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# Recent Trends and Innovations in Modelling City Logistics

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**Abstract**

There are many challenges associated with moving goods within cities as urban areas become larger and elderly residents require more healthcare in their homes. Air quality is also impacted by urban freight vehicles. This paper presents a review of recent trends and innovations in modelling city logistics. New techniques for modelling city logistics developed in the areas of emissions, healthcare and mega-cities are outlined. This paper describes the formulation, solution methodologies and applications of these models.


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*Keywords:* Models; city logistics; emissions; healthcare; megacities

## 1. Introduction

City logistics plays an important role in creating efficient, environment friendly and safe urban freight transport systems. A number of policy measures, including urban consolidation centres, regulations of access control to city centres, off-peak hour deliveries, low emission zones have been tested and implemented in urban areas of cities around the world to achieve the goals of city logistics; mobility, sustainability, and liveability. Modelling city logistics schemes is required for evaluating the effects of implementing these measures. This paper reviews recent innovative trends of modelling techniques for city logistics.

Recent significant advances in modelling city logistics can be observed associated with the sustainability and

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liveability of urban areas. People are seeking improved air quality, safer communities and healthier lives. These components are essential for a higher quality of life. City logistics can contribute towards making urban areas more attractive and productive. With the progress of urbanisation in the world, about half of the population is concentrated within urban areas in 2010 according to the statistics of United Nations and it is predicted that this will increase to 70% by 2050. A number of mega-cities with populations of over 10 million have appeared and there have been various issues due to dense populations in mega-cities, including traffic congestion, air pollution, crashes and large energy consumption. These issues are very complicated and innovative methodologies are required to overcome them. City logistics solutions can assist in solving these difficult problems, since city logistics considers multiple objectives as well as the behaviour of multiple stakeholders who are involved in urban logistics activities, which provides the basis for sustainable and liveable cities.

This paper highlights recent developments in modelling city logistics in three important areas; emissions, health care and mega-cities. Emissions by freight vehicles often generate harmful effects on the health of residents. This paper describes a number of models relating to emissions by freight operations, including network modelling, fleet modelling, routing models and life cycle analyses. These models and analyses are effective for evaluating policies for reducing Green House Gas (GHG) emissions as well as local emissions of NOx and SOx by freight operations.

There has been more concern recently about health issues in aging societies. City logistics should incorporate healthcare issues, especially home healthcare, since home healthcare will be more critical with the increase of demands by elderly people for medical and nursing services in homes since the capacity of supplies is limited. This paper reviews and discusses models for home healthcare towards the optimal use of workloads and human resources as well as vehicle operations.

In mega-cities complicated problems arise relating to urban freight transport from the demand of higher levels of service in terms of the time of goods are received and tracing of goods in the e-commerce environment. City logistics policies are required to provide better services with lower costs for customers as well as reducing negative environmental impacts and improving safety. The paper highlights models for demand forecasting, emergency logistics and the location of logistics facilities in mega-cities.

## 2. Emissions

### *2.1. Introduction*

Urban freight vehicles can produce significant amount of emissions including sulphur oxide, particulate matter and nitrogen oxide. There is a need to minimise harmful emissions due to the high level of exposure to populations living and working in urban areas.

Browne, Allen, Nemoto, Patier & Visser (2012) described the relationships between the features of urban freight transportation and the negative impacts of urban freight transport operations. A number of features such as air pollutant emissions per vehicle kilometre, fossil fuel consumption per vehicle kilometre and total vehicle kilometres or journeys travelled were identified as influencing local air pollution. Use of vehicles powered by non-fossil fuels (including bicycles) and driver behaviour were among the initiatives that were presented that had potential for reducing impacts associated with fossil fuel consumption per vehicle kilometre.

A variety of modelling approaches have been used to predict the emissions associated with urban freight operations. This section describes a number of studies involving the development and application of network, lifecycle and fleet models as well as routing algorithms that have been applied to forecasting the emissions of freight vehicles operating in urban areas. Applications of models for investigating the benefits relating to the implementation of alternative modes and low emission zones are also presented.

### *2.2. Modelling approaches*

#### *2.2.1. Network modelling*

A traffic network model was developed to evaluate the impacts of policies for reducing greenhouse gas emissions from road freight vehicles in Sydney (Taylor, Zito, Smith & D'Este, 2005). The best policy options identified for reducing GHG emissions from freight transport were, 'higher load factors' and 'best fuel technology'. Emission models were created for various vehicle and fuel types. Assignment procedures were developed for combining trip matrices for truck types obtained from a previous commercial vehicle survey with passenger vehicles. A link based function was applied that incorporated the effects of the number of vehicles by type as well as their speed, loads and fuel used. A load correction factor was used to adjust the base emissions to estimate the effects of vehicles carrying higher loads. This allowed the trade-off between the number of vehicles and the loads carried to be investigated.

Traffic congestion has been found to lead to substantial increases in $CO_2$ emissions for freight vehicles (Barth & Boriboonsomsin, 2008; Frey, Rouphail & Zhai, 2008; Figliozzi, 2011). TRL (1999) have developed relationships between emissions, travel distance and travel speeds for large trucks.

*2.2.2. Fleet modelling*

When predicting aggregate emissions from the overall fleet it is important to consider the dynamics associated with vehicle replacement decisions as well as usage patterns for classes of freight vehicles. Wadud, Aye, Beer and Watson (2006) developed a model for predicting emissions from the Australian motor vehicle fleet with rigid trucks and articulated trucks segments considered separately. This model consists of three interconnected modules, travel activities, fuel and emissions.

New vehicle sales in a given year were estimated from the projected vehicle fleet and the proportion of previous vintages still surviving that year using survival functions. The distribution of vehicles over the modelling horizon were estimated by combining the projected new vehicle sales and previous vintages still surviving. Assumptions relating to the fuel mix were made including the use of LPG for trucks. Total exhaust emissions of air pollutants including PM10 were estimated by year to 2025. The model did not incorporate higher levels of congestion in urban areas that may increase emissions.

*2.2.3. Routing models*

Suzuki (2011) presented an approach to reduce fuel consumption and emissions by developing routes that minimise the distance vehicles travel with heavy goods. The sequence of customer visits was determined such that heavier goods are delivery during the first stages of tours. This model leads to solutions where heavy items are delivered early in tours leading to fuel savings between 4.9% and 6.9% compared with minimum distance routes.

Scora, Boriboonsomsin & Barth (2013) describe the development and application of Eco-Friendly Navigation (EFNav) algorithms designed specifically for Heavy-Duty Trucks (HDT). This system aims to generate routes that minimise fuel consumption for trips.  A mesoscale model was constructed from truck energy and emissions data collected by UC-Riverside's heavy-duty Mobile Emissions Laboratory (MEL) and a data set simulated for a wide range of operating conditions using a heavy-duty truck energy and emissions model. This model allows fuel use to be accurately predicted by incorporating vehicle mass and road gradients.

Simulation of a large number of routes generated by EFNav-HDT were compared with minimised travel time routes. Significant fuel savings were estimated but there were also substantial increased travel times.

*2.2.4. Life cycle analysis*

It is important to estimate the energy consumption and emissions of freight vehicles over their life to fully understand the total environmental costs associated with freight operations. The components of the life cycle of a vehicle involves the energy, material, process and service inputs being considered through a vehicles design, production, use and end-of-life stages.

Traditionally Life Cycle Analysis (LCA) is based on a process approach that makes it difficult to include upstream manufacturing and materials requirements. Process LCA (PLCA) tends to mainly focus on the use and end-of-life stages of a product's life. Economic input-output LCA (EIOLCA) incorporates economic equilibrium modelling that combines input-output analysis with environmental databases to analyse the supply chains of products.

Maclean & Lave (1998) present a use stage model that incorporates resource use and environmental discharges for components of a vehicle's lifecycle, including the fuel cycle (exploration and production, refinery, petroleum marketing and vehicle refuelling), vehicle servicing (parts and fluids, raw material and labour) as well as manufacture, vehicle use, fixed costs and disposal. Data was generated using a EIOLCA model, was aggregated into 3 categories, economics, externalities (air pollution, global issues and resource use) and vehicle attributes (vehicle interior space, curb weight and fuel economy).

It is become acknowledged that the effects of upstream and downstream processes such as energy production, vehicle production and maintenance as well as infrastructure construction and maintenance should also be considered in the environmental assessment of motor vehicles (Rothengatter, 2003:18). Energy production effects relate to the generation and distribution of fuel before combustion. Vehicle production involves the effects for the entire supply chain of vehicles, including all components used in its manufacturing as well as ongoing maintenance. Infrastructure effects relate to the impacts on the natural and social systems from construction and maintenance of facilities required to operate vehicles.

Recently the entire life cycle (design, production, use and end-of-life) of the infrastructure and fuels as well as vehicles have been included in a more comprehensive life cycle analysis of transport modes, including freight vehicles (Chester & Horvath, 2007).

Much analysis of energy consumption and emissions focuses on the tailpipe, ignoring factors such as the resource requirements and the pollution generated from the production of vehicles and their fuels as well as the development of infrastructure. Total energy inputs and greenhouse gas emissions have been estimated to contribute an additional 63% over vehicle tailpipe operations for on-road vehicles (Chester & Horvath, 2009). A vehicle's non-operational components can often dominate total emissions.

LCA is a complex modelling exercise, involving a vast number of assumptions and requiring a large amount of data. It often is difficult to compare results between countries due to differences in energy production, transport network conditions (such as infrastructure and congestion levels) and available vehicle technologies.

The results from the LCA can be expressed in many ways. Typically, the total emissions and energy inputs over the entire life of a vehicle are estimated. However, it is often more useful to use the total costs to determine rates, expressing the efficiency of vehicles over distances travelled and loads transported. This often allows more meaningful comparisons across modes in urban areas to be undertaken.

The inclusion of parking facilities is not generally considered in lifecycle analysis. However, a recent study considered the energy and emission from constructing and maintaining parking infrastructure for SUVs and pickup vehicles (Chester, Horvath & Madanat, 2010). This study showed that significant additional emissions can be attributed to parking infrastructure.

*2.2.5. Other modeling approaches*

The fuel consumption and emissions associated with the use of freight vehicles is largely dependent on the age and type of vehicle, its power or energy supply as well as driving characteristics. Fuel consumption for petroleum powered internal combustion engines (ICE) used in vans depends largely on the engine size and the driving cycle. Higher levels of acceleration and braking in urban areas leads to higher fuel consumption compared with rural driving.

It is desirable when comparing emissions and fuel consumption from motor vehicles to use a common driving cycle that represents typical driving patterns over a period of time. This is due to the rates often produced by manufacturers being based on average speeds, not on actual trips under real traffic conditions on road networks. Driving cycles comprise a speed profile for a general trip in a specific city. However, there has been limited work undertaken in developing driving cycles for trucks and vans (Barth, Scora & Younglove, 2004).

A systems dynamics model was developed for estimating the $CO_2$ emission trends from freight transport in Beijing over the period 2005-2030 (Wang, Fei, Feng, Imura & Hayashi, 2010). This model incorporates projections of macroeconomic conditions and demographic factors.

The need to consider the structure of secondary distribution channels as well as customer collection systems in estimating $CO_2$ emissions from retail distribution in urban areas was highlighted by McKinnon & Woodburn (1994). This modelling exercise involved assumptions relating to truck consolidation factors, distances between retail distribution centres and shops, distances travelled by suppliers' delivery vehicles as well as the frequency and loads carried by customers from shops to homes. The results showed that the positive effect of urban distribution centres on $CO_2$ emissions can be offset by increased customer travel due to a higher concentration of retail outlets.

### 2.3. Alternative modes

Electric vans and trucks have the potential to reduce tailpipe emissions in urban areas that can improve health and reduce greenhouse gases. Electric vans and tricycles were recently trialled in delivering stationary and office supplies from a small consolidation centre in London, resulting in an estimated 54 percent reduction in $CO_2$eq emissions per parcel delivered (Browne, Allen & Leonardi, 2011; Leonardi, Browne & Allen, 2012).

Electric vehicles currently tend to have higher purchasing costs (Leonardi, Cullinane & Edwards, 2013). A model for investigating the financial competitiveness of electric freight vehicles against diesel trucks was presented by Feng & Figliozzi (2012). Integer programming was used to identify breakeven points where electric vehicles could become competitive. This model minimises the capital, operating and maintenance as well as salvage costs within demand, vehicle age and budgetary constraints for a fleet over a 15 year period.

Deliveries by bike is a back to the future concept that has recently been promoted in Time Magazine as one of the 10 big ideas in transportation (Sanburn, 2013). Bike deliveries result in reduced environmental costs from mode substitution as well as less congestion from larger vehicles using the road for travel and parking.

Maes & Vanelsander (2012) presented a simulation model to estimate the financial and environmental impacts of bike couriers. This model estimated that 6 tonnes of $CO_2$ per year could be saved for every van replaced.

Nuzzolo, Crisalli & Comi (2008) presented a methodology for predicting the revenues and impacts of goods distribution by rail in metropolitan/urban areas. A three level freight demand zone based model was developed to estimate the average flow of goods, deliveries and vehicles. This model was used to analyse the technical and economic feasibility of a new freight railway service in the Sorrentina Peninsula in Italy. Benefits from reduced externalities were able to be estimated.

### 2.4. Low emission zones

Low emission zones (LEZ) aim to promote the operation of cleaner vehicles, and reduce the number of older, more polluting vehicles operating in central city areas. Browne, Allen & Anderson (2005) used surveys to investigate the likely effects of LEZ in London in terms of the types of vehicles used in operations in London as well as elsewhere in the UK. Distributions of the replacement cycles of vehicles below and above 3.5 tonnes were obtained. Ellison, Greaves & Hensher (2013) presented an evaluation of the LEZ in London highlighting the need to consider the impacts of LEZ outside as well as inside the cordon.

Greaves (2009) presented details of a Strategic Tool for the Environmental Analysis of Road Freight (STEAR-F). This model integrates a range of existing public data including freight surveys, fleet profiles and emission rates to estimate emissions. Results from a large scale commercial transport study were used to estimate origin and destination patterns and vehicle kilometres of travel (VKT) by vehicle type. Fleet characteristics from government databases including age and fuel types were used to estimate VKT by vehicle type, age and fuel type. Emission factors were then used to predict GHG and non-GHG emissions.

STEAR-F has been applied to evaluate a number of policies in Sydney including accelerated vehicle scrappage schemes, LEZ and alternative fuel programs. Estimates of the 2015 business as usual scenario were based on projections of vehicle replacement patterns and future emission standards. The effects of a number of scenarios including a LEZ targeting pre-Euro III vehicle around the city centre and port areas of Sydney were estimated. The LEZ was predicted to produce a reduction of major pollutants by 10-15% within the LEZ.

## 3. Healthcare Problems

Recently the population of elderly persons over 65 years old is increasing in many countries and healthcare problems have become important. The medical and nursing care of elderly persons in hospitals or homes are major problems in aging societies. Better services for patients under conditions of limited budgets and resources are required. The number of patients has increased due to the increasing population of elderly people, but the number of medical doctors, nurses and other medical staff is limited. The capacity of hospitals and clinics are also limited. Therefore, there are gaps between the demand and supply for medical and nursing care services.

City logistics can address these healthcare problems, since city logistics is the process of total optimisation of logistics activities in urban areas considering economic, environmental, social and safety aspects. As the goals of city logistics are mobility, sustainability and liveability, taking into account the healthcare problems in city logistics includes establishing an efficient and healthy society.

As the number of beds in hospitals is limited, many patients have to stay at their homes to receive medical and nursing care and other supporting services including the delivery of drugs, food and bath services. In former days, family members took care of elderly relatives in their home, but today due to the change of family structure, patients need support from outside their family. Consequently, home healthcare (HHC) problems have become a new evolving research area with the application of vehicle routing and scheduling problems with time windows (VRPTW) as well as designing staff rosters problems. HHC problems try to minimise the costs of delivering medical and nursing services and maximising the satisfaction of patients to find optimal scheduling of works and routing.

Some models have been developed to solve these problems. Begur, Miller & Weaver (1997) presented a decision support system for home healthcare. Bertels and Fahle (2006) presented a hybrid method of using a combination of linear programming, constraint programming and meta-heuristics for the home healthcare problem. Eveborn, Flisberg & Rönnqvist (2006) proposed a decision support system for staff planning of home care. Nickel, Schröder and Steeg (2012) took into account a master schedule which is modified to incorporate operational changes in HHC problems. Rasmussen, Justesen, Dohn & Larsen (2012) modelled the problem as a set partitioning problem with side constraints and developed an exact branch-and-price solution algorithm. Liu, Xie, Augusto & Rodriguez (2013) addressed a vehicle scheduling problem encountered in home healthcare logistics and considered hospitals and patients as a special vehicle routing problem with simultaneous delivery and pickup and time windows between depots. Benzarti, Sahin & Dallery (2013) formulated the HHC districting problem as a mixed-integer programming model. Their computation results showed that the model can improve the service quality for patients as well as optimising the workload balance of human resources. As these problems are NP-hard, meta-heuristics approaches including tabu search, simulated annealing and genetic algorithms are usually applied.

Home healthcare in times of natural disasters is a very critical problem for elderly people or patients who need special medical and nursing care. In the case of the Tohoku earthquake disasters in Japan in 2011, many elderly and disabled persons were displaced to shelters or stayed at home even if their house was partially damaged by the earthquake or tsunami. Providing medical services and other support for these persons was a very difficult task. From the viewpoints of planning human aid, appropriate modelling is required. Trautsamwieser, Gronalt & Hirsch (2011) presented a model which minimises the sum of driving and waiting times, and the dissatisfaction levels of patients and nurses in the case of flooding.

There is often a need to transport patients between care units. Ambulance mangers have to make plans for transporting patients considering the dynamically changing demand. Kergosien, Lente, Piton & Billaut (2011) presented a patient transport model considering the priority of urgent demands for care units.

## 4. Logistics Modelling for Megacities

About half of the world's population is concentrated in urban areas because of the opportunity for a better quality of life. Consequently, many of these areas are expanding rapidly, leading to the growth of megacities, which are typically defined as metropolitan areas with populations exceeding 10 million inhabitants (Molina & Molina, 2004). Megacities are dense centres of population, economic activity, and pollutant emissions (Duren & Miller, 2012).

Continuing rapid population and economic growth, typically seen in megacities, has led to significant increase in freight movements in transport networks, causing traffic congestion and environmental damage. This enhances the need to accurately estimate the freight movements as well as to forecast the expected future truck flows and underlying commodity flows.

Megacities can also experience a range of disasters, including earthquakes, floods and hurricanes, which can disrupt urban distribution systems. Disasters are the results of vast ecological breakdowns in the relations between humans and their environment (Gunn, 2003). Traffic systems are often disrupted as a result of disasters, and efficient means of continuing distribution services need to be identified for cases when the capacity of the urban traffic system is reduced. In addition, optimising the location of logistics facilities is important in megacities, not only in the case of emergencies but at any time, since it always strongly influences land use and traffic flows and incidentally produces external diseconomies such as traffic congestion and air pollution.

### *4.1. Demand forecasting*

Freight models are utilised to assist in the tasks of estimating demand for travel and the impacts of proposed land use or transport system changes (Ogden, 1992). Freight models can be used as a general term, but in existing literature, sometimes they are called freight demand models, freight transport models, freight flow models or goods movement models. Most freight models are however, still under development and are not as mature as passenger models.

These models can typically be categorised into three types: commodity-based models, trip-based models and tour-based models. In practice, trip and commodity based models have dominated. Commodity-based models usually estimate the amount of commodities being transported between zones using various economic variables, which are then converted to freight vehicle travel (e.g., Hutchinson, 1974; Wisetjindawat, Sano & Matsumoto, 2006; Giuliano, Gordon, Pan, Park & Wang, 2010). Holguín-Veras & Thorson (2003) developed a model for empty truck movements that could be integrated with commodity flows. Holguín-Veras & Patil (2008) estimated OD freight flows incorporating both loaded and empty truck trips. Trip and tour based models directly generate zonal trip production and attraction rates based on economic variables, such as land use classification, number of establishments, employment, population, land area, and floor area. (e.g., Oppenheim, 1993; List & Turnquist, 1994; Hunt & Stefan, 2007; Muñuzuri, Cortés, Onieva & Guadix, 2010). Trip based models often suffer from lack of economic behavioural rationale, since the underlying supply and demand relationships that drive freight demand is not modelled. Tour-based models can encompass factors that logically chain trips into tours.

Urban freight vehicles often deliver cargo to more than one customer per load and make multiple stops before returning to the base location in one vehicle run during their daily operations. Hensher & Figliozzi (2007) demonstrated the importance of accounting for the trip-chaining behaviour in freight transport. Hence, Wang and Holguin-Veras (2008) focused on trip-chaining behaviour, and Ruan, Lin & Kawamura (2012) proposed tour-chaining approaches to model and analyse freight vehicle daily operations and urban logistics. In this regard, activity chain-based approaches (e.g. Joubert & Axhausen, 2011) also have good potential.

Recently, there have been logistics or supply chain based models taking into account the interactions among various economic entities throughout the supply chain (Wisetjindawat & Sano, 2003; Roorda, Cavalcante, McCabe & Kwan, 2010; Samimi, Mohammadian & Kawamura, 2010). Tavasszy, Ruijgrok & Davydenko (2012) emphasised the importance of including logistics or supply chain elements into freight modelling. This type of model typically simulates commodity flows in an urban area within the framework of supply chain management. Locations of manufacturers, distributors and consumers are considered, whereas most models can only highlight a few industries where data is readily available, which is largely due to data availability. The stream of supply chain network modelling from Nagurney, Dong & Zhang (2002) represents an important research direction, using multi-level multi-tiered networks that allow distinct flows to be captured, including logistical, informational and financial flows within the same network system, whilst retaining the spatial nature of the network of decision-makers. In this context, Yamada, Imai, Nakamura & Taniguchi (2011) proposed a supply chain-transport supernetwork equilibrium model, which is able to represent the mutual effects between the behavioural changes in supply chain networks and transport networks.

### *4.2. Emergency logistics*

Several existing studies (e.g., Sheu, 2007; Balcik & Beamon, 2008; Caunhye, Nie & Pokharel, 2012) have revealed key challenges for emergency logistics planning compared to business logistics. These involve uncertainties (e.g., routes, safety, facility capacities and demand), communication and coordination (e.g., difficulty in access to accurate real-time demand information), efficient and timely delivery and limited resources (e.g., transport capacity and fuel). Related research has adopted a variety of approaches (e.g., stochastic modelling and simulation) and optimisation modelling.

The literature relating to emergency logistics can be classified into two types: facility location; relief distribution and casualty transportation. In facility location optimisation for emergency logistics, maximal covering approach has typically been used in terms of number of facilities allocated to a demand point (e.g., Jia, Ordóñez & Dessouky, 2005, 2007; Dessouky, Ordóñez, Jia & Shen, 2006). A stochastic vehicle routing model was developed by Dessouky, Ordóñez, Jia & Shen (2006) for rapid distribution of medical supplies. Relief distribution and stock-prepositioning are often combined into facility location models(e.g., Chang, Tseng & Chen, 2007; Mete & Zabinsky, 2010; Rawls & Turnquist, 2010). The most common type of models for relief distribution and casualty transportation look at both resource allocation and commodity flow (e.g., Özdamar, Ekinci & Küçükyazici, 2004; Yi & Kumar, 2007).

### *4.3. Location of logistics facilities*

Location problems have mostly been developed in a single facility type. Comprehensive reviews of the existing location models have been undertaken, including Francis, McGinnis & White (1983), Brandeau & Chiu (1989), Owen & Daskin (1989), Drezner & Hamacker (2002). A current stream of location modelling focuses on a hierarchical approach (e.g., Şahin & Haldun, 2007). Hierarchical facility location models take into account the location of their interacting facilities within a multiple layer configuration.

In a hierarchical system of facilities, the demand or customer sites are the base level, and the underlying structure is assumed to be a network whose nodes represent facility and demand sites. Hierarchical facility location problems can be classified by four attributes: flow patterns (i.e., flow features of services or goods on arcs between nodes of the network), service availability, spatial configuration of services and objectives for locating facilities (Şahin & Haldun, 2007). These types of models have mainly been applied to health-care facility systems (e.g., Boffey, Yates & Galvão, 2003; Şahin, Süral & Meral, 2007).

Location-routing problems (e.g., Toyoglu, Karasan & Kara, 2012) are a class of problems usually used to determine both facility locations and routes around the facilities at the same single level. Potential application areas are waste management, production-distribution services and postal services. In the case of production-distribution systems, when the distribution is handled through warehouses owned by a manufacturer, the structure is basically a multi-level system of facilities. A common example is composed of retailers (and/or wholesalers), warehouses and production plants. Products are first distributed from manufacturers' plants to warehouses and then to retailers. In the case where the availability of services is nested (i.e., direct delivery exists from production plants to retailers as well as from warehouses to retailers), the flow pattern is generally multi-flow (e.g., Hinojosa, Puerto & Fernández, 2000).

Another important aspect of location modelling of urban logistics facilities is to incorporate the change in traffic flow on transport networks, such as using traffic assignment procedures. However, there have been few studies considering traffic assignment within location modelling (e.g., Yamada, Russ, Castro & Taniguchi, 2009; Meng & Wang, 2011).

## 5. Conclusions

Trends relating to the increasing size of cities and the growing number of elderly persons with healthcare needs are presenting substantial treats to liveability and mobility. Ensuring adequate air quality and healthcare are major challenges. This paper has described modelling approaches that can be used for designing and evaluating City logistics schemes for reducing the impacts of freight in cities.

Regarding emissions, there is a need to consider the lifecycle costs of freight vehicles and alternative fuels being introduced in cities. Effects of schemes such as Low Emission Zones also need to consider the effects of operations outside such zones.

City logistics concepts can assist in reducing the costs and increasing the service levels of urban home healthcare systems. New modelling approaches are however required to design schemes that can reduce the environmental and social impacts.

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