IPIC 2023
9th International
Physical Internet Conference
June 13-15, 2023
Athens, Greece

Assessing the Performance of Urban Distribution Networks

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Abstract:
Due to increasing concerns regarding rising emissions, urban congestion and financial costs it is important to develop and identify appropriate performance measures that can be used to aid the design of improved urban distribution networks. The Physical Internet (PI) concept involves transforming independent logistics networks into open and shared networks for improving sustainability. This involves designing new networks that are based on utilising multiple transport modes and transfer points. There is a need to compare the performance of typical urban freight networks with collaborative networks that involve shared use of warehouses and freight vehicles. This paper presents an assessment of several criteria that can be used to quantify the performance of freight and logistics networks in cities. Multi-criteria analysis is conducted for common urban goods networks including retail swaps and retail distribution.
The analysis contained in this paper can be used to assist network planners and designers to identify the most appropriate criteria to aid the design of future urban freight networks for achieving net zero emissions. Such measures can provide direction for fleet managers, urban freight planners as well as communities.

Keywords: *Network Design, Collaborative Freight Networks, Network Performance Measures*

Conference Topic(s): *distributed intelligence last mile & city logistics; logistics and supply networks*

Physical Internet Roadmap*: ☐ PI Nodes, ☒ PI Networks, ☒ System of Logistics Networks, ☐ Access and Adoption, ☐ Governance.*

1 Introduction

Hyperconnected City Logistics (HCL) combines concepts from the Physical Internet and City Logistics (Crainic and Montrieul, 2016). The aim of HCL is to create more collaborative and integrated distribution networks to address sustainability issues. Sharing vehicles and warehouses can reduce the distance travelled by freight vehicles that can reduce operating costs, emissions and energy consumption as well as noise and congestion. However exchanging goods involves additional costs such as unloading and unloading goods as well as storage and vehicle wait times. There is a need to understand more about the trade-offs between transport and transfer/storage costs to assist in promoting HCL.

Major cities in Australia generate a substantial volume of freight movement and are characterised by some of the largest metropolitan areas in the world, with low population densities and limited transport infrastructure. Increasing urban congestion, coupled with increased levels of home deliveries from eCommerce, has created significant sustainability challenges for Australian urban freight systems. This worsening congestion is expected to cost Australian cities $37.3 billion by 2030 (Bureau of Infrastructure, 2015), while Australia's urban freight volumes are predicted to increase by up to 60% before 2040 (Transport and Infrastructure Council, 2021).

Australian governments are committed to reducing emissions with the aim of achieving net zero emissions. However, to attain environmental goals, new initiatives for transforming urban freight movement towards the use of more shared vehicles and storage facilities is required. This will require a radical transformation of existing urban freight systems into real-time based collaborative networks, which will subsequently reduce vehicle emissions, noise levels, and increase system efficiency.

There is a need to identify appropriate performance measures for urban freight networks considering a range of stakeholders and to combine them to provide measurable goals for designing more open and collaborative urban distribution systems. This paper describes a range of performance that can be used to assess the sustainability of urban distribution networks. Case studies involving retail swaps and retail distribution networks are presented.

2 Network performance measures

Vehicles performing urban distribution tasks typically undertake routes or tours visiting more than 1 customer before returning to the depot or distribution centre. Tonne kilometres (TKM) is a measure of freight demand, calculated as the product of the weight of goods transported by the distance between origins and destinations. There are a number of common measures of performance for urban distribution networks, including number of vehicles used by type and vehicles kilometres travelled by vehicles (VKT). However other network measures can provide useful information for addressing sustainability issues, including:

(i) Efficiency (TKM/VKT) (ITF, 2018)
(ii) Load Factors (proportion of capacity of vehicles: weight or volume used over all legs on routes)(McKinnon, 2000)
(iii) Work (product of load carried by distance travelled for all legs on routes)
(iv) Laden (percentage of distance travelled with goods in vehicles on routes) (McKinnon, 2000)
(v) MNAD (average number of arrivals and departures at receivers)

City Logistics considers that benefits and costs for various stakeholders including shippers, carriers, receivers, administrators and residents (Taniguchi and Thompson, 2015). Therefore, it is important to estimate vehicle operating costs for carriers as well as social and environmental costs. It is common to only consider the transport costs of distributing costs in urban freight networks. However, logistics costs incorporate storage and transport costs that include costs of transferring goods between vehicles.

2.1 Financial costs

Vehicle operating costs (VOC) for carriers are the financial costs of operating a delivery vehicle. Key components of VOC models include time based and distance-based costs. Common types of vehicles used include walkers with a trolley, cargo bikes, e-cargo bikes, vans, e-vans and trucks. The main attributes for determining the costs for each mode of transport are wages, purchase price, energy costs, vehicle registration costs, maintenance and repair costs. Usage rates directly impact the lifespan of each mode of transport.

Non-motorised vehicles such as walkers with trolleys as well as cargo bikes and e-cargo bikes typically have the lowest cost rates per hour with wages for walkers and rider constituting the majority of these. Vans are costlier to operate than e-vans when they have high use due to lower costs of electricity than diesel. Trucks are the most expensive to operate but have the greatest capacity. The differential in speeds between modes renders motorised vehicles more efficient when customer densities are low.

2.2 Social and Environmental Costs

Air quality impacts from urban distribution networks are influenced by the emissions produced per vehicle kilometre of freight vehicles as well as the vehicle kilometres travelled. Emissions per vehicle kilometre depends on characteristics of vehicles such as the mode of transport, type of fuel, vehicle engine emission standards and load capacity as well as the operating conditions such as travel speed and the weight of the goods being carried. Vehicle kilometres travelled depends on the nature of the distribution networks such as the location of depots and customers as well as the demand for goods to be transported. Rates ($/km) have been determined from public health and economic studies for estimating the air pollution, noise, accidents, congestion and infrastructure costs for vehicle types (Kin and Macharis, 2015).

2.3 Exposure metrics

A selection of thirty eight freight measurements and metrics was presented Hassall, (2008). Two types of measures were defined, Type 1: that deals with community observations of a growing freight task. This involves such metrics and truck numbers, truck lengths and truck trips that could be used to estimate accidents and freight noise. Type II metrics are compiled from another set of metrics notably those that impact more specifically on road infrastructure such as tonne-kilometres, gross vehicle mass, axle loadings and total tonnes carried.

2.4 Reliability

Generally speaking, an urban distribution system is more reliable when there are fewer product transfers. Unreliability can be estimated by the number of transfers made (Zhang and Thompson, 2021). The trade-off between VKT and the number of transfers was highlighted in Zhang and Thompson (2021). However, costs associated with transferring goods at stores were not considered apart from vehicle related costs.

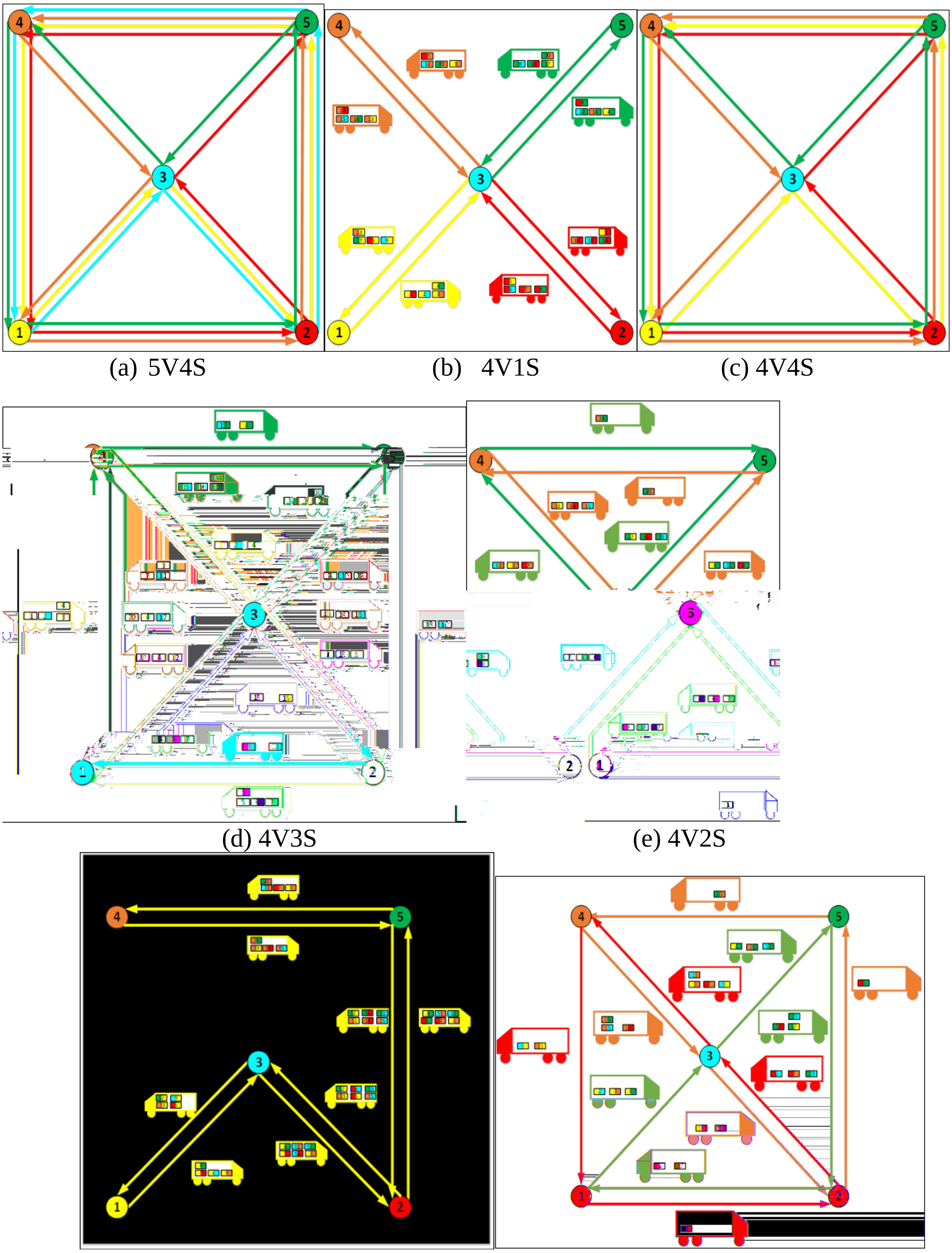
2.5 Transfer and Storage Costs

Personnel and administration costs consisting of management expenses as well as operational staff costs were found to account for the majority of expenses at a urban consolidation centre (Aljohani and Thompson, 2021). Equipment and facility costs were shown to be significant. However, Sydney's Courier Hub has minimal personnel and administration costs (Stokoe, 2017). Forklift and hub lease costs should also be considered (Thompson et al., 2020).

3 Retail Swaps

A common problem in urban areas in swapping goods between retail stores where there is a small amount of goods moving between individual stores to satisfy customer requirements where there is stock shortages at some locations. This type of network is also common for deliveries between local post offices or B2B networks particularly with parcel lockers. Such networks are characterised by having multiple common origins and destinations requiring services operating from many to many nodes.

A simple network will be used to illustrate how various measures of performance can be used to assess common networks. This network is based on distributing 500kg of electrical goods between retail shops. Transhipment is possible at each store and each van has a load capacity of 2000kg. A number of feasible distribution configurations have been defined (Figure 1).



(a) 5V4S (b) 4V1S (c) 4V4S

(d) 4V3S (e) 4V2S

(f) 1V4S (g) 3V3S

Figure 1 Swap Networks

For each configuration considered a number of performance measure were derived including Vehicle Kilometres of Travel (VKT), Network Efficiency (NE), Load Factor – weight (LF(w)), Number of Swaps (# Swaps), Number of Vehicles Used (NVs) and Mean Number of Arrivals and Departures at stores (MNAD). Figure 2 illustrates the relative performance of the network configurations for each criteria.

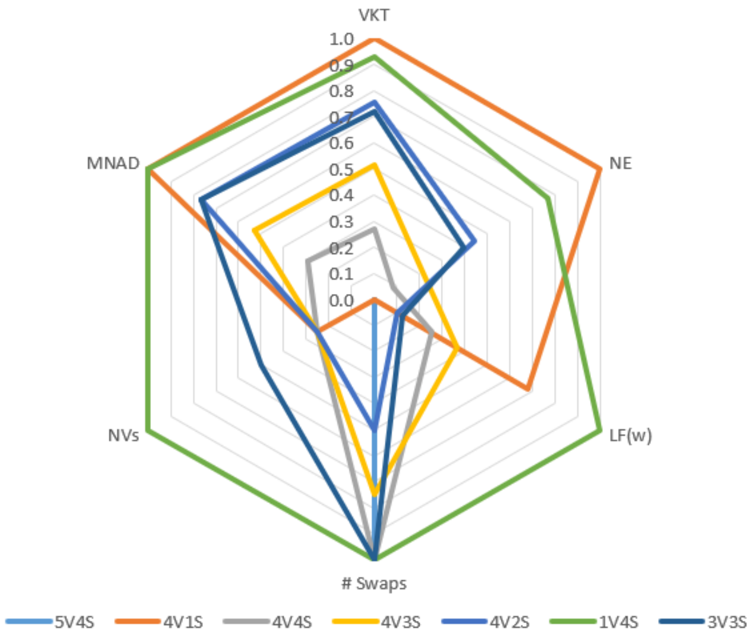


Figure 2 Performance of Network Configurations

Criteria were assigned to 3 key stakeholders, carriers, receivers and administrators (Table 1). Several weightings for the stakeholders were considered to identify the performance of the network configurations (Table 2).

Table 1 Stakeholders and Criteria

Stakeholder	Criteria	
Carriers	Load Factor – weight (LF(w))	Number of Vehicles (NVs)
Receivers	# Swaps	Mean Number of Arrivals and Departures (MNAD)
Administrators	Vehicle Kilometres of Travel (VKT)	Network Efficiency (NE)

Table 2 Rankings of Network Configurations considering stakeholders

Stakeholder weighting	5V4S	4V1S	4V4S	4V3S	4V2S	1V4S	3V3S
Uniform	6	2	5	5	4	**1**	3
Administrator only	6	**1**	5	4	3	2	3
Carrier only	5	2	3	3	4	**1**	3

The single vehicle network configuration has the highest ranking when stakeholders and their assigned criteria are consider equal. However, when administrators are only considered, 4 vehicles visiting 1 store is the highest ranking network. The network with all stores operating their own vehicle (5V4S) consistently achieves a low ranking.

4 Retail Distribution Networks

Distribution systems in many metropolitan regions are characterised by shippers operating their own vehicle fleets, distributing only their goods to common customers on a regular basis. Within specific sectors such as retail there is an opportunity to combine distribution networks to reduce the distance travelled by delivery vehicles from warehouses to major retail outlets. This can result in substantial savings in distances travelled by vehicles leading to reduction in emissions from freight vehicles.

Suppliers who are own account or not-for profit carriers can operate collaborative distribution networks by sharing vehicles and warehouse space. This involves suppliers integrating their networks with other suppliers and carriers requiring coordination.

Distributing goods in a large metropolitan area such as Melbourne is challenging as there are typically a low density of customers, with some customers being located a considerable distance (over 50 kilometres) from warehouses or distribution centres. The benefits of collaborative urban freight networks can be illustrated by considering how several suppliers distribute goods to common retail outlets within the metropolitan area of Melbourne. When suppliers operate independent distribution networks, daily routes can be optimised to service stores in each area (Figure 3).

Figure 3 Independent Network Routes

In urban areas the distances involved in TKM and actual distances are quite different due (Figures 4 & 5; Table 3).

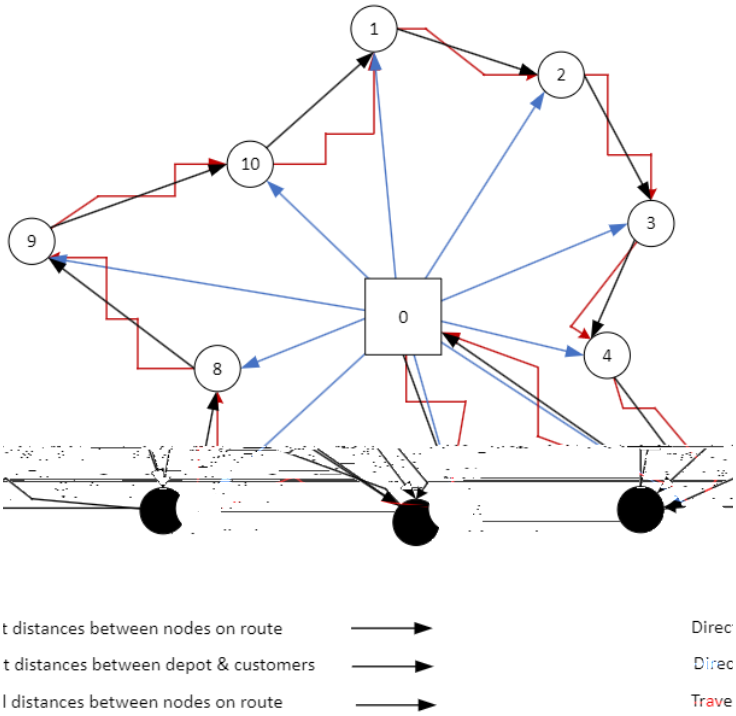
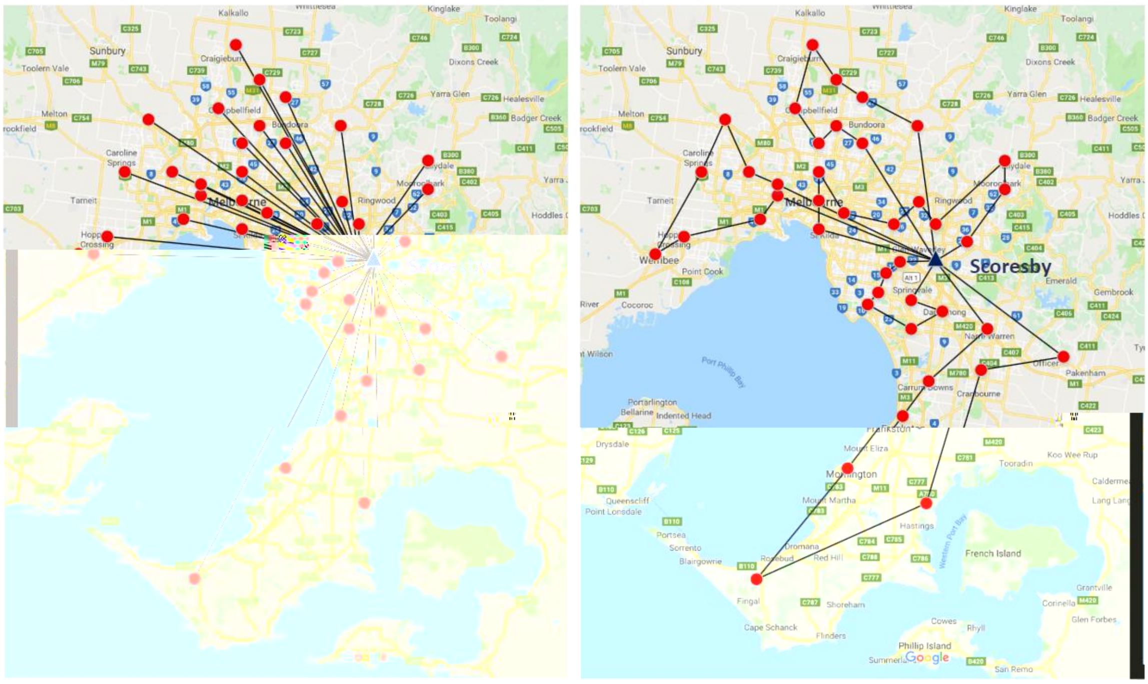


Figure 4 Distances in urban distribution networks



(a) Direct Distances (b) Vehicle Routes

Figure 5 TKM and Vehicle Routes from the Scoresby warehouse

Table 3 Independent Network Performance

	Scoresby Supplier	All Suppliers
Direct Distance (from Warehouse to all stores)	858.4 km	4449.6 km
Tonne Kilometres (from Warehouse to all stores)	175.9 t km	800.1 t km
Total Travel Distance (from Warehouse on vehicle routes to all stores)	568.6 km	2899.5 km
Network Efficiency	0.31 t	0.28 t

With the collaborative network, suppliers are allocated to areas (Figure 6). One supplier is selected for the location to exchange goods between suppliers where goods with destinations near other suppliers are transferred to these suppliers. Specialised optimisation procedures were developed to determine the best supplier to transfer the goods to design the collaborative distribution network. The shared network allows delivery routes from suppliers to be developed with higher utilisation and substantially lower vehicle travel distances. A sizeable reduction (77.9%) in the distance travelled were estimated for a retail distribution network using existing warehouses and delivery vehicles. This would lead to a similar reduction in emissions from freight vehicles. Shorter local routes from warehouses to customers can be more suitable for electric trucks or vans. The collaborative network has a significantly higher network efficiency (1.25) compared with the independent networks (0.28).

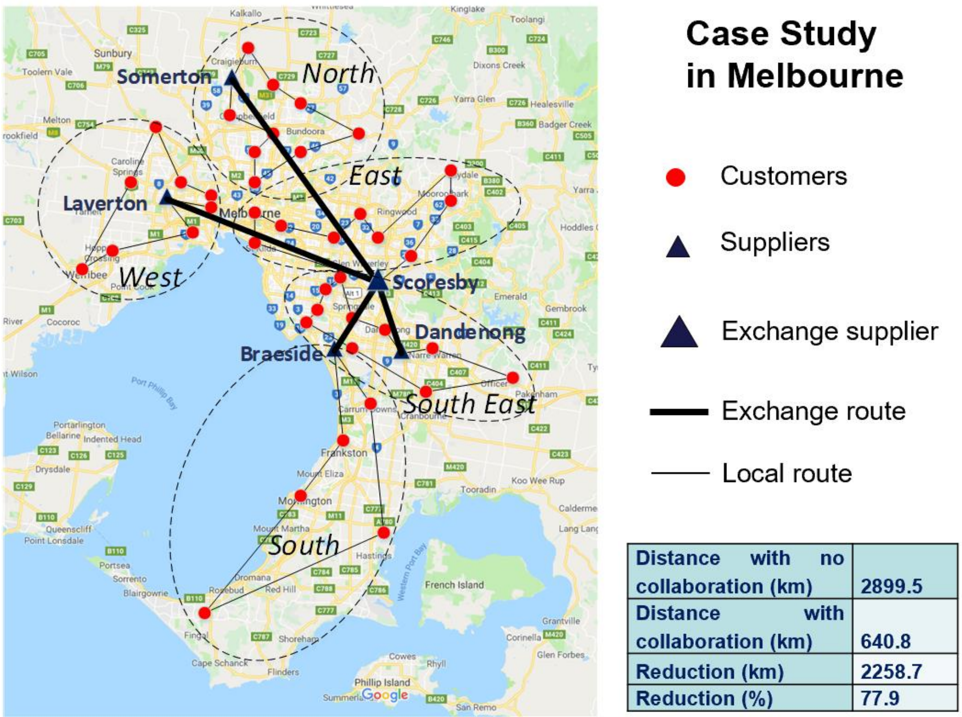


Figure 6 Collaborative Retail Distribution Networks

5 Conclusions

The distribution of goods within metropolitan areas is currently dominated by independent networks that are designed to minimise the transport costs for individual networks. Integrating networks can dramatically reduce transport costs but leads to increased transfer and storage

costs. This paper highlights the need to consider a range of stakeholders and performance measures to promote more collaborative distribution networks.
A set of network performance measures relating to various stakeholders were defined. The relative performance of traditional and PI networks was illustrated. The need to consider transfer and storage costs in transformed networks was demonstrated. Sharing warehouses and storage space within retail stores would require additional resources to manage facilities and would be more disruptive to shippers and receivers.

References

Aljohani, K. and R.G. Thompson (2021). Profitability of freight consolidation facilities: A detailed cost analysis based on theoretical modelling, *Research in Transportation Economics*, 101122.

Bureau of Infrastructure, (2015). Transport and regional economics. In Information sheet 74: Traffic and congestion cost trends for Australian capital cities, Canberra.

Crainic, T.G. and B. Montrieul, (2016). Physical internet enabled hyperconnected city logistics, *Transport Research Procedia* 12, 383–398.

Hassall, K. (2008). *Freight Exposure and how to measure it*, Proceedings International Conference on Transportation and Land Use Interaction, University Polytechnica Bucharest, Romania.