279	2.8152	-17.7786	374	1052.8848	-6649.1964

S	Puni	22.5	286	6.201	-21.62925	1	6.201	-21.62925
S	Ramarama	12.5	252	-3.8625	-11.88875	42	-162.225	-499.3275
S	Tuakau	25	266	-1.745	-24.94	47	-82.015	-1172.18
S	Waiau pa	19	324	15.371	-11.1682	9	138.339	-100.5138
S	Waiuku	30	308	18.471	-23.64	11	203.181	-260.04
S	Wattle Downs	3.5	340	3.28895	-1.197	3	9.86685	-3.591
S	Weymouth	5.5	355	5.4791	-0.4796	19	104.1029	-9.1124
S	Wiri	7.5	30	6.495	3.75	3	19.485	11.25
W	Blockhouse Bay	7.8	355	7.77036	-0.68016	205	1592.9238	-139.4328
W	Favona	3.6	115	-1.52136	3.26268	29	-44.11944	94.61772
W	Glen Eden	12.7	5	12.65174	1.10744	142	1796.54708	157.25648
W	Glendene	12.3	18	11.69853	3.8007	35	409.44855	133.0245
W	Green Bay	10	356	9.976	-0.698	18	179.568	-12.564
W	Grey Lynn	7.8	60	3.9	6.7548	91	354.9	614.6868
W	Henderson	15	20	14.0955	5.13	563	7935.7665	2888.19
W	Hillsborough	15	32	12.72	7.9485	110	1399.2	874.335
W	Kelston	11	12	10.7591	2.2869	85	914.5235	194.3865
W	Laingholm	15	18	14.2665	4.635	5	71.3325	23.175
W	Lynfield	6	352	5.9418	-0.8352	30	178.254	-25.056
W	Mangere	6	266	-0.4188	-5.9856	580	-242.904	-3471.648
W	Mangere Bridge	6	266	-0.4188	-5.9856	45	-18.846	-269.352

W	Morningside	7	50	4.4996	5.362	8	35.9968	42.896
W	Mt Albert	7.6	36	6.1484	4.46728	154	946.8536	687.96112
W	Mt Eden	5.2	50	3.34256	3.9832	621	2075.72976	2473.5672
W	Mt Roskill	4.2	2	4.19748	0.14658	252	1057.76496	36.93816
W	New Lynn	9.7	9	9.58069	1.51708	162	1552.07178	245.76696
W	New Windsor	6.6	14	6.40398	1.59654	52	333.00696	83.02008
W	Point Chevalier	9.5	42	7.05945	6.35645	178	1256.5821	1131.4481
W	Ponsonby	9.2	62	4.3194	8.12268	38	164.1372	308.66184
W	Ranui	7.8	21	7.28208	2.79552	83	604.41264	232.02816
W	Royal Oak	2	44	1.4386	1.3894	8	11.5088	11.1152
W	Sandringham	6	44	4.3158	4.1682	34	146.7372	141.7188
W	St Lukes	7	43	5.1198	4.774	5	25.599	23.87
W	Sunnyvale	13.7	13.5	13.32188	3.19758	99	1318.86612	316.56042
W	Swanson	20	19	18.91	6.512	132	2496.12	859.584
W	Te Atatu Peninsula	14	32	11.872	7.4186	287	3407.264	2129.1382
W	Te Atatu South	14	32	11.872	7.4186	97	1151.584	719.6042
W	Three Kings	3	32	2.544	1.5897	25	63.6	39.7425
W	Titirangi	12.1	351	11.95117	-1.89244	42	501.94914	-79.48248
W	Waiatarua	18.3	357	18.27438	-0.95709	4	73.09752	-3.82836
W	Waterview	9	34	7.461	5.0328	290	2163.69	1459.512
W	Western Springs	9	47	6.138	6.5826	2	12.276	13.1652

Appendix G *List of publications during the period of research*

a) Journal publications

Dhawan, K., Tookey, J., GhaffarianHoseini, A., & GhaffarianHoseini, A. (2022). Consolidating Loads for Sustainable Construction in New Zealand: A Literature Review-based Research Framework. *Smart and Sustainable Built Environment*, *11*(2), 313–333. https://doi.org/10.1108/sasbe-08-2021-0151

Dhawan, K., Tookey, J.E., GhaffarianHoseini, A., & GhaffarianHoseini, A. (2022). Greening Construction Transport as a Sustainability Enabler for New Zealand: A Research Framework. *Frontiers in Built Environment*, *8*. https://doi.org/10.3389/fbuil.2022.871958

Dhawan, K., Tookey, J.E., GhaffarianHoseini, A., & Poshdar, M. (2023). Using Transport to Quantify the Impact of Vertical Integration on the Construction Supply Chain: A New Zealand Assessment. *Sustainability, 15, 1298.* https://doi.org/10.3390/su15021298

b) Conference publications

Dhawan, K., Tookey, J., GhaffarianHoseini, A., & GhaffarianHoseini, A. (2020). Consolidating Construction Loads: A Future Pathway to Sustainability. In Ghaffarianhoseini, A., Ghaffarianhoseini, A., & Nasmith, N. (Eds.) *Imaginable Futures: Design Thinking, and the Scientific Method, Proceedings of the 54th International Conference of the Architectural Science Association 2020, 26-27 November 2020, Auckland University of Technology, Auckland, New Zealand* (pp. 306–315). Retrieved from https://anzasca.net/wp-content/uploads/2021/03/32-Consolidating-construction-loads-A-future-pathway-to-sustainability.pdf

Dhawan, K., Tookey, J., GhaffarianHoseini, A., & GhaffarianHoseini, A. (2020). Optimising Construction Consolidation Centres in New Zealand: Defining a Research Framework. In Ghaffarianhoseini, A., Ghaffarianhoseini, A., & Nasmith, N. (Eds.) *Imaginable Futures: Design Thinking, and the Scientific Method, Proceedings of the 54th International Conference of the Architectural Science Association 2020, 26-27 November 2020, Auckland University of Technology, Auckland, New Zealand* (pp. 835–844). Retrieved from https://anzasca.net/wp-content/uploads/2021/03/86-Optimising-New-Zealand-construction-consolidation-centres-Defining-a-research-framework.pdf

Dhawan, K., Tookey, J., GhaffarianHoseini, A., & GhaffarianHoseini, A. (2022). Logistics Management as a Sustainability Solution for New Zealand Construction: A Literature Review Based Research Framework. In Shahzad, W., Rasheed, E., & Rotimi, J. (Eds.) *Creating Capacity and Capability for the Future of the Built Environment, Proceedings of the 7th New Zealand Built Environment Research Symposium 2022* (pp. 343–369). Retrieved from https://mro.massey.ac.nz/handle/10179/16910

Dhawan, K., Tookey, J., GhaffarianHoseini, A., & GhaffarianHoseini, A. (2022). Operationalisation of Logistics Management for Improved Construction Performance: A New Zealand Specific Research Framework. In Park, C., Dawood, N., Rahimian, F., Pedro, A., & Lee, D. (Eds.) *The Future of Construction in the Context of Digitalization and Decarbonization, Proceedings of the 22nd International Conference on Construction Applications of Virtual Reality, Chung-Ang University, South Korea, November 16-18, 2022* (pp. 931–951). Retrieved from http://convr2022.com/