Developing a conceptual framework for the evaluation of urban freight distribution initiatives

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Abstract

The evaluation of urban freight distribution initiatives is an essential process to the successful and effective implementation. The ultimate goal is to identify solutions where economic, social and environmental objectives can be combined, in order to achieve sustainable urban freight transport development. This paper presents the development of a conceptual framework for modelling the dynamic behaviour of various stakeholders in urban freight distribution and evaluates different strategic policies. The framework allows decision makers to conceptualise the promising initiatives and the factors that will be integrated into the model development. The methodology proposed takes into consideration the behaviour of several stakeholders and their interactions using the multi-agent system approach. Then the urban freight distribution initiatives can be prioritised. The case study of Rundle Mall Precinct, Adelaide is introduced and will be the test case for the model developed.

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1. Introduction

Determining the appropriate urban freight distribution initiatives to be implemented in a certain context is a complex and challenging task. The decision makers require good knowledge and comprehensive information to analyze and make decisions regarding a specific policy or strategy. Some of the successful implementations and recommendations from cities with distinct characteristics like for example the consolidation centre in Monaco may not be a common template that can directly apply to...
other cases. In addition, there is a multitude of factors and several stakeholders associated with urban freight distribution that has to be taken into consideration when designing and analyzing viable measures.

The objective of this paper is to review some of the major measures or initiatives implemented in urban freight distribution and identify those factors that will need to be taken into consideration for future successful implementations. This paper also aims to present the development of a methodology for evaluating urban freight distribution initiatives and in particular propose a conceptual framework for evaluating urban freight distribution initiatives considering the economic benefit as well as their social and environmental impacts and take into account the behavior of various stakeholders involved in the urban freight distribution.

In the next section some major urban freight distribution initiatives with the successful factors that need to be considered for implementation are reviewed. An overview of transport policy decision process and evaluation methods is presented. Then the case study of Rundle Mall Precinct, Adelaide is briefly introduced. The multi-agent approach is discussed and a conceptual framework for evaluating the impacts of urban freight distribution initiatives is proposed.

2. Urban freight distribution initiatives

Over the last decade, several measures and initiatives have been proposed or implemented aiming to reduce the negative impacts of urban freight distribution and logistics operations, improve quality of life and ultimately achieve sustainable development. The urban freight distribution initiatives discussed in this section mainly focus on some of them which are promising for implementation in the case study.

Time windows primarily aim to keep designated street or areas free of freight traffic during particular times. Freight delivery vehicles are allowed to enter certain part of the city during specific time periods [1]. Night time or off peak delivery is a form of time windows that leads to better utilization of infrastructure. The investigation of stakeholders’ perception and challenges for off-peak delivery measure in congested areas of New York City revealed that a number of incentives are required to promote participation and successful implementation [2]. Incentives recommended are an off-peak deliveries permit that loosens up the parking rules depending on certain conditions for freight carriers and tax incentives to receivers accepting off-peak deliveries. PIEK program in the Netherlands examined a range of technical modifications to delivery vehicles and related equipments to maintain noise at an acceptable level [3]. However, the opposition for this measure was on the actual operation that could disturb the resident in the city area. Time windows are also implemented in the Rundle Mall Precinct, of Adelaide as delivery vehicles are permitted to access the precinct during specific time periods.

Vehicle weight and size regulations aim to limit the physical damage that freight vehicles cause to existing infrastructure. This is a common measure in several cities in Europe. Rome, Italy has implemented a Limited Traffic Zone in the inner city area where heavy vehicle of more than 3.5 tonnes are permitted to access and park during 8 pm to 7 am while light vehicles are allowed to enter and park during 8 pm to 10 am and 2 pm to 4 pm. Antwerp and Brussels, Belgium have banned trucks from some of their urban roads [4]. Nevertheless, this may lead to more trips carried out by smaller delivery vehicles and as a consequence increase in traffic congestion, fuel consumption and emissions.

Low emission vehicles and alternative fuels intend to maintain the quality of life in urban areas. The European engine emission standards, Euro-4 and Euro-5 are a driving force for innovation in emission control for diesel engines. The enforcement of these standards for heavy vehicles has a significant impact on pollution emission [5]. The use of electric vehicles and trucks on alternative fuels such as compressed natural gas (CNG), liquefied petroleum gas (LPG) is increasing in many countries. In addition, the Electric Vehicle City Distribution (ELCIDIS) project examined the feasibility of electric vans and trucks for urban distribution, preferably in combination with the use of urban distribution centre [6].
finding confirmed the benefits of using electric vehicles for urban distribution concepts, although there are some technical and capacity issues to be further improved such as battery system, limited driving range and loading volume.

Urban consolidation centres basically include all measures that use a facility to consolidate the flow of goods from outside the city and bundle the inner city distribution. It aims to improve load factors of delivery vehicles as the facilities can be accessed by trucks and goods are then consolidated from different suppliers to smaller vehicles for final delivery which now have to cover shorter distances. A well-known implementation is in Monaco which was initiated by the Monaco government in 1989 in combination with strict truck regulations and provision of substantial subsidies. This makes the results hardly transferable to other cities [7]. On the other hand, the urban consolidation centre in La Rochelle, France was unsuccessful due to lack of enforcement for heavy goods vehicles to enter the city and limited capacity of electric vehicle resulted in more trips and thus increases in urban congestion. Although urban consolidation centres offer several advantages, the major drawback is the introduction of new transshipments in the logistics chain with additional costs and delays involved. However, extensive use of these facilities may improve traffic and freight delivery in the city.

Cooperative delivery systems intend to increase vehicle load factors, reduce freight distribution costs and provide higher level of service to customers by joint service of several shippers or carriers. The experiment of cooperative delivery system inside a building has been attempted in Japan [8]. The result showed that the potential solution is to shorten the parking time of trucks by assigning two workers at the parking area in the building to assist the driver by delivering goods to the final recipients. However, cooperative delivery systems have to be adjusted to the local circumstance and user requirements.

Technology measures related to information and communication technology may enhance the effectiveness and efficiency of logistics flows, reduce negative externalities as well as improve enforcement efficiency and broadening scope of enforcement [4]. With the use of Intelligent Transport Systems (ITS), it is possible to connect different modes of transport together as well as optimize distribution systems.

From the literature reviewed, there is no one best solution and not all the initiatives can be successfully implemented. The causes and impacts of urban freight distribution in all cities are similar, however; the problems may be different depending on particular urban environment.

The implementation of any of the above mentioned initiatives has to take into account the conflicting objectives and interests of different urban freight distribution stakeholders. There are a number of factors to consider for successful implementation:

- The early and active involvement of all stakeholders from the initiation of the project
- Cooperation and communication among stakeholders [9]
- Identification of target group as some of these initiatives benefit a particular stakeholders but effect negatively other
- Enhance knowledge, understanding and awareness in the sustainable urban freight distribution. The information and knowledge from previous failure and successful implementation should be shared to achieve a long term sustainable urban freight distribution [9]
- The evaluation is important for assessing the possibilities and negative effects of the implementable measure
- Identification of costs and benefits of implementation and operation including the distribution of costs and benefits of the stakeholders involved
3. Transport policy decision and evaluation methods

Transport policy refers to very specific solutions focusing on the instruments of implementation such as access restrictions and road pricing. In practice, there are two difficulties exist, first a single transport policy alternative may not be suitable for all the purposes and second due to the complex transport system, changes to one transport mode will have secondary effects on other modes [10]. Additionally, transport policies have a number of considerable economic, social and environmental impacts which are distributed across different areas and people. Therefore, making policy decisions on transport to achieve the right balance between benefits and costs is critical.

Policy evaluation aims at rationalizing planning and decision problems by systematically incorporate all related aspects of policy alternatives. Evaluation can have several objectives; to judge whether a policy intervention is legal or not; to examine whether an activity conforms to statutory and regulatory requirement; to provide feedback as part of a monitoring process; or for assessing the outcome of a policy intervention and to provide information on the use and allocation of public resources or the efficiency of a programme [11].

According to Giorgi & Tandon [11], the classical decision-making model consists of four main phases; agenda setting or problem definition, policy design, policy legitimation and implementation (Fig. 1). Evaluation can take place in all phases of the decision making and it has become a key element of public planning.

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Fig. 1. Decision making model

In the transport context, evaluation is carried out during different phases, ex ante evaluation is carried out in the problem definition phases; intermediate evaluation undertaken during the implementation stage for monitoring purpose and ex post evaluation is carried out once the implementation is completed to assess the project’s impacts [11]. This study focuses on the evaluation of several alternative urban freight distribution initiatives that take place in the policy design phase in order to make a decision on the most sustainable measure.

Policy evaluation should be as comprehensive as possible. Any cost or benefit that may be significant should be considered including indirect, long-term and non-market impacts [12]. Hence, it is crucial to use a comprehensive evaluation framework when comparing alternatives that affect the range of stakeholders. Evaluation or assessment of transport projects or policies has been carried out in the past using various methods.
Traditionally, cost-benefit analysis (CBA) has been commonly used for evaluating transport projects and policies from an economic perspective. CBA is utilized to determine whether the benefits involved in undertaking or implementing a specific project or policy exceed the costs and achieve the efficient use of resources [13]. However, the limitation of CBA is that non-quantifiable effects are usually treated by description only and there are various assumptions established in the process.

Multi-criteria analysis (MCA) is an alternative to CBA in cases where the majority or an important set of relevant effects cannot be quantified [10]. An important assumption in MCA is that weights applied to different impacts, reflecting their degree of importance, can be established with reference to decision makers’ opinions. Such methods can be applied in transport projects in many different ways. The study by Kapros, Panou & Tsamboulas [14] developed an integrated methodological process, using MCA, for evaluating the anticipated effects of intermodal freight villages in Greece, considering their viability and stakeholder priorities. The study stated that the methodology developed is widely applicable because it can handle the multidimensional effects of different decisions.

The study by Thompson and Hassall [15] presented a methodology that allows ranking of potential road freight enhancement projects based on predetermined goals, objectives and criteria. Weightings of goals and objective for the urban freight system were estimated using this analytical method. Ranking procedures based on estimated utilities and quantum score were developed. In addition, Patier and Browne [16] examined a methodology to enhance the consistency with the evaluation of urban goods innovations and project. The developed matrix take into account both quantitative and qualitative aspects.

In recent years, game theory has been increasingly applied in the traffic and transport areas particularly focused on the description of deregulated markets [17]. Game theory is a subject of economics which provides a framework for modelling strategic interactions between groups of decision-makers when actions jointly determine the outcome. Many of the application of game theory in agent systems have been to analyse multi-agent interactions, particularly those involving negotiation and coordination [18]. Friesz and Holguin-Veras [19] developed a dynamic urban freight models and also pointed out that urban freight is best modelled using the perspective of game theory. Rouboutsos and Kapros [17] developed a game theoretical framework model to forecast possible outcomes of strategies implemented by individual public transport operators depending on the existing level of deregulation and their relevant impact on the concept of integration. In addition, game theory-based theoretical approach offers a number of theories such as Nash equilibrium, mixed strategy equilibrium and correlated equilibrium to study different problems.

The modelling technique has also been applied in transport evaluation. The study by Hosoya et al. [20] developed a micro-simulation model to evaluate a number of logistics policies in Tokyo metropolitan areas considering individual company’s behavior and their interaction. The model applied the conventional four-step travel demand estimation process and utilize disaggregate models and micro-simulations to reflect each firm’s characteristics. However, the four-step approach was originally developed for passenger and may not be able to capture the complexity of interaction between the key stakeholders in freight distribution in the more complex and challenging environment. Taniguchi et al. [21] employed multi-agent models for evaluating the behavior and interaction among stakeholders who are associated with urban freight transport and consequences of city logistics measures. The simulation results showed that the Vehicle Routing and Scheduling Problem with Time Window-Dynamic (VRPTW-D) model which dynamically adjusted vehicle routing planning to the current travel times, generated good performance in terms of increasing profits for freight operators and decreasing costs for shippers. Tamagawa et al. [22] proposed a methodology for evaluating city logistics measures considering the behavior of several stakeholders involved in urban freight transport using also a multi-agent model.
From the literature reviewed, some of the evaluation methods have limitations in representing individual objectives and behavior of urban freight distribution stakeholders as well as incorporating their interactions when evaluating alternative policy measures. One distinct important feature of MAS is that more emphasis is put on the ability, characteristics and function of individual agents rather than system optimization [21]. Therefore, the application of MAS to study urban freight distribution provides the ability to simulate the impacts and effects of different scenarios of urban freight distribution initiatives and how the decision is influenced by that.

4. The case study: Rundle Mall Precinct, Adelaide

Adelaide is the capital city of South Australia, Australia. It is a mid-size city comprising of 1.19 million inhabitants, approximately 73% of the total state population of South Australia (1.62 million) [23]. The population of Greater Adelaide is forecasted to increase to 1.85 million people by 2036 [24]. In 2006, the total population in the area governed by the Adelaide City Council was estimated at 17,630 people. An increase of over 14,000 people to 31,765 is projected by 2021 and to 41,131 by 2031 [25]. The dominant economic sectors in the city of Adelaide are finance and insurance and property and business services, together accounted for 38% of the City’s economy [26].

The Rundle Mall Precinct (Fig. 2) is the major retail location in the centre of Adelaide and visited by many thousands of people every day. Rundle Mall Precinct offers a wide range of facilities including 3 major department stores, 15 arcades and centers, 700 retail stores and more than 300 non-retail services and offices as shown in Figure 3. The Mall is ideally located and connected to major public transport and several undercover car parks within 100 meters. Over the years, the number of visitors to Rundle Mall Precinct has remained steady, while the number of those visiting suburban shopping malls has increased. Rundle Mall Precinct needs major development to maintain its appeal to customers and to create an attractive retail hub in the city centre.

The Rundle Mall Precinct comprises of a variety of access route including the primary pedestrian mall areas, covered arcades as well as public and private vehicle access roads. At present, vehicles are not allowed to access into the Mall from 10 am - 5 pm Monday to Saturday and 11am - 5pm on Sunday. Outside of these hours, vehicle access is allowed under permit only.
At present, the Masterplan is being developed which aims to bring together all stakeholders with a unified vision for the future development of the Rundle Mall Precinct. In addition, the study by Blandy [26] has projected economic and population growth over the next 10 and 20 years. A twofold increase in City of Adelaide’s population is expected in the next 30 years. These projected growths will certainly lead to higher demand for urban deliveries.

The observation of current freight distributions reveals that majority of goods delivered to the retail outlets are carried out in the early morning using light commercial vehicles and mid-sized trucks. The delivery vehicles are parked in the Mall. The majority type of goods delivered are clothes and fashion accessories. In most of the cases, the driver is responsible for unloading the products into a hand cart or trolley and manually pushing it down the street to the individual shop to complete the delivery. However, during the peak business hour, delivery vehicles may be parked a distance away from the premises, thus drivers spend more time to complete deliveries. In addition, it is difficult to deliver the goods when the mall is crowded during peak hours.

5. Multi-agent approach

Multi-agent systems (MAS) is applied to the modelling and simulation in various fields such as stock market, supply chain, freight distribution, evacuation, traffic management and operational risk [29-32]. MAS are aggregations of goal-oriented, interacting autonomous agents situated in some environment [33]. MAS is composed of an environment; a collection of agents; a collection of objects, whose spatial coordinates are known, and interact with agents; and a number of laws which control all the agents’ activities [30].

In agent-based modeling, a system is modeled as a collection of agents which individually assesses their situation and makes decisions on the basis of a set of rules. The interesting aspects that are offered by MAS is the possibility to represent individuals, their behavior and their interactions therefore it is possible to analyze different real world alternatives as the result of interactions of the agents. Furthermore, MAS is enable to experiment the consequences of any theory and of any possible alternative in a fast and efficient way [30]. Knaak et al. [33] pointed out the challenging problems of multi-agent based-simulation which are model validation; parameter calibration and the search for optimal strategies, however, a combination of simulation-based optimization and data mining can deal with these problems.
There are a number of studies in urban freight distribution that applied the MAS approach. The study by Davidsson et al. [34] carried out a survey of existing research on agent-based techniques in freight transport and logistics and generally concluded that agent-based model appear very suitable for this area. The main reasons mentioned in the papers for adopting an agent-based approach are; facilitates distributed control, ability to cope with partial and noisy data and ability to model complex problems. Additionally, Knaak et al. [33] developed an agent based model as a tool to assess alternative logistics concepts of city courier services, Fixed Exchange Points. The model developed was implemented in an existing discrete-event simulation framework, FAMOS and pilot runs conducted. The results of these runs demonstrated that a refinement and extension of the model is necessary. The number and placement of fixed exchange points should be calibrated using simulation-based optimization. In addition, Boussier et al. [29] attempted to specify and design a software tool for the management of goods distribution in small and medium size cities using electric vehicles. The study focused on the modeling of the management process of the parking place sharing between passenger cars and dedicated areas for freight deliveries. MAS is used to simulate impacts of the share between passenger cars and freight vehicles on the degree of congestion. Taniguchi & Tamagawa [35] investigated a methodology for evaluating city logistics measures incorporating the behavior of several stakeholders associated with urban freight transport. The simulation was carried out on a test road network and implemented truck ban and tolling of urban expressway as city logistics measures. The results showed that implementation of the two measures did not improve the conditions of all stakeholders. However, reducing the toll to half-price is favorable for the residents and the administrators and truck ban has the effect to spread out the zones that the residents make complaints and provide an equal environment for the residents.

The literature showed that few studies on urban freight distribution particularly consider the behavior of stakeholders in the evaluation of urban freight distribution policy. However, as Davidsson et al. [34] pointed out there are very few studies of the applicability of agent technology to strategic decision-making to urban logistics problems. Although the number of studies focusing on application of MAS to transport logistics is increasing, the majority focus on the assessment of a particular urban freight distribution measure.

MAS offer a number of characteristics that enable to deal with the limitations of the existing models for urban freight distribution. The multi-agent approach seems to be a promising technique to apply in this study that aims to evaluate the impacts and effects of different urban freight distribution initiatives. It is believed that by adopting the MAS approach, the behavior of stakeholders and interaction among them can be incorporated and able to test the impact different urban freight distribution initiatives would have on the economic, social and environmental aspects.

6. Conceptual framework

The present form and organization of freight distribution in the Rundle Mall Precinct, Adelaide, and the high pedestrian concentrated areas, lead to several issues. These issues are noise pollution, safety, parking space damage to the pavement and other infrastructure, inefficient and difficulties of movement when the public space is crowded, and the generally negative impact of trucks on the ambience of the Precinct. Several alternative urban freight distribution strategies have been considered by transport planners. However, evaluation of alternative strategies must consider their economic benefits as well as social and environmental impacts.

The motivation of the proposed conceptual framework is initiated from the study by Knaak et al. [33] that developed multi-agent based simulation of alternative logistics concepts for city courier services. Different logistics strategies have been simulated and analysed to evaluate the economic and ecological
impacts. In the case study of Adelaide, we aim to develop an evaluation framework for a number of alternative urban freight distribution strategies using multi-agent based simulation.

Several stakeholders, that can be viewed as agents are involved in urban freight distribution. In the case of the Rundle Mall Precinct, there are four main stakeholders or agents to consider. It is assumed that agents have their own objectives and behave to achieve their own objectives. When the urban freight distribution initiatives are implemented, stakeholders will change their behavior to adapt to their changed environment. Each agent is responsible for one or more activities in the urban freight distribution and each interacting with other agents in planning and executing their responsibilities.

The key stakeholders, their objectives and behavior assumed can be described as follows:

- **Retailers**: the aim is to increase profit. To achieve the objective, retailers have to increase sales as well as reduce the total costs while maintaining the availability of the products. Retailers will select freight carriers and request of deliveries.

- **Freight carriers**: the aim is to increase profit. To achieve the objective, freight carriers have to minimize the operational costs in addition to increase sale. Freight carriers are responsible for offering transport service to shippers/retailers and delivery or collection of goods to/from the retailers according to the quantity, place and time specified.

- **Residents**: the aim is to ensure the quality of living environment. Therefore, they aim that the negative impacts on their living environment such as noise, visual intrusion and air pollution from the traffic are kept to the minimum. If the negative impact exceeds their set limit, we assume that they will make a complaint to the local authorities.

- **Transport planners or local authorities**: are responsible for the well being of the residents as well as promoting economic and environmental development. The aim is to minimize the level of residents’ dissatisfaction as well as decide whether they should implement new urban freight distribution measures in the areas that received complaints or considered to have negative impacts from freight distribution.

The interaction between agents could be illustrated as in Fig. 4.

![Fig. 4. Interaction among major urban freight distribution stakeholders](Adapted: 22)

The proposed conceptual framework (Fig. 5) for evaluating the impacts and effects of urban freight distribution initiatives will be developed to enable decision makers to conceptualize the range of urban freight distribution initiatives under consideration. The stakeholders involved in each particular initiative may vary slightly. The evaluation tool will be developed using multi-agent based simulation technique as
it allows the incorporation of the individual stakeholder behavior and is able to capture the interactions among them. It is expected that the model will enable the observation of the effects of different urban freight distribution initiatives and will provide a good comparison measure for the initiatives of interest. Ultimately this will be a decision support system to aid with the selection and ranking of proposed urban distribution initiatives prior to implementation.

The model designs will consist of two sub-models: a learning model for stakeholders behavior and an operational model such as VRPT. The agents in the learning model will act independently and proactively according to the changed environment as a result of the measures implemented. The decision taken in the learning model will then initiate the actions in the operational model.

The next stage of the study will be data collection which consists of retail business survey, interview and also focus group of associated stakeholders in the Rundle Mall Precinct. The data collect will be analyzed and incorporated in the model development.

7. Conclusion

Urban freight distribution is fundamental for the economic and social development of city centre. The decision made by the policy makers should be comprehensive and take into consideration all the implication for both economic, social and environment benefits. The conceptual framework proposed in this paper is the first step towards the development of a model that aims to assist decision makers with the selection of viable urban freight distribution strategies prior to implementation. Multi-agent based simulation is a promising approach to apply for the model development, incorporating the behavior and interaction among urban freight distribution stakeholders. The expected outcome of the study is to develop an evaluation tool to assess alternative urban freight initiatives and assist the policy makers in deciding the most appropriate urban freight distribution strategy to implement.
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