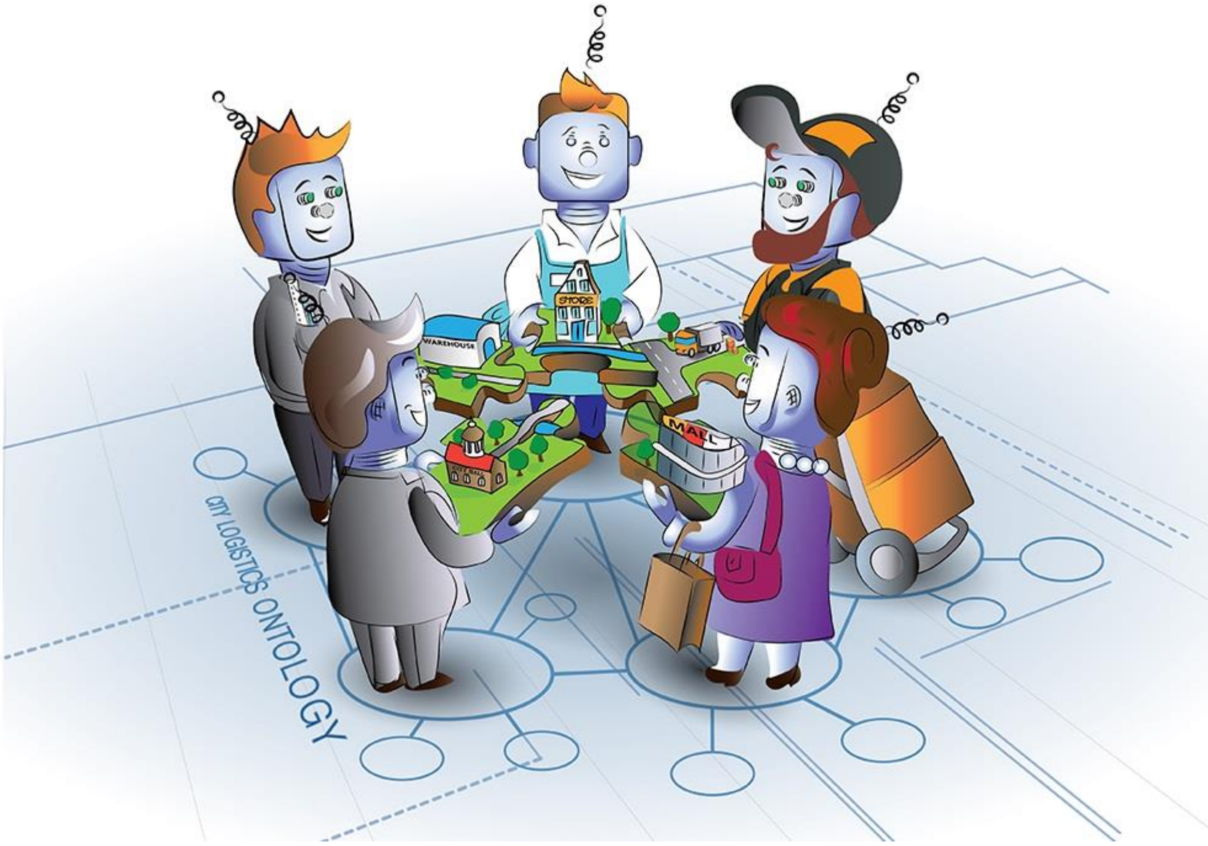


An Agent Based Modelling Approach for Multi-Stakeholder Analysis of City Logistics Solutions

Nilesh Anand
Delft University of Technology

An Agent Based Modelling Approach for Multi-Stakeholder Analysis of City Logistics Solutions

Nilesh Anand

Delft University of Technology

Cover design: Vladimir Marinovic Martini, E:ga0bava@gmail.com, W: http://www.marmarart.com/

An Agent Based Modelling Approach for Multi-Stakeholder Analysis of City Logistics Solutions

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof.ir. K.C.A.M. Luyben
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op
donderdag 17 september 2015 om 12:30 uur

door

Nilesh ANAND
Master of Science, the Royal Institute of Technology, Sweden
geboren te Ahmedabad, India

This dissertation has been approved by the promotor:
Prof. dr. ir. L.A. Tavasszy
Copromotor: Dr. J.H.R. van Duin

Composition of the doctoral committee:

Rector Magnificus	Chairman
Prof. dr. ir. L.A. Tavasszy	Delft University of Technology, Promotor
Dr. J.H.R. van Duin	Delft University of Technology, Copromotor

Independent members:

Prof. dr. C. Macharis	Vrije Universiteit Brussel
Prof. dr. ir. P.M. Herder	Delft University of Technology
Prof. dr. G. Kant	Tilburg University
Prof. dr. ir. V.A.W.J. Marchau	Radboud University
Prof. dr. G.P. van Wee	Delft University of Technology, reserve member

TRAIL Thesis Series no. T2015/12, the Netherlands TRAIL Research School

TRAIL
P.O. Box 5017
2600 GA Delft
The Netherlands
E-mail: info@rsTRAIL.nl

ISBN: 978-90-5584-195-0

Printed in the Netherlands

Dedicated to

All urban consumers

Preface

Yes…This is the moment when I know that in a few weeks the long wait to the 'PhD Degree' will be over. There is no doubt that learning will continue as long as I am breathing but getting a PhD is definitely a milestone in this learning journey. Countless people have contributed to this endeavour.

Ron van Duin – co-promotor of thesis, introduced me to the topic of 'Agent based modelling (ABM) in urban freight'. ABM, Ontology – were completely alien words for me at that time. Now at the end of this project I know something about them :). I would like to extend my thanks to Ron for his advice and confidence in me and my work throughout this period. My sincere thanks to Prof. Lorant Tavasszy – promotor of the thesis – for his innovative ideas and inspiring talks.

I would also like to extend my thanks to Hans Quak (TNO), Prof. Taniguchi (Kyoto University) and Prof. Marcus Wigan for giving me useful guidance at the different stages of my research. Many thanks to NWO for funding this project.

My sincere thanks to…

All the members of section TLO and faculty TBM,

Their seen-unseen efforts made my stay at TUD comfortable,
Small things like waiting in a queue for coffee will always be memorable…

Secretaries of TLO section - Ellen, Betty, Thea and Karin and TRAIL – Conchita,

Their help is appreciated in office work, planning my visa and travel,
From within my heart, I offer them a sincere 'Dank u wel'…

Fellow PhD candidates – Chao, Zack, Mo, Nicole, Karimah, Ozgul, Nick, Sander, Maarten, Allert, Diana, Yashar, Ronald, Pradyumna,

Chatting with whom I knew that in this PhD tension I am not alone,
This is the wind of PhD research where everyone gets blown…

Chris, Emile, Srirama (Section E&I, TBM), Mathijs de Weerdt (Faculty EWI),

Their explanation and talk about Java, ABM and GIS is deeply appreciated indeed,
They were very supportive in time of my need…

Bachelor and Master thesis students – Mengchang, David…,

Whose research helped my research to find new heights,
Guiding them in their research thesis was definitely a delight…

Igor Davydenko,

Whose talks were informative, sometimes weird and often enchanting,
Frequently it happened that we talked about all but urban logistics planning…

My friends – in India, Netherlands, Sweden, US, Poland,…,

Who often asked me "how much more time to complete your study?",
And then their soothing words… "It's ok…don't you worry buddy"…

Special thanks to Nayan and Ajay for summary in *Gujararti*.

My parents and family,

Who always trust me and have confidence in what I am doing,
Whose warmth and love always kept me going…

My wife Mamta,

My deepest thanks to her,
Who is the sweetest and most understanding person I have ever known,
Her love and support ensured I never felt alone…

Eternal gratitude to Buddha for peace and love…

Nilesh Anand
Den Haag, August, 2015

Content

1 Introduction

1.1. Background and motivation

World urban population is 4 billion today and is expected to reach 5 billion by 2030. In the search for a better life, employment and development, more and more people are migrating from rural areas to urban areas. This trend is the primary reason for the expansion of existing urban areas and the development of new cities (Castle and Crooks, 2006). With economic, technological and societal development, cities are witnessing a proportional increase in the number of commercial vehicles (Neto et al., 2008). For example, in Netherlands, the number of commercial vans has increased by approximately 48% from 1998 to 2003[1].

Transportation and information advances, along with globalization have made it possible to 'produce at one pole and consume at another'. The consequent dramatic expansion of trade has resulted in an abundance of product varieties that has created not only complex decision making in goods delivery systems, but also endowed roads crowded with goods transportation vehicles. In addition, logistical developments such as just-in-time and smart retailing made retailers/shop-keepers keen in maintaining inventory as low as possible in order to save inventory and storage cost. All these factors have reduced the ordering quantity and increased the frequency of delivery, finally resulting in an increased number of truck-km travelled in urban areas.

The volume of goods delivery vehicles is estimated to be 10-20% of passenger traffic. Although a fewer in number, these vehicles are bigger in size. Therefore, the contribution of congestion of freight delivery vehicles is higher than that of ordinary cars. Freight delivery vehicles contribute to 20-30% of vehicle-kilometres but, depending upon the type of pollutant, produce 16-50% of the emissions of air pollutants (Dablanc, 2007). Due to their

[1]Statistics Netherlands, http://www.cbs.nl/en-GB/menu/themas/verkeer-vervoer/publicaties/artikelen/archief/2003/2003-1277-wm.htm

size and frequency of trips, whether on the road or parked for loading/unloading, goods delivery vehicles raise road safety related issues. Noise generated by trucks is even a greater nuisance, especially when operating in a quiet neighbourhood or during night time. With the future running towards urbanization, all these problems generated due to urban goods movements compel us to think about how we should plan our cities in order to reduce these negative externalities without sacrificing the need for goods of city inhabitants.

The branch of urban transportation focusing on the research about goods transportation in urban areas is called ‘City Logistics’. This branch is also known as ‘urban freight transportation’ or ‘urban logistics’; however, the term ‘city logistics’ will be used throughout this thesis. Although many different types of transportation are linked with it, city logistics mainly focus on goods transportation in cities. It is related to pick-up and delivery of goods and parcels, service trips of vans, waste disposal activities, construction material trucks and other type of large vehicle movements. City logistics has been defined as: “the process for totally optimizing the logistics and transport activities by private companies with support of advanced information systems in urban areas considering the traffic environment, the traffic congestion and energy consumption, the traffic safety and the energy savings within the framework of a market economy” (Taniguchi et al., 2001). In other words, city logistics is the optimization of activities related to goods movement in urban areas within the framework of a market economy.

1.1.1. City logistics problems

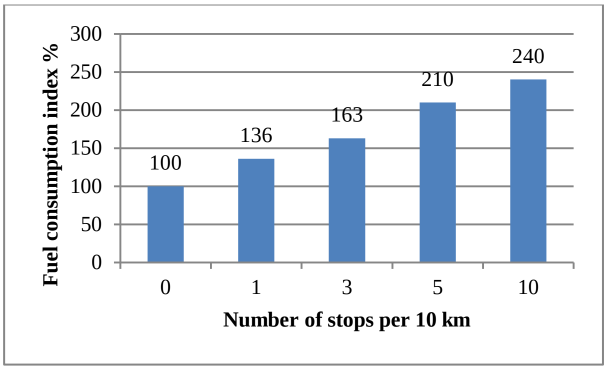
City logistics activities are mainly concentrated in densely populated areas and so accessibility, congestion, air and noise pollution are inevitable problems connected to it.

Accessibility and congestion

Congestion occurs when demand levels approach the capacity of a facility and the time required to use it increases well above the average under low demand conditions (de Dios Ortúzar and Willumsen, 2011). With the increase of congestion on the road network, the accessibility in the city decreases. Due to insufficient infrastructure (e.g. road, loading/unloading zones, parking place), access restrictions and traffic jams, cities are becoming less accessible in the past few years. One of the factors contributing to the problems of accessibility and congestion is goods delivery activities. Although good delivery vehicles are only 10-20% of the city traffic, the size of vehicles and activities of loading/unloading of goods contribute substantially to the congestion problem.

Environmental issues

Environmental issues are also connected with city logistics activities due to emissions and noise generated by freight delivery vehicles.



(Source: Volvo Truck Corporation, Environmental Affairs, June 2005)

Figure 1.1 Impact of number of stops on fuel consumption

Compared to long-distance freight vehicles, city logistics vehicles are more polluting due to the number of stops they make delivering goods. According to Figure 1.1, the fuel consumption of the vehicle increases more than two-fold when it makes five stops during a tour of 10 km. The combustion of fuels used in freight delivery vehicles produces harmful emissions including Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitrogen Oxides (NOx) and Particulate Matter (PM). In general, air and noise pollution by freight vehicles deteriorate the environment in urban areas.

Safety

Congestion on the urban road network is the result of various factors including limited space, high traffic volume, on-road parking, and pedestrians. In addition, large vehicles delivering goods to the shops in a city, high frequency of truck movements, improper parking, loading/unloading and delivery of hazardous waste give rise to safety-related problems (Russo and Comi, 2010).

In addition, often, shops and buildings do not have proper parking facilities for large goods delivery vehicles. Due to limited parking space the loading and unloading often being carried out from vehicles that are double parked which increases the risk of accidents.

1.1.2. Initiatives and policy measures in city logistics

Frequent delivery, inefficient use of trucks, poor routing, improper/unauthorized (un)loading, and air polluting vehicles are primary reasons for the above mentioned problems. Regardless of its importance in city life, city logistics has received less importance in policy making than public transportation (Visser et al., 1999; EU-Report, 2006; Van Duin and Quak, 2007). Although city logistics activities create problems in urban areas, these activities are affected by other logistics activities at regional, national or even international levels. Despite this, there are no national or regional policy initiatives to solve city logistics problems. Municipalities of big cities are taking steps towards these problems, but small cities are still unable to make any significant improvement.

Although many policy measures exist aiming at reducing negative externalities generated by urban goods movements, the field of city logistics policy making is still in its *juvenile* stage. Until recently most city logistics policy measures implemented by urban planners are directed towards restricting goods delivery vehicles instead of encouraging an efficient goods delivery system. Vehicle access restrictions (e.g. size, time and emission), urban freight villages, and consolidation centres are some of the most tried policy measures and initiatives (Muñuzuri et al., 2005). Vehicle time regulations impose specific time-window within which the goods vehicles can enter (a part of) the urban areas, and the times at which loading and unloading can take place. Vehicle weight and size regulations restrict the size and/or weight of goods vehicle that can enter (a part of) urban areas. Time-windows and weight restrictions are popular measures, implemented mainly in European cities (Muñuzuri et al., 2005). To reduce the emissions generated by freight delivery vehicles, new types of restrictions, such as eco-zoning are also emerging. With eco-zoning, only low-emission vehicles can enter a specific zone. For example, the city of Amsterdam (The Netherlands) introduced a low emission zone on the 9th October 2008. Since this regulation, only vehicles with Euro 3 with retrofit particulate trap and Euro 4 and above were allowed in the zone until July 01, 2013. After that, only vehicles with Euro 4 and above are allowed.

Urban consolidation centres (UCC) are one of the most discussed and tried initiatives by many local municipalities. UCCs can be used by delivery companies to overcome the need to make deliveries in busy urban areas. The system enables carriers to deliver their goods to the UCC, which is often located on the outskirts of the urban area. Then the goods are delivered from the UCC to the final point of delivery by a dedicated fleet of vehicles, which can be environment friendly vehicles. Browne et al. (2011) give a detailed report about characteristics of consolidation centres by reviewing UCC schemes in different countries.

Along with these popular measures, some other sporadic measures have also been considered to improve the city logistics system. For example, an effort is made to provide freight-related information by providing lorry maps in a paper form and online. These maps give information about appropriate lorry routes, freight vehicle access arrangements, loading/unloading regulations and lorry parks. Additional information is also provided about prevailing traffic conditions so that goods delivery vehicles can update their routes and avoid traffic jams.

Another example is night delivery operations using quiet, environmentally friendly vehicles. In the Netherlands and France, pilot projects were run under the program called ‘PIEK’. This solution allows access to city centres for larger vehicles when the traffic flow is limited. Performing goods delivery during night time reduces the time of delivery and consequently the presence of trucks in towns. It also implies an immediate cut of total energy consumption and pollution due to less fuel consumption during transport operations.

In London and Newcastle (UK), the authorities introduced the concept of shared lanes for lorries in appropriate circumstances where freight vehicles could use the lane dedicated to public transport buses. Also, efforts exist related to the use of technology such as information and telematics applications with a scope to increase logistics efficiency in urban areas by improving vehicle routing and scheduling.

In addition, environment friendly goods delivery vehicles are introduced on some occasions. For example, in the city of London, a trial was conducted by replacing diesel vans with electric vans and tricycles for goods delivery. Cities are also encouraging goods delivery using other non-road modes (e.g. canals, rivers and rail), wherever possible, by introducing incentives and improvements to infrastructure and facilities. The beer boat concept was introduced in the city of Utrecht in 1996 in order to perform efficient last mile operations in the delivery of beer to catering and drinking establishments located near the canals. In 2010, this beer boat was updated with an environment friendly electric boat. Besides, cities such as London and Stockholm have also introduced congestion charging system. In this system, the carrier vehicles must pay a charge in order to enter a particular geographical area at a particular time.

Table 1.1 gives a comprehensive overview of city logistics policy measures.

Table 1.1: Policy and initiatives in the city logistics domain (Source: BESTUFS 2007)

Objective	Policy Measures and Initiatives
Gaining freight industry support for freight strategies and initiatives	Freight transport partnerships
Improving journey reliability of goods vehicles	Telematics for urban goods transport Signing City logistics information and maps Road pricing Allowing night deliveries Lorry lanes or no car lanes
Assisting the journey of goods vehicle drivers and reducing goods vehicle trips and kilometres	Telematics for urban goods transport Signing Lorry routes Simplification and harmonization of vehicle weight, size and construction regulations City logistics information and maps Urban consolidation centres
Assisting freight transport companies at the point of delivery	Providing on-street loading bays Nearby Delivery Area Urban consolidation centres
Reducing the environmental impacts and the risk of accidents involving goods vehicles	Vehicle weight, size and emissions standards regulations Time regulations for goods vehicle access and loading Allowing night deliveries Environmental zones Lorry lanes Infrastructure improvements Off-street loading bays Road design and layout Encourage use of environment friendly vehicles Enforcement

The awareness about city logistics in policy making varies from country to country. Accordingly, there are many countries who still do not take city logistics problems seriously, whereas in Japan city logistics problems have been studied for the last three decades. The vast differences in perspectives are noteworthy. In Europe, most countries are aware of the problems concerning city logistics, but still a serious lack of effective policy measures prevails. Every country perceives problems of city logistics in a different way and implements measures accordingly. For instance, countries such as Belgium, Denmark, UK, Netherlands, France and Japan, consider congestion, safety, environment and accessibility as the main problems. In Germany, transport efficiency is considered as the main problem. Thus, with the different perceived problems there are different policy objectives (Allen and Eichhorn, 2007). However, it should be noted that all the problems related to city logistics are interwoven. Poor accessibility, congestion and pollution may be caused by inefficient goods delivery vehicle movements. Lower average load factors result in more goods vehicles in the city, causing environmental problems.

One of the main reasons for the ineffectiveness of city logistics policies is the methods used for policy making. For instance, UCCs were implemented in several countries to improve the efficiency of urban goods distribution processes and to reduce urban truck traffic. The boom started in 1990s, resulted in abandoning the projects because of a lack or absence of a proper business model, an insufficient number of customers and a cold response from concerned stakeholders (Russo and Comi, 2010). Many times policy measures are taken considering visible possible countermeasures to city logistics problems and many times there is no data evaluated or method used for policy measures. Surprisingly, there is no ex post policy evaluation of the effectiveness of implemented policies. In conclusion, city logistics policy mostly has been following a "Leaning by doing" approach (Visser et al., 1999) with very limited or no use of modelling or scientific approach. Also, policy making in city logistics mostly tries to deal with existing problems and no forecast are made for the future situation.

On a positive note, in recent years the efforts for mitigating city logistics problems have been showing positive results. For instance, in a study by Browne et al. (2011) on the use of electrical vehicles for goods delivery in London, the results show that the total distance travelled and the CO_2 emissions per parcel delivered fell by 20% and 54% respectively. In another example, a study by Holguín-Veras (2008) about off-hour deliveries (OHD) indicates that by providing proper financial incentives, carriers and receivers can be persuaded to shift to OHD operations. The results of the pilot study show a reduction in service time and travel time for carriers, while performing goods delivery during off-peak hours. The analyses indicate that the economic benefits of a full implementation of an OHD program are in the range of $147 to $193 million per year. However, apart from these few positive examples, measures for city logistics problems have been not met with the anticipated success. In the future, city logistics is going to create more problems with e-shopping trends. Conclusively, the initiatives and policy measures that aim at reducing city logistics problems must be decided using scientific methods and analysis that can capture the holistic view of the domain and its entities.

1.1.3. Lack of convergence among stakeholders' perspectives

The problems arising from urban goods delivery activities are often associated with organizational synergy problems between city logistics stakeholders. The idea of collaboration and cooperation does not come naturally to organizations, especially between companies offering the same or similar products or services. A step further towards this problem reveals that the city logistics domain consists of many different types of stakeholders. These stakeholders perform urban goods movement related activities in isolation. Thus, each activity might be efficient from an individual stakeholder viewpoint but the entire process of goods movement is characterised by the inefficient use of retail space, truck capacity and other resources, leading to city logistics problems. Often these stakeholders are unaware of the fact that collaboration can solve social and environmental issues and, at the same time, can be profitable for businesses. An example of this might be the sharing of retail space by two firms, each carrying popular lines of merchandise for different seasons. Each firm can achieve its objectives and also reinforces the ambitions of the other by collaborating on the ownership and utilization of retail space. Such a lack of synergy is partly attributed to a lack of information exchange between city logistics stakeholders. This example shows that one of the keys to solve city logistics related problems is to provide a platform for cooperation and collaboration.

Section 1.1.1 showed that a variety of measures can be implemented to reduce/eliminate the problems resulting due to urban goods transport. However, the outcome of the implementation shows that there are only a few successes but many failures. It is evident that measures, often, planned and implemented by local administrative authorities do not always bear fruitful outcomes in creating a sustainable city logistics domain. Along with administrative authorities, private sector stakeholders as well as city inhabitants must understand the importance of a sustainable goods transportation system and realise that this objective can only be achieved if all the stakeholders work together.

To achieve this objective, a wider picture of the city logistics domain that takes input from all associated stakeholders and generates inclusive benefits to the whole domain must be considered. Heterogeneity among stakeholders is an inherent characteristic of the city logistics domain. The domain involves eclectic stakeholders – both public and private – who interact interdependently while performing urban goods related activities. These stakeholders have different – often conflicting – objectives and issues. All these interests and issues should be addressed to carry out an effective analysis of the city logistics domain. City logistics problems are associated with the activities performed by private stakeholders and thus their solutions must involve them. Success of regulations implemented by administrative authorities is only possible if the regulations are feasible and practical for these private stakeholders. Therefore, the regulations must consider different interests and point of views of all stakeholders.

From the modelling viewpoint, the above mentioned description expresses that in order to analyse the city logistics domain, individual interests, issues and its effects on the entire domain must be included in the modelling framework. Such a model allows for the exploration of the interconnected patterns of decision making of different stakeholders. Knowledge about such decision making processes can help to understand the effects of implications of various regulations and policy measures. Here, capturing the distinctive traits of stakeholders can be done by establishing each stakeholder as an independent entity. An agent based modelling technique provides such a paradigm for modelling and developing self-adaptive distributed applications (Bonabeau, 2002). It can model a distributed decision making domain as a set of autonomous, cooperating entities who reside in a common (distributed) environment. The use of agent technology for the representation of organizations or interest groups provides a more realistic modelling of stakeholders' behaviours and city logistics processes. It allows addressing desires, beliefs, and preferences of actors in the planning processes itself and translates them into visions of actors. Such a model can be designed to achieve system wide behaviour through agents with purely localized (situated) perceptions and actions in the environment (i.e. a selected group of municipalities, products or services). The prime advantage of agent technology is its flexibility and scalability. Thus, agents can join or leave the system, the environment of the system can be changed, and also the problems of system can change as the system emerges.

Roorda et al. (2009) describe a conceptual framework for an Agent-Based Model (ABM) for the city logistics domain by developing a number of functionally specific and nearly modular objects depicting stakeholder's characteristics. These objects act as city logistics stakeholders and interact with other stakeholder-agents to fulfil their individual objectives. Combinations of their interactive movements result in an emergent complex system – a typical characteristic of the city logistics domain. Building on this, a model that represents the individual stakeholder or a group of stakeholders with similar attributes and attitudes can be developed. In so doing, the key to many unrequited policy analysis problems in the city logistics domain can be found. Notably, the precision required for developing such a system to reap all those benefits is a challenging task, and that goes without saying for the city logistics domain as well. Finally, it is essential to evaluate the usefulness of such approach and develop an appropriate framework for its successful implementation in the city logistics domain.

1.2. Research objective and research questions

The previous sections gave an overview of problems, the variety of policy measures and underlying problems of the city logistics domain. This overview indicates that for the successful solution of city logistics-related problems, we need to understand the functioning of the city logistics domain by mapping the heterogeneity of stakeholders' behaviours and their interactions. Agent-based modelling is a promising choice for understanding the complexities of city logistics activities. Using this technique, we can model the details of continuously changing city logistics characteristics in an efficient way and map the emergent behaviour of the dynamically changing city logistics processes. Accordingly, the focus of this thesis is to identify the methodological correlations between characteristics of the city logistics domain and an agent based model. Consequently, the focus of this thesis is on formulating a scheme for using agent technology for the city logistics domain. In doing so, we aim to integrate the important aspects of modelling and provide a practical guide for the development of a well-articulated and viable agent based model for the city logistics domain.

With the scope of the research defined, we formulate the objective of the thesis as:

"To explore the usefulness of the agent based modelling technique and develop a framework for the successful implementation of this technique for the city logistics domain."

City logistics problems have generated interest in city logistics related research and analysis among government, researchers, companies, and environmentalists. These studies are aimed at gaining a better knowledge of the city logistics domain in order to solve city logistics problems. A wide variety of methodologies exists in the literature for modelling the city logistics domain and solving its problems. The review of these methodical approaches can critically summarize the current knowledge, identify strengths and trends of the research in the field and finally detect the unattended gaps. The city logistics domain is characterised by heterogeneous stakeholders. Although socially and economically connected, these stakeholders interact with each other in isolation and, often, do not exchange information. The activities performed in such conditions generate inefficiencies in the system. Current models deal with city logistics problems using techniques such as optimization, statistical modelling, and system dynamics. However, researchers have not yet fully succeeded in understanding the cause and effect relationships of city logistics problems. Using the reviewed modelling efforts from the city logistics domain, we can explore the limitations of current modelling techniques. Knowledge gained from the review will allow us to identify missing links between current models and new approaches that should be more effective at solving city logistics problems. Hence, the first research question is:

Research question 1: What are the relevance and gaps in city logistics modelling research and how can these gaps be filled?

Many researchers around the world perform research on the city logistics domain. These researchers, modellers, and real-world stakeholders (e.g. shippers, retailers, carriers) use different terminologies to explain the same process or entity. To converge in their mutual understanding and to make their information exchange more efficient, a common information base for models is needed, that can help to communicate the information without any ambiguity. For this reason, an efficient mechanism is needed to categorise the heterogeneity of the city logistics domain. Such a mechanism should also be able to deal with the growing scope of the domain. In the wake of this need, the next research question is:

Research question 2: What kind of system model can capture the perspectives of multiple stakeholders of the city logistics domain?

Developing a common knowledge database covering information about the city logistics domain is a very useful step. Nevertheless, this must cover all the important data about domain entities, their attributes, and their relationships with other entities. In addition, it should also reflect the domain in the correct manner. Such a knowledge database can be used for purposes such as model building or knowledge sharing. Consequently, the database must be evaluated to determine whether the information presented is a correct representation of the city logistics domain. For this reason, the next research question is:

Research question 3: How to evaluate the scope and accuracy of the information database of the city logistics domain?

Characteristics of the city logistics domain such as heterogeneity of stakeholders, distributed decision making and dynamic interactions demand a novel modelling approach. A model developed using the new approach should be able to represent the details of continuously changing city logistics characteristics in an efficient way. Such a model should be able to help understand undergoing changes of the system. The insights gained from such a model can be used to create a knowledge base of the system and its emerging patterns for generating appropriate solutions of the problems associated with the city logistics domain.

Agent based modelling (ABM) is a powerful simulation technique that can model each entity (e.g. stakeholder, resource) as an independent agent. The agent has characteristics such as autonomy, bounded rationality, and mobility (Castle and Crooks, 2006). Agents are given specific behaviour, and they interact with other agents accordingly during the simulation. This description corresponds to the city logistics system where different stakeholders, with specific behavioural attributes, interact with other stakeholders to achieve their individual goals. Agent based models (ABMs) can thus model the domain of city logistics in a natural way. The resulting simulation can give insights into functioning of the system at the macro level as a result of activities carried out at the micro level. ABMs can be used for explanatory purposes by exploring a theory and generating hypotheses. Another purpose of ABMs could be to act as a prediction tool that can be used for extrapolation of trends, evaluation of scenarios and the prediction of future states.

Developing ABM for any domain requires scrutiny at least at two levels 1) scope 2) purpose. The scope of the city logistics domain, besides pure goods movement, can include garbage collection, the services industry, and construction related traffic. Thus, a huge variety of products are moved through urban goods movements. Multiple stakeholder types and sub-types are operating in the city logistics domain to carry out different freight related activities.

In conclusion, the city logistics domain includes a variety of strategic, technical as well as social aspects. In this situation, it is essential to draw the boundary on the amount of detail to be included in the model. The choice between adopting an explanatory or predictive approach to modelling is not mutually exclusive. This choice is dependent on the required precision of the model, which in turn, is directly related to the type of information and knowledge that is required. Thus, there are many different ways in which ABM can be developed for the city logistics domain. Therefore, the next important research question is:

Research question 4: What is a good approach for ABM design for including multiple perspectives of city logistics stakeholders?

After the model development, the next question is about validation. Validation has been the big question mark in most modelling platforms, including for ABMs. Since ABM is a simulation technique, a traditional empirical validation approach is often used. However, there are certain difficulties associated with using the traditional approach of comparing the model output with the system output. First, often the model is developed for predictive purposes and to evaluate various scenarios. However, it is not possible to get real data of the future scenario. The more important question, therefore, is the appropriateness of such empirical validation techniques. Conventional techniques are not suitable because agents do not behave in an isolated and predicable fashion. Generally, their behaviour is affected by the behaviour of other agents or the environment. Thus, the final state of the system can be achieved by following completely different patterns and paths that are difficult to predict.

Characteristics such as path dependency, emergence and multiple interactions as well as the absence of the relevant data have made the traditional empirical validation of ABMs notoriously difficult. Furthermore, the complexity of social processes does not guarantee that each simulation run follows the same sequence leading to conflict in the final output and making validation different than in a well-controlled experiment. This argument raises the last research question as:

Research question 5: How to validate an agent based model for the city logistics domain?

City logistics is a complex domain due to the wide scope of the domain, the large number of heterogeneous stakeholders and a large variety of goods movement related activities. This complexity of the domain creates inefficiencies in the system, as the stakeholders have control over only a part of the goods movement and hence cannot optimize the decisions for the entire system. Inefficiencies can be improved by different measures such as policy, business incentives that aim to limit adverse activities and decisions, and promotion of best practices in the city logistics domain. Successful measures can only be designed if the internal mechanism of the system is known. City logistics research and practical approaches towards understanding the system have not been fruitful due to limitations of the methods employed (Russo and Comi, 2011). A distinctive approach of ABM can be useful for many unrequited analysis questions of the city logistics domain that cannot be answered using traditional methodologies (Heath et al., 2009). However, it is a challenging task to determine the precision required for developing such a system to reap the benefits of agent technology. Along with multiple benefits, there are multiple challenges associated with ABM development. In fact, depending on the complexity desired and complexity of the domain to be modelled, more challenges will surface in the future.

In this Ph.D. research, a comprehensive framework is introduced that provides guidelines for the development of an agent based model for the city logistics domain. The objective of the thesis is folded out in the form of research questions where each question represents a specific research direction firmly linked with other questions. These research directions, in fact, represent elements of agent technology which are often ignored. By systematically exploring these elements, this Ph.D. research evaluates their importance and embeds them in the model development framework.

1.3. Thesis outline

The outline of the thesis is as follows.

Chapter 1 gave a general introduction of the city logistics domain by discussing problems associated with city logistics activities and implemented countermeasures. Next, characteristics of the city logistics domain were discussed that influence the ineffectiveness of policies. Finally, the chapter introduced the research objective of this Ph.D. thesis and associated research questions.

Chapter 2 reviews the literature on the city logistics domain. The chapter presents the motivation for a review and proposes the framework for classifying city logistics models. Next, the review of the models is done and results are discussed. The chapter concludes by giving an overview of the trends and gaps in city logistics modelling.

Chapter 3 describes the framework for developing an ABM for the city logistics domain. The chapter interprets the findings of the literature review and details the required characteristics of the city logistics domain. The framework suggests the development of a knowledge data model that systematically categorizes the domain-entities and their relationships. For the development of an agent based simulation model, the framework recommends using the information from the knowledge data model developed in the earlier stage. The last stage of the framework emphasises the need for validating the agent based model.

Chapter 4 conceptualizes the city logistics domain and reveals the scope of the knowledge data model or ontology. The chapter develops a city logistics ontology with its main classes/concepts followed by defining axioms and relationships between these classes. The chapter also illustrates applications of the city logistics ontology in knowledge sharing, data querying and simulation model development.

Chapter 5 deals with the quantitative evaluation and qualitative validation of the city logistics ontology. Frameworks presented in the literature for quantitative evaluation are used to compute important parameters (e.g. depth, breadth, attribute richness, inheritance richness and relationship richness) of the ontology. These parameters are very useful for understanding the scope and size of the ontology. To evaluate the substantive quality of the city logistics ontology we use the data collected from interviews with 12 real-world stakeholders as well as more than 30 city logistics models and various other sources.

Chapter 6 describes the agent based model for the city logistics domain by depicting each entity of the logistics chain as an independent agent. Entities include, for example, a firm, a store, a logistics service provider, and a truck. The model uses classes from the city logistics ontology, explained in *Chapter 4*, as building blocks. Next, the chapter details the independent behaviours and interaction protocols of the agents in the simulation. Finally, the model shows the potential of agent technology for evaluating policy measures to reduce negative effects of city logistics processes.

Chapter 7 explains the difficulties of validating agent based models using traditional techniques. The chapter proposes an original approach to validation of an agent based model by aligning the underlying decision making mechanism of the agents with that of real stakeholders. The chapter describes a validation framework based on a participatory simulation game (PSG). It proposes collecting information about stakeholders' decision making using a PSG and to validate the individual agent types for their intended decision making processes. Next, it describes a proof of concept of a game that is developed for the agent based model developed for the city logistics domain in *Chapter 6*.

Chapter 8 describes a scenario analysis for city logistics using the ABM developed in *Chapter 6*. It analyses the use of a UCC (Urban Consolidation Centre) in combination with a policy that allows only limited free deliveries for shops in the city areas. The outcomes are evaluated to show how the system emerges by decision making of multiple stakeholders. The scenario shows the usefulness of ABM in modelling multi-perspective cases within the city logistics domain.

Chapter 9 summarizes the contributions of our research by answering the research questions formulated in *Chapter 1*. Future research directions are discussed in terms of improvements and extensions. Finally, the thesis is concluded with recommendations for using this Ph.D. research for academic and practical purposes.

References

Allen, J. and Eichhorn, C. (2007). D 1.3 BESTUFS Policy and Research Recommendations III: Port cities and innovative urban freight solutions: Managing urban freight transport by companies and local authorities.

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences of the United States of America 99(Suppl 3): 7280.

Browne, M., Allen, J. and Leonardi, J. (2011). Evaluating the use of an urban consolidation centre and electric vehicles in central London. IATSS research 35(1): 1-6.

Castle, C. J. and Crooks, A. T. (2006). Principles and concepts of agent-based modelling for developing geospatial simulations.

Dablanc, L. (2007). Goods transport in large European cities: Difficult to organize, difficult to modernize. Transportation Research Part A: Policy and Practice 41(3): 280-285.

De Dios Ortúzar, J. and Willumsen, L. G. (2011). Modelling transport, John Wiley & Sons.

Eu-Report (2006). An overview of the European research and policy.

Heath, B., Hill, R. and Ciarallo, F. (2009). A survey of agent-based modeling practices (January 1998 to July 2008). Journal of Artificial Societies and Social Simulation 12(4): 9.

Holguín-Veras, J. (2008). Necessary conditions for off-hour deliveries and the effectiveness of urban freight road pricing and alternative financial policies in competitive markets. Transportation Research Part A: Policy and Practice 42(2): 392-413.

Muñuzuri, J., Larrañeta, J., Onieva, L. and Cortés, P. (2005). Solutions applicable by local administrations for urban logistics improvement. Cities 22(1): 15-28.

Neto, A. G. L. P., Galves, M. L., Lima, O. F. and Tacla, D. (2008). Challenges of urban transport problems and city logistics: Sao Paulo city center case. Urban Transport Xiv 101: 133-142.

Roorda, M., Cavalcante, R., Mccabe, S. and Kwan, H. (2009). A conceptual framework for agent-based modelling of logistics services. Transportation Research Part E: Logistics and Transportation Review.

Russo, F. and Comi, A. (2010). Measures for sustainable freight transportation at urban scale: expected goals and tested results in Europe. Journal of urban planning and development 137(2): 142-152.

Russo, F. and Comi, A. (2011). A model system for the< i> ex-ante</i> assessment of city logistics measures. Research in Transportation Economics 31(1): 81-87.

Taniguchi, E., Thompson, R. G., Yamada, T. and Van Duin, R. (2001). City Logistics. Network modelling and intelligent transport systems.

Van Duin, J. and Quak, H. (2007). City logistics: a chaos between research and policy making? A review. Urban Transport XIII-Urban Transport and the Environment in the 21st Century: 135-146.

Visser, J., Binsbergen, V. A. and Nemeto, T. (1999). Urban freight transport policy and planning.

2 Relevance of City Logistics Modelling Efforts: A Systemic Review[2]

2.1. Introduction and motivation

Notable interest in city logistics research started during the 1970s with the main focus on safety issues concomitant to heavy goods-delivery vehicles in cities (Browne et al., 2007). However, no significant research activities occurred until 1990 when researchers and policymakers started paying attention to the increasingly severe logistics problems facing urban areas. These efforts resulted in initiatives such as vehicle access restriction measures and consolidation centres (Kohler, 2004). From the beginning of 2000, city logistics associated problems have created city logistics related research popularity among government, researchers, companies and environmentalists alike. These research studies are mainly aimed at acquiring better knowledge about city logistics to support the policy making process. Revitalizing the city centre for better economy and removing the harmful effects of goods delivery vehicles are two main objectives found in city logistics research. Countries that are actively participating in urban goods related studies include France, the UK, Germany, the Netherlands, Switzerland, Italy, Sweden, the USA, Canada, Australia, and Japan. However, a wide variety of modelling approaches are used for similar challenges because of the different levels of importance assigned to them by different countries (Lewis, 1997).

Multiple studies are reported in the literature assessing city logistics related research. A review by Regan and Garrido (2001) on freight demand and shipper behaviour states that city logistics modelling is less focused domain. A review by Woudsma (2001) examines the number of planning studies that have been carried out for major Canadian cities covering the

[2] This chapter is based on the journal paper: Anand, N., Van Duin, R., Quak, H. and Tavasszy, L. (2015). Relevance of City Logistics Modelling Efforts: A Review. Transport Reviews: 1-19.

period 1974–96. The author classifies these studies according to objectives and methods used for the model development, and suggests that city size and form play an important role in influencing the characteristics of urban goods movements. Ambrosini and Routhier (2004) review city logistics models based on the country of the origin and split models into two families. One, operational models that are primarily directed towards the improvement of traffic flow management. Two, systemic models that are meant for evaluating the impact of urban logistics modifications on the traffic flows generated. The survey of urban goods modelling by BESTUFS[3] (Best Urban Freight Solutions) shows that Italy, Spain, UK, Belgium, Netherlands, Germany, and France have developed modelling platforms for city logistics related policy analysis (Browne et al., 2007). These models are primarily used to understand the qualitative and quantitative pattern of city logistics related problems and comprehend the policy impacts.

Other reviews on city logistics can be found in literature from (Anderson et al., 2005; Paglione, 2007; Behrends et al., 2008; Samimi et al., 2009; Russo and Comi, 2010). These reviews are an important step towards categorising modelling efforts in the city logistics domain. Summarising the important outcomes of these analyses: Firstly, these reviews evaluate the city logistics models based on criteria such as the country of origin, methods of modelling or status of the models. Secondly, most studies complain that city logistics modelling is a less focused domain where very little research has been carried out to understand vehicle flows. Thirdly, since the commodity flow represents actual demand whereas vehicle flow represents city logistics related traffic, elements from both flows should be present in a city logistics model.

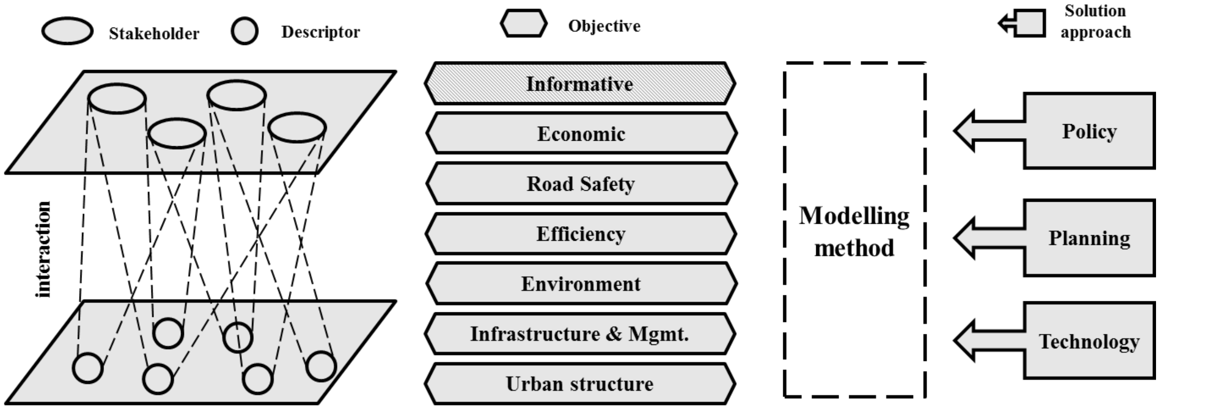
The author of this thesis suggests that city logistics studies should be assessed with respect to the stakeholders and elements associated with the demand and supply side of urban goods movements. It is also important to evaluate what aspect of city logistics (e.g. environment, economy, safety) the model is trying to improve. Accordingly, factors such as an objective of the model and a solution approach applied in the model are very important while assessing the relevance of the model dealing with city logistics problems. The author argues that these factors are evidently demonstrating the forces behind city logistics transportation and must be included for analysing city logistics models. In the following section, these factors are considered as the starting point for developing a framework for reviewing city logistics modelling literature. The remainder of the chapter is organised as follows. Section 2.2 presents a prescriptive review framework for classifying available urban goods movement models. In section 2.3, the search methodology for the selection of models for the review is explained. In section 2.4, the existing city logistics models are reviewed. Next in section 2.5, the results obtained from the review and trends in city logistics modelling are discussed. Finally in section 2.6, conclusions and suggestions for future research are reported.

2.2. Framework for the review

The review framework is partially based on the city logistics domain analysis by Ogden (1992). The author explores the city logistics domain by studying stakeholders, descriptors and objectives associated with it. While doing so, the author emphasises the importance of analysing these factors in understanding city logistics processes. Building on the same line of reasoning this thesis proposes that stakeholders from the demand and supply side exhibit the scope of the city logistics domain. For this reason, they are an important factor in evaluating the relevance of the city logistics model. The demand side of the freight activities can be

[3] http://www.bestufs.net/

expressed in terms of commodities and land use whereas the supply side can be represented by the road network, non-road network, vehicle fleet, and vehicle movement. In order to satisfy freight demand, parameters from demand and supply side interact with each other and generate descriptors. These descriptors exemplify some important parts of the city logistics processes (Ogden, 1992). Thus, reviewing the model with respect to stakeholders and descriptors gives an indication of the breadth (e.g. coverage of domain or scope) and depth (e.g. detail level or scale) of the model respectively.



(Source: Derived from (Ogden, 1992) and (Browne et al., 2007))

Figure 2.1 The review framework for city logistics models

The majority of stakeholders associated with the city logistics activities are private stakeholders. Under the rubric of "Supply chain management", these stakeholders optimize their total logistics cost, of which city freight distribution is only a small segment. In addition, although being the source of external costs (e.g. pollution, road safety, and urban structure) these private stakeholders usually only take into account their internal costs. By not attending to the inefficiency of the system, assuming that the effort from a single stakeholder will not result in any major improvement in the system efficiency, the responsibility for efficient orchestration of city logistics related activities falls on the government. Consequently, the objective of the city logistics analysis is to internalize the external costs. Ogden (1992) divides the total costs into six identifiable objectives mentioned in Figure 2.1. Thus, the third dimension for evaluating the model is the number of objectives considered in the model.

These objectives can be achieved so as to make city logistics system more efficient in various ways. Browne et al. (2007) classify potential solution approaches in categories such as consolidation, city logistics facilities, modes involved in city logistics transport, technology aspects and policy. Since mode change or mode availability, consolidation facilities and other city logistics facility are related to the planning of infrastructure; the first three categories can be merged into one category called planning (of infrastructure). Accordingly, solution approaches for achieving city logistics objectives can are grouped into three broad categories of planning, policy and technology. Thus, the fourth criterion for the review framework is the solution approach adopted in the city logistics model.

A variety of methodologies exists for modelling the city logistics domain at different levels and for different purposes. In a broad perspective, city logistics models are developed to describe the working of the city logistics activities (i.e. descriptive models). They are also used to prescribe solutions or measures to improve the efficiency or reduce negative effects of goods delivery activities (i.e. prescriptive models). In addition, they can be used to foresee the changes in the city logistics domain (i.e. predictive models). Different types of methods are used to developed city logistics models. There are econometric models that use disaggregate or aggregate data of the system to formalize relationships between city logistics variables in the form of mathematical equations and estimate system outcomes for different scenarios. Optimization is another popular method for developing city logistics models. Optimization models focus on prescribing the solution that is best for the system under certain assumptions and constraints. However, these models are time independent and do not consider the interdependence of activities or processes. Simulation models fill this gap by modelling a city logistics system that is time dependent, and where the inputs and outputs of the processes are dependent on other processes. Notably, models are also developed by combining different methodologies to take benefit of each approach. The scope of the domain representation (e.g. stakeholders, processes, interdependency of decision making) varies between models and is based on the objectives and methods of the model.

2.3. Search methodology

The sources used for this review consist of scientific refereed journals, textbooks, doctoral dissertations and refereed conference proceedings. Publications in languages other than English and non-refereed professional publications were not included. This search is based on keywords such as ‘city logistics’, ‘urban goods movement’, ‘urban freight transport’, ‘urban distribution’, ‘urban logistics’, ‘city distribution’, ‘sustainable freight transport’, ‘sustainable transport development’. In addition, we consider research that deals with the analysis of the city logistics domain from a societal point of view that includes conceptual models, analytical works and fully developed models using relevant data. In this view, only those models that consider the overall impact on the city logistics domain are included. The models dealing with improving the efficiency of a specific supply chain without considering the overall impact on the city logistics domain are not considered.

To identify relevant articles that could describe city logistics modelling efforts, computerized databases including Proquest, Emerald, Business Source Premier, Google Scholar, Science Direct, Scopus and the Web of Science were searched. Conference proceedings from City Logistics Conferences, the Transportation Research Board Conference and the World Conference on Transport Research (WCTR) were also searched. Finally, project materials from BESTUFS about surveys on transport and delivery of goods in urban areas were considered.

2.4. City logistics modelling efforts

In total 31 city logistics models were selected from literature based on the search methodology described in the previous section. The selected models are evaluated using the following four factors of the review framework:

- Stakeholder: indicates the scope of the model by assessing the types of stakeholders considered
- Descriptor: indicates the scale of the model by assessing the type of activities considered
- Objective: indicates the type of problem the model is trying to solve and,
- Solution approach: indicates the approach implemented to achieve the objective at stake.

2.4.1. Stakeholder

City logistics traffic is an outcome of interactions between stakeholders from supply and demand sides. Thus, to analyse the urban goods movements one should understand and analyse attributes and behaviours of different stakeholders. Stakeholders in the city logistics domain can be roughly divided into four broad categories (Taniguchi et al., 2001).

- Administrator: includes authorities at local, regional or national (or even international) level that can influence urban goods movements (e.g. traffic authorities, infrastructure authorities, municipalities, and railway terminal/port authorities). Road users and residents are not directly involved in city logistics activities; however their objectives align with those of the administrator and thus we assume that they are being represented by administrators.
- Supplier: includes stakeholders who supply commodity or service (e.g. producers, wholesalers, intermediate retailers, and traders)
- Carrier: includes stakeholders connected with activities of distribution of goods (e.g. trucking firms, 3PL, forwarders, and truck drivers)
- Receiver: includes stakeholders who receive goods or service (e.g. shopkeepers, restaurants, office, house, and individuals)

Although all stakeholders share one common goal- the delivery of goods from the supplier to receiver - their other individual interests often conflict. In addition, due to lack of any concrete incentive, private stakeholders do not proactively work towards reducing system cost but work towards achieving their personal objectives (sometimes even at the cost of system efficiency). In this situation, only the administrator is interested in achieving the overall objective, i.e. reducing the total social cost (Ogden, 1992), because the administrator is responsible for an economically sound, safe and pollution free city. This interest in total social cost reduction clarifies why most city logistics modelling efforts are directed from an administrative point of view. Additionally, in city logistics literature, often models are developed using statistical information such as traffic counts and trade flow. These models do not include behaviour or attributes of private stakeholders. Although the behaviour of an administrator is not included explicitly, we consider that the modelling is carried out from an administrator's point of view since the solution approaches are directed by an administrator without any reactions from private stakeholders. For example, a planning model by Southworth (1982) examines the implications of alternative freight terminal zone location patterns considering trip generation and distribution. A model by Visser and Maat (1997) evaluates the effectiveness of different measures solely from an administrator's point of view to solve environmental and accessibility problems in urban areas.

For the private sector stakeholders 'total logistics cost' is of the highest interest and not the 'specific transportation cost'. Under the banner of 'Supply chain management,' private stakeholders optimize their total logistics cost – specific to their supply chain, of which city freight distribution is only a small segment. Thus, mostly, modelling efforts by private stakeholders are found more in supply chain literature and are not limited to city logistics related literature (Hong and Yeh, 2012). However, there exist models that understand the importance of including behaviour and attributes of private sector stakeholders, which is a more realistic way to perform city logistics analysis. For instance, J Holguín-Veras (2000) proposes a framework for 'integrative freight market simulation' that considers producers, carriers and customers for city logistics analysis. The planning model by Crainic et al. (2004) considers carriers and their attributes to improve the efficiency of city logistics activities. A framework introduced by Hensher and Puckett (2005) investigates the effectiveness of interactions between a shipper and a carrier who try to reduce the cost of city freight distribution. The Tokyo Model (Wisetjindawat et al., 2007) was developed on the basis of the GoodTrip model (Boerkamps et al., 2000). The Tokyo model includes carrier selection process and vehicle routing process of a shipper and a carrier respectively. Russo and Comi (2010) consider different types of receiver (e.g. family/individuals and business/shopkeepers) in their model.

It is clear that heterogeneous stakeholders make the city logistics domain a distributed decision making system. Current modelling approaches include stakeholders in a static way. Therefore, they do not consider stakeholder responses in decision making. Consequently, the challenge is to include a variety of stakeholders to incorporate the dynamics of their decision making in the model.

2.4.2. Objective

The Institute of City Logistics defines city logistics as “the process for totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, the traffic congestion and energy consumption within the framework of a market economy.” City logistics focuses on improving the efficiency of urban goods related transportation while reducing traffic congestion and lessening environmental impacts. According to Ogden (1992), city logistics has the overall objective to reduce the total social cost of urban goods movements. The author further divides this overall objective into six specific objectives. Table 2.1 gives a comprehensive overview of these objectives. One can observe here that the objectives are intermingled. Therefore, modelling the city logistics domain to achieve one objective also affects other objectives positively or negatively.

Table 2.1 Overview of objectives for city logistics analysis (Source: Ogden, 1992; Woudsma, 2001)

Objective	Description
Economic	Develop and improve the freight system towards improving the local, regional and national economy Focus on trade-exposed sectors of the urban economy Focus on ports and intermodal facilities
Efficiency	Minimization or reduction in transport operation costs related to en-route travel, end-point activity and energy Focus on congestion; role of freight and costs to freight Road network deficiencies including road design and geometry, maintenance, signage, local area traffic management and arterial capacity End-point costs associated with loading and unloading, parking, terminal activities, hours of operation and site access and egress Energy costs associated with vehicle speed and character and shipment type
Road safety	Minimization of property damage, injury- and fatality-related accidents Focus on policy related to traffic management, road design, vehicle design, driver training and land-use
Environmental	Focus on mitigation of noise, air and vibration pollution Perceived threat of large vehicles and intrusive activity in residential areas
Infrastructure and Management	Explore government influence through regulations, pricing controls, taxation and investment Road construction and maintenance and its relationship with the freight sector
Urban structure	Focus on interaction between freight facilities and urban structure including interaction between freight and urban structure, city size and its effects on freight costs, and freight as a user of urban land

Efficiency improvement can be achieved in a wide range of city logistics activities. For this reason, efficiency is one of the most addressed objectives in the city logistics models. For example, a model by Young et al. (1983) focuses on efficient planning of infrastructure to efficiently divide traffic between rail and road. Xu et al. (2003) developed a Dynamic Freight Traffic Simulation (DyFTS) model to improve the efficiency of the goods delivery operations. Crainic et al. (2009) described the general two-tiered city logistics system and introduced the ‘day before tactical planning system’. This system focuses on the carrier’s selection of routes and the scheduling the vehicles to create an efficient city logistics system.

Pollutants emitted from goods delivery vehicles deteriorate air quality in cities. Most vehicles also create noise pollution during its operation. A model by Visser and Maat (1997) emphasis on achieving the environmental objective by reducing environmental externalities caused by city logistics activities. The economics objective deals with development and improvement of the freight system towards expanding the local, regional, and national economy. Harris and Liu (1998) carried out input–output modelling of the urban and regional economy which can be helpful for planning and policy making at the local level.

Exploring the administrative influence through regulations, pricing controls, taxation and investment is the focus of the infrastructure and management objective. Focusing on this objective, Hensher and Puckett (2005) set out a framework to investigate the behavioural response of stakeholders and explore regulations, such as congestion fees, as a way of improving the efficient flow of traffic in cities. The analytical model by Holguín-Veras (2008) analyses the necessary conditions for the road pricing and off-hour delivery. The model indicates that the most potent stimulus for off-hour delivery is to introduce freight road pricing in combination with financial incentives. It is important to minimise property damage, injury, and fatality-related accidents occurring due to freight vehicles. Likewise, attention must be paid to urban structure planning so that it facilitates city logistics activities. A single model - FRETURB (Routhier and Toilier, 2007) - is reported that explores the association between vehicle parking and freight facility. Unfortunately, there was no model found that incorporates road safety in city logistics context.

There is a group of models that use real data for the city logistics domain analysis. These models do not work towards any tangible objective but mainly create knowledge about the city logistics domain by capturing the current state of urban goods movements. For example, the model by Hunt and Stefan (2007) develops tours of commercial vehicles using generation rates and vehicle allocation models. The model by Kanaroglou and Buliung (2008) addresses the contribution of urban commercial vehicle movements to emissions of HC, CO, NOx and PM at the aggregate and link levels. Consequently, this type of model can be used for various scenario analyses to understand the factors affecting urban goods movement. Knowledge gained from the analysis can be used to improve city logistics related activities.

The system objectives are interwoven and interdependent, and can be achieved if all stakeholders work towards it collaboratively. However, city logistics stakeholders have their personal objectives/interests. Some of these objectives are consistent with the system objective while others are difficult to achieve simultaneously. For the analyses of the city logistics domain, these objectives must be represented in a model along with the associated stakeholders and their activities. Importantly, the stakeholders must have knowledge about each other's objectives and activities. Unfortunately, in traditional modelling approaches, the conceptual model used as a base of the system model, is developed informally or in an ad hoc fashion. Use of such an informal conceptual model results in inconsistencies between the users' concepts and the model developed. Therefore, a common knowledge database representing different terminologies and the types of decision making must be developed to model the domain correctly.

2.4.3. Descriptor

The urban goods movements are the result of stakeholders' interactions to carry out goods delivery related activities. During the interactions, in fact, several variables from demand and supply side interact and define system descriptors. For example, the interaction between variables 'land use' and 'vehicle' results in a system descriptor 'building site and design'. This descriptor refers to compatibility (or lack because of that) between a site or building design and the vehicles which serve that site (refer Table 2.2 for an explanation of all descriptors). The descriptors are indicators that can be observed, measured and analysed. While analysing urban goods movement we, in reality, analyse one (or more) of these descriptors. Analysing the effects of different descriptors, one can gain knowledge about how the system or a part of the system works and how or modify the system to achieve different objectives.

Since the effects of goods delivery activities are visible in traffic, 'traffic flow' is clearly the most used descriptor. With the widespread use of a 4-step approach freight generation, trip generation, and commodity flow are widely used descriptors. A model by Southworth (1982) uses descriptor 'location' patterns of freight terminals for a planning purpose. Similarly, Crainic et al. (2004) uses 'location' of distribution centres (i.e. satellite) to improve goods distribution and reduce its impact on the environment. Other models (Xu et al., 2003; Holguin-Veras et al., 2004; Taniguchi and Shimamoto, 2004; Wisetjindawat et al., 2007) consider 'loading rate' while generating tours for goods delivery. One instance of the use of 'modal transfer' is found in the model by Young et al. (1983). The model considers the behaviour of shippers while selecting the mode of transportation.

Table 2.2 City logistics descriptors

Variable 1	Variable 2	Descriptor	Explanation
Commodity[d]	Land use[d]	Freight generation	Generation of commodity flow by origin and destination land uses or economic activities.
	Road/Non-Road network[s]	Commodity flow	Flow of commodities over the transport network, by mode.
	Vehicle[s]	Vehicle design	Technicalities presents in a vehicle, for example: low emission, small size vehicle. (Size, engine)
	Vehicle movement[s]	Vehicle loading	The loading rate of commercial vehicle used for goods transportation in urban areas.
Land use[d]	Road/Non-Road network[s]	Location	Location within the urban area for the various freight generating land uses.
	Vehicle[s]	Building and site design	Compatibility (or lack thereof) between site or building design and the vehicles which serve that site.
	Vehicle movement[s]	Trip generation	Number of truck trips generated by particular land use categories. This variable can also give information about VKT (vehicle kilometre travelled), TLD (Trip length distribution) etc.
Road network[s]	Non-Road network[s]	Modal transfer	Interaction between different modes available for freight transportation.
	Vehicle[s]	Traffic design	Design of transport infrastructure for the vehicles using transport facilities.
	Vehicle movement[s]	Traffic flow	Movement of freight vehicles on the road network, or its equivalent for other networks
Vehicle[s]	Vehicle movement[s]	Industry structure	Freight industry which can include shipper, carrier, retailer and receiver. It accounts for interactions between different stakeholders and their decision making structure.

d= demand side variable, s= supply side variable

Likewise, a single model – FRETURB – includes the ‘building and site design’ descriptor to analyse the effects of parking facilities on city logistics activities. Many modelling approaches use different names for the descriptors, for example the GoodTrip model (Boerkamps et al., 2000) and the Tokyo model (Wisetjindawat et al., 2007) consider supply chain structure, which is mentioned here as ‘Industry structure’. In addition, depending on the stakeholder and specific objective of the model, the descriptor can be very specific. For example, a model to understand the effect on the environment can consider the level of pollutant as a descriptor. At the same time, the number of trucks or total kilometres travelled can also be considered to measure the level of pollution. For this review, these specific descriptors are placed closely to their related descriptor-category. Clearly, vehicle design is the largely missing descriptor in city logistics models.

Descriptors indicate the diversity of activities considered in the model. To effectively include decision making processes of the stakeholders, the relationships between the stakeholders and their activities must be clearly marked. Additionally, the effect of certain activities on other activities must be integrated into the model to represent the city logistics domain in a realistic manner. Current modelling efforts fall short in this aspect and thus a different modelling approach is needed that can incorporate such interdependencies in the model.

2.4.4. Solution approach

A variety of solution approaches is observed in the literature trying to deal with city logistics related problems. Based on its focus, these approaches can be broadly classified into three categories.

- Planning: The model analyses/implements (infrastructure) planning decisions (e.g. planning of roads, loading/unloading sites, parking places) and/or its effect on city logistics activities.
- Technology and information: The model implements and/or analyses a technology measure (e.g. ITS, providing real-time traffic/congestion information) and its effects on urban goods movements.
- Policy: The model implements policy measures (e.g. weight and size restrictions) and analyses its effect.

The city logistics models implementing the planning approach analyse how planning (traffic, infrastructure, port, and terminal) can enhance the city logistics related processes. Crainic et al. (2004) present modelling framework to identify important planning and operational issues related to the planning of distribution centres for improving urban goods delivery activities by goods consolidation. The GoodTrip model (Boerkamps et al., 2000) implements planning initiatives such as an urban distribution centre and the underground logistics system and analysed its effect on the city logistics system.

Considering technological advancement in a city logistics context, Xu et al. (2003) describe the Dynamic Freight Traffic Simulation (DyFTS) model. DyFTS is used for studying the effects of highly developed information technologies and logistics strategies on the characteristics of vehicle trips for city logistics transportation. Taniguchi and Shimamoto (2004) present a dynamic vehicle routing and scheduling model that incorporates advanced information systems or intelligent transport systems (ITS) in urban areas. The model by Figliozzi (2006) investigates the impact of technological changes on urban commercial trips by commercial activity routing. The author describes how information and communication technology can create an impact on the truck traffic flows.

Table 2.3 Review result of urban freight models

Author	Stakeholder				Objective							Descriptor											Solution		
	Shipper	Carrier	Administrator	Receiver	Economic	Efficiency	Road-safety	Environment	Infr. & Mgmt.	Urban structure	Knowledge	Freight generation	Commodity flow	Vehicle design	Vehicle loading	Location	Building & site design	Trip generation	Modal transfer	Traffic design	Traffic flow	Industry structure	Planner	Policy	Technology
(Southworth, 1982)			x						x							x							x		
(Young et al., 1983)	x					x					x								x						
(Visser and Maat, 1997)			x					x										x			x				
(Harris and Liu, 1998)			x		x							x											x		
(Holguín-Veras, 2000)	x	x		x							x		x								x				
(Boerkamps et al., 2000)	x	x	x	x		x		x				x	x		x			x			x	x	x	x	
(Russo and Comi, 2002)				x							x		x					x			x				
(Xu and Hancock, 2003)		x				x		x				x			x			x			x				x
(Crainic et al., 2004)		x	x			x									x	x				x			x		
(Holguín-Veras et al., 2004)	x	x									x				x			x				x			
(Taniguchi and Shimamoto, 2004)		x	x			x		x							x			x			x			x	x
(Taniguchi and Tamagawa, 2005)	x	x	x			x		x	x						x						x			x	
(Hensher and Puckett, 2005)	x	x	x	x		x			x												x	x		x	
(Friesz and Holguin-Veras, 2005)		x				x												x					x		
(Figliozzi, 2006)		x				x															x				x
(Yannis et al., 2006)			x					x	x												x			x	

Table 2.3. Review result of urban freight models - continued from previous page

Author	Stakeholder				Objective							Descriptor											Solution		
	Shipper	Carrier	Administrator	Receiver	Economic	Efficiency	Road-safety	Environment	Infr. & Mgmt.	Urban structure	Knowledge	Freight generation	Commodity flow	Vehicle design	Vehicle loading	Location	Building & site design	Trip generation	Modal transfer	Traffic design	Traffic flow	Industry structure	Planner	Policy	Technology
(Figliozzi, 2007)			x			x												x			x			x	
(Hunt and Stefan, 2007)			x								x							x			x				
(Wisetjindawat et al., 2007)	x	x	x			x					x	x	x		x			x			x	x			
(Routhier and Toilier, 2007)			x		x	x		x	x	x						x	x	x			x		x	x	
(Wang and Holguín-Veras, 2008)			x								x							x							
(Kanaroglou and Buliung, 2008)			x								x							x			x		x		
(Holguín-Veras, 2008)		x	x	x		x		x	x												x	x		x	
(Friesz et al., 2008)	x	x		x		x						x						x				x			
(Muñuzuri et al., 2009)			x								x	x	x								x				
(Crainic et al., 2009)		x	x			x									x	x					x		x		
(Gentile and Vigo, 2009)			x								x	x	x					x			x				
(Donelley et al., 2010)		x	x						x		x		x		x			x	x				x		
(Van Duin et al., 2010)	x	x				x									x			x				x			x
(Russo and Comi, 2010)				x							x		x					x			x				
(Muñuzuri et al., 2010)			x								x										x				
Total	9	16	21	7	2	16	0	8	7	1	13	7	8	0	10	4	1	18	2	1	21	7	9	8	4

The administrator uses policy as an instrument to alter the way private stakeholders perform their domain activities leading to an efficient and sustainable city logistics system. A variety of policy measures is tested using the city logistics models. Taniguchi and Tamagawa (2005) simulate test road network by implementing policy measures such as truck ban and tolling on an urban expressway. Yannis et al. (2006) investigate the effects of implementing delivery time restrictions on freight delivery vehicles on urban traffic. The authors conclude that while delivery restrictions during peak traffic hours lead to traffic and environmental improvements during these periods, a respective deterioration is observed outside these periods, when the restricted delivery activities need to be accommodated. A model by Holguín-Veras (2008) considers three policy combinations of road pricing and financial incentives to estimate its impact on stakeholders' profit and consequently to get insight on their reactions. A complete summary about solution approaches considered in city logistics models can be found in Table 2.3.

2.5. Results and discussion

In the previous section, city logistics models were reviewed with respect to stakeholder involvement, descriptor choice, the objective pursued, and implemented solution approaches. The result of this exercise is presented in Table 2.3. The analysis of the result gives important insights into the state-of-the-art of city logistics models. For example, from Table 2.3, we can see that the administrator is the most examined stakeholders in the city logistics models. 21 out of 31 models include various aspects of the behaviours and the decision making processes by an administrator. Freight delivery vehicles are assumed as the main source of city logistics problems and therefore 16 out of 31 models include a carrier stakeholder in the analysis. Supply side stakeholders (i.e. suppliers and receivers) are relatively less represented in city logistics models. Nine models include a supplier stakeholder whereas less than one-third of the models consider decision making processes of a receiver stakeholder.

There are six objectives mentioned in the review framework where each objective aims at improving some aspect of the city logistics domain. Efficiency is the most addressed objective in city logistics modelling literature. 16, out of 31, models consider improving the efficiency of the system. Negative effects of urban goods movement activities are reflected by environmental pollutants such as CO_2 and NOx. In order to create environmentally sustainable cities, eight models are developed considering the environmental objective. Aiming at exploring government influence using infrastructure planning and management, seven models address the infrastructure objective. Despite its importance as a major economic activity, only two models - (Harris and Liu, 1998; Routhier and Toilier, 2007)- are reported dealing with the economic objective in a city logistics setting. Similarly, only the FRETURB (Routhier and Toilier, 2007) model reportedly explores the location and design of city logistics facilities under the urban structure objective. Issues related to safety are also important; however no model is found dealing with the road safety objective in our literature search. Finally, there is a big group of models (13 out of 31) that do not deal specifically with any of the six objectives. Instead, they are aimed at mapping city logistics activities and creating a knowledge base to understand the factors affecting urban goods movements. Such models serve as a laboratory for analysing a variety of policy and scenarios for the city logistics domain.

Review of descriptors illustrates that the existing models consider a wide range of descriptors for evaluating the city logistics domain. Traffic flow, commodity flow, freight generation, and trip generation are the most widely used system descriptors. Since most problems and inefficiencies associated with city logistics activities are visible at the traffic level, traffic flow is considered in more than half of the models (21 out of 31). Following the ‘four-step approach’ from passenger modelling, descriptors such as commodity flow, freight generation and trip generation are used relatively more frequently. Most of the remaining descriptors are used only occasionally – averagely once or twice. For example, a descriptor ‘building and site design' that is useful to get insight into the source of problems related to two-lane parking and (un)loading accessibility, is used only by a single model (Routhier and Toilier, 2007) . Unfortunately, there was no model found that deals with vehicle design in the context of city logistics.

The administrator is concerned with transport planning and infrastructure management. Moreover, administrators can also influence urban goods movement related activities by introducing policy regulations. As the review of stakeholders suggests, the administrator is the most examined stakeholder in the city logistics models. For this reason, planning (nine models), and policy (eight models) are widespread solution approaches found in the city logistics models. On the other hand, only four models considered technology as a solution for city logistics-related problems. Improving city logistics activities using technology includes improving vehicle routing, availability of real-time information about the road network. Since, the decisions about routing and goods delivery patterns are taken by the private stakeholders; the technological solution approaches are often implemented by the private stakeholders. The review result suggests that current city logistics models marginally represent private stakeholders and their decision making processes. In this view, fewer models are considering technology as a solution approach.

2.6. Conclusions and suggestions for future research

Apart from covering the state-of-the-art decision models available at present, this review analysed city logistics models with respect to four factors. One, the stakeholder represented in the model. Two, the activity descriptor. Three, the objective of the model, and four the solution approach implemented to achieve the objective. The author believes that these factors are important and serve as a base for an effective analysis since it can comprehensively carry out a review of city logistics models in terms domain coverage, scale, associated problem and remedy approach. From our analysis of the efforts currently being reported for city logistics models and the potential still left unused, we draw the following conclusions.

Conclusions

The vast majority of the modelling efforts consider an administrator as a sole stakeholder within the city logistics domain. Most literature on city logistics modelling sums up how an administrator can create efficient city logistics transportation without considering inputs from other active stakeholders. There are only a few models found where all stakeholders and their influence in the city logistics domain are included. City logistics activities are the result of interactions among different stakeholders. Therefore, it is essential to investigate and incorporate the specifics of decision making methods of all stakeholders in city logistics modelling.

City logistics models need to widen the descriptors choices used in modelling. Since most negative effects related to city logistics transportation are visible in transportation, most models consider trip generation and traffic flow as the primary (often only) descriptors. This point is a missing-link because the generation of city logistics traffic is largely dependent on other system descriptors from earlier stages of the decision processes; for example modal transfer and vehicle loading. For this reason, in order to understand the causes of city logistics traffic, other descriptors must be considered. It is interesting to observe that the missing descriptor of 'vehicle design' has gained importance in a more recent study of electric vehicles by Browne et al. (2011).

A variety of cost associated with urban goods movements can be translated into six broad objectives as mentioned by Ogden (1992). The vision of creating economically and environmentally sustainable cities can only be satisfied if all the six objectives are attended. The review suggests that city logistics models need a broader emphasis on multiple segments of the system. Majority of current modelling articles aim at improving the efficiency of goods delivery activities and reducing negative effects on the environment. Few models explore the infrastructure objective, mostly by analysing the congestion charging on goods delivery vehicle. However, other important aspects of the domain such as economy, road safety, and urban structure still need to be explored in conjunction with other objectives.

Three broad categories of solution approach are reported in city logistics modelling literature; policy, planning, and technology. Often policy measures are implemented considering visible possible countermeasures to city logistics problems without any data evaluated or method used. These policies, often, incite negative incentive (e.g. time-window restriction, congestion charging) and therefore policies providing positive incentives should be devised and tested for its outcomes. Apart from building new infrastructure, planning and management of current freight facilities can also improve the urban goods system. Similarly, technological advancements (e.g. dynamic traffic information, low-emission, low-noise truck) can reduce city logistics related congestion and pollution effects. Models in city logistics are falling short of exploring these types of solutions.

Future research directions

A continuing opportunity for the development of better city logistics models exists, and the insights identified through this review will help extend the future research in the right directions. Based on the knowledge gained from reviewing the models and the conclusions, we put forward following future research possibilities.

The review factors of the frameworks – stakeholder, descriptor, objective and solution approach – are interconnected and understanding these interconnections can help in selecting modelling parameters. For instance, a relational database about how various solutions affect city logistics objectives can be helpful selecting suitable solution approach for future models. Likewise, the association between stakeholders, descriptors and objectives can help selecting correct stakeholders and activities to model. Therefore, future research should focus on exploring the interconnection between these factors.

The outcomes of the review also suggest that characteristics of the city logistics domain and weaknesses of current models demand a new modelling approach. The new approach should be able to map the details of continuously changing city logistics characteristic in an efficient way and coin emergent behaviour of the dynamically changing city logistics processes and its stakeholders. For that, an effort should be made to understand city logistics network establishing each stakeholder as an independent entity (Panayides, 2002). This approach can be useful in solving city logistics problems by browsing through the possibility of cooperation among all stakeholders. Implementing policy or regulation for the city logistics domain can be advantageous or disadvantageous to associated stakeholders. Therefore, it is important to incorporate viewpoint of the multiple stakeholders in the analysis (Macharis et al., 2012). Similarly, it is also very important to find common platform for collaboration and communication between public and private stakeholders (Lindholm and Behrends, 2012). Roorda et al. (2009) describe a conceptual framework for such an approach, agent based modelling (ABM). In ABM, by developing a number of functionally specific and nearly modular objects representing stakeholders' and their decision making processes, one can model the interactions among heterogeneous stakeholders. Combinations of agents' interactive movements result into an emergent complex system – a typical characteristic of the city logistics domain. In last few years, researchers (Taniguchi and Tamagawa, 2005; Donelley et al., 2010; van Duin et al., 2012) have started exploring city logistics dynamics using the ABM technique. However, this trend is just starting, and there is a long way to go before we can reap the benefits of this new modelling paradigm.

Lastly, the dynamic nature of the city logistics domain and variant of the problem from one city to another makes it very difficult to come up with some standard framework for city logistics modelling. However, guidelines for modelling the city logistics domain can be provided by combining the common features and activities of the city logistics domain in the form of a data model (i.e. ontology). Such an ontological description provides a basic model where modifications of object and data properties are possible. The introduction of such model can converge the modelling efforts and facilitate the transformation of the knowledge regarding the city logistics practice.

References

Ambrosini, C. and Routhier, J. (2004). Objectives, methods and results of surveys carried out in the field of urban freight transport: An international comparison. Transport Reviews 24(1): 57-77.

Anderson, S., Allen, J. and Browne, M. (2005). Urban logistics--how can it meet policy makers' sustainability objectives? Journal of Transport Geography 13(1): 71-81.

Behrends, S., Lindholm, M. and Woxenius, J. (2008). The Impact of Urban Freight Transport: A Definition of Sustainability from an Actor's Perspective. Transportation Planning and Technology 31(6): 693 - 713.

Boerkamps, J., Van Binsbergen, A. and Bovy, P. (2000). Modeling behavioral aspects of urban freight movement in supply chains. Transportation Research Record: Journal of the Transportation Research Board 1725(-1): 17-25.

Browne, M., Allen, J. and Leonardi, J. (2011). Evaluating the use of an urban consolidation centre and electric vehicles in central London. IATSS research 35(1): 1-6.

Browne, M., Piotrowska, M., Woodburn, A. and Allen, J. (2007). Literature Review WM9: Part I-Urban Freight Transport.

Crainic, T., Ricciardi, N. and Storchi, G. (2009). Models for evaluating and planning City Logistics systems. Transportation science 43(4): 432-454.

Crainic, T. G., Ricciardi, N. and Storchi, G. (2004). Advanced freight transportation systems for congested urban areas. Transportation Research Part C: Emerging Technologies 12(2): 119-137.

Donelley, R., Wigan, M. and Thompson, R. (2010). A hybrid microsimulation model of urban freight travel demand.

Figliozzi, M. (2006). Modeling Impact of Technological Changes on Urban Commercial Trips by Commercial Activity Routing Type. Transportation Research Record: Journal of the Transportation Research Board 1964(-1): 118-126.

Figliozzi, M. (2007). Analysis of the efficiency of urban commercial vehicle tours: Data collection, methodology, and policy implications. Transportation Research Part B: Methodological 41(9): 1014-1032.

Friesz, T. and Holguin-Veras, J. (2005). Dynamic Game-Theoretic Models of Urban Freight: Formulation and Solution Approach. Methods and Models in Transport and Telecommunications: Cross Atlantic Perspectives: 143.

Friesz, T. L., Mookherjee, R., Holguín-Veras, J. and Rigdon, M. A. (2008). Dynamic pricing in an urban freight environment. Transportation Research Part B: Methodological 42(4): 305-324.

Gentile, G. and Vigo, D. (2009). Movement generation and trip distribution for freight demand modelling applied to city logistics. Relation 10(1.111): 5200.

Harris, R. and Liu, A. (1998). Input–output modelling of the urban and regional economy: the importance of external trade. Regional Studies 32(9): 851-862.

Hensher, D. A. and Puckett, S. M. (2005). Refocusing the Modelling of Freight Distribution: Development of an Economic-Based Framework to Evaluate Supply Chain Behaviour in Response to Congestion Charging. Transportation 32(6): 573-602.

Holguín-Veras, J. (2000). A framework for an integrative freight market simulation. 2000 IEEE Intelligent Transportation Systems, 2000. Proceedings: 476-481.

Holguín-Veras, J. (2008). Necessary conditions for off-hour deliveries and the effectiveness of urban freight road pricing and alternative financial policies in competitive markets. Transportation Research Part A: Policy and Practice 42(2): 392-413.

Holguin-Veras, J., Thorson, E. and Ozbay, K. (2004). Preliminary Results of Experimental Economics Application to Urban Goods Modeling Research. Transportation Research Record: Journal of the Transportation Research Board 1873(-1): 9-16.

Holguín-Veras, J., Thorson, E. and Ozbay, K. (2004). Preliminary results of experimental economics application to urban goods modeling research. Transportation Research Record: Journal of the Transportation Research Board 1873(1): 9-16.

Hong, I. and Yeh, J.-S. (2012). Modeling closed-loop supply chains in the electronics industry: A retailer collection application. Transportation Research Part E: Logistics and Transportation Review 48(4): 817-829.

Hunt, J. D. and Stefan, K. J. (2007). Tour-based microsimulation of urban commercial movements. Transportation Research Part B: Methodological 41(9): 981-1013.

Kanaroglou, P. and Buliung, R. (2008). Estimating the contribution of commercial vehicle movement to mobile emissions in urban areas. Transportation Research Part E: Logistics and Transportation Review 44(2): 260-276.

Kohler, U. (2004). New ideas for the city-logistics project in Kassel. Logistics Systems for Sustainable Cities: 321-332.

Lewis, A. (1997). Alternative Urban Freight Strategies, synthesis report: Alternative Strategies for Urban Freight Transport Management,.

Lindholm, M. and Behrends, S. (2012). Challenges in urban freight transport planning–a review in the Baltic Sea Region. Journal of Transport Geography 22: 129-136.

Macharis, C., Turcksin, L. and Lebeau, K. (2012). Multi actor multi criteria analysis (MAMCA) as a tool to support sustainable decisions: State of use. Decision Support Systems 54(1): 610-620.

Muñuzuri, J., Cortés, P., Onieva, L. and Guadix, J. (2009). Modeling Freight Delivery Flows: Missing Link of Urban Transport Analysis. Journal of Urban Planning and Development 135: 91.

Muñuzuri, J., Cortés, P., Onieva, L. and Guadix, J. (2010). Modelling peak-hour urban freight movements with limited data availability. Computers & Industrial Engineering.

Ogden, K. (1992). Urban goods movement: a guide to policy and planning, Arena.

Paglione, G. (2007). City logistics: the need for a behavioural model. I trasporti ed il mercato globale: 73.

Panayides, P. M. (2002). Economic organization of intermodal transport. Transport Reviews: A Transnational Transdisciplinary Journal 22(4): 401 - 414.

Regan, A. and Garrido, R. (2001). Modelling Freight Demand and Shipper Behaviour: State of the Art, Future Directions. IN HENSHER, D.(Ed.) Travel Behaviour Research. Pergamon-Elsevier Science.

Roorda, M., Cavalcante, R., Mccabe, S. and Kwan, H. (2009). A conceptual framework for agent-based modelling of logistics services. Transportation Research Part E: Logistics and Transportation Review.

Routhier, J.-L. and Toilier, F. (2007). FRETURB V3, a policy oriented software tool for modelling urban goods movement. 11th World Conference on Transport Research.

Russo, F. and Comi, A. (2002). A general multi-step model for urban freight movements. Population 700: 800,000-900,000.

Russo, F. and Comi, A. (2010). Measures for sustainable freight transportation at urban scale: expected goals and tested results in Europe. Journal of urban planning and development 137(2): 142-152.

Russo, F. and Comi, A. (2010). A modelling system to simulate goods movements at an urban scale. Transportation: 1-23.

Samimi, A., Mohammadian, A. and Kawamura, K. (2009). Behavioral freight movement modeling. The 12th International Conference on Travel Behaviour Research Jaipur, Rajasthan • India •

Southworth, F. (1982). An urban goods movement model: framework and some results. Papers in Regional Science 50(1): 165-184.

Taniguchi, E. and Shimamoto, H. (2004). Intelligent transportation system based dynamic vehicle routing and scheduling with variable travel times. Transportation Research Part C: Emerging Technologies 12(3-4): 235-250.

Taniguchi, E. and Tamagawa, D. (2005). Evaluating city logistics measures considering the behavior of several stakeholders. Journal of the Eastern Asia Society for Transportation Studies 6: 3062-3076.

Taniguchi, E., Yamada, T. and Kakimoto, Y. (2001). Models for evaluating city logistics measures. Proceedings of the Eastern Asia Society for Transportation Studies, Vol 3, No 2: 511-526.

Van Duin, J., Quak, H. and Muñuzuri, J. (2010). New challenges for urban consolidation centres: A case study in The Hague. Procedia-Social and Behavioral Sciences 2(3): 6177-6188.

Van Duin, J. R., Van Kolck, A., Anand, N., Tavasszy, L. and Taniguchi, E. (2012). Towards an Agent-Based Modelling Approach for the Evaluation of Dynamic Usage of Urban Distribution Centres. Procedia-Social and Behavioral Sciences 39: 333-348.

Visser, J. G. S. N. and Maat, K. (1997). A Simulation Model for Urban Freight Transport with GIS. Proceedings of Seminar J at the 25th ETF Annual Meeting,. Brunel University, England, 1-5.

Wang, Q. and Holguín-Veras, J. (2008). A tour-based entropy maximization formulation of urban commercial vehicle movements. Association for European Transport and contributors 2008

Wisetjindawat, W., Sano, K., Matsumoto, S. and Raothanachonkun, P. (2007). Micro-simulation model for modeling freight agents interactions in urban freight movement, Citeseer.

Woudsma, C. (2001). Understanding the movement of goods, not people: Issues, evidence and potential. Urban Studies 38(13): 2439-2455.

Xu, J. and Hancock, K. (2003). Enterprise-wide freight simulation in an integrated logistics and transportation system. 2003 IEEE Intelligent Transportation Systems, 2003. Proceedings: 534-538.

Xu, J., Hancock, K. L. and Southworth, F. (2003). Freight simulation: dynamic freight traffic simulation providing real-time information. Proceedings of the 35th conference on Winter simulation: driving innovation. New Orleans, Louisiana, Winter Simulation Conference.

Yannis, G., Golias, J. and Antoniou, C. (2006). Effects of Urban Delivery Restrictions on Traffic Movements. Transportation Planning and Technology 29(4): 295 - 311.

Young, W., Richardson, A., Ogden, K. and Rattray, A. (1983). An inter-Urban freight mode choice model. Transportation Planning and Technology 8(1): 61-80.

3 An agent based modelling approach for multi-stakeholder analysis of city logistics solutions

3.1. Lesson learned and research opportunities

City logistics related research aims to increase the efficiency of the city logistics system and to reduce negative externalities caused by urban goods movements. Models developed for this purpose work as forecasting and analysis tools to help gain insight into current (and future) city logistics transportation, commodity flow, infrastructure use, and information exchanges. Such knowledge can be used to understand and predict city logistics trends and problems in an attempt to invent policy measures and initiatives that can create an efficient city logistics domain.

The city logistics domain is characterized by heterogeneity of stakeholders with different, often conflicting, objectives, who practice autonomy in decision making while performing their individual urban goods movement related activities. Thus, the resulting inefficiencies of the city logistics system are, in fact, the outcome of the distributed decision making by multiple stakeholders. For this reason, capturing interactions between heterogeneous stakeholders of the system is the key to understanding the causes of the inefficiencies in the city logistics domain. Consequently, the model developed to study city logistics related solutions need to incorporate multiple perspectives of the stakeholders and their interactions. One of the conclusions of the review of city logistics modelling efforts is that most studies do not include the interactions of stakeholders. Only a few studies (Holguin-Veras et al., 2004; Hensher and Puckett, 2005) capture the interactions between stakeholders, albeit between limited types of stakeholders.

Another important observation from the review is that the terms to categorize different entities (e.g. stakeholders and resources) and events (e.g. activities and interactions) of the city logistics domain differ in the models. For example, a restaurant owner who orders goods is a receiver when he/she receives the goods. However, when a household orders food from that restaurant, then the restaurant owner takes a role of the supplier. This type of situation can lead to confusion in defining communication between stakeholders in the model. To avoid such ambiguity we need a clear description of the type of entities and events involved in the city logistics domain. We also need to mark clearly how these entities and events are connected (i.e. relationships) with each other. Defining city logistics entities and events in such a clear format allows sharing a common understanding of the structure of concepts and perspectives of the stakeholders.

With this background about current city logistics models and its limitations, the research opportunity lies in modelling different actors independently (e.g. firm, store, logistics service provider, truck) and capturing their interactions to understand the emerging city logistics system. In broader terms, we can explore interrelations between stakeholders and their activities by representing their business decisions ranging from fundamental long term decisions to short term operational decisions. Such analysis is capable of assessing the effects of a variety of technology trends, business trends, and policy scenarios that conventional approaches are not. The strategic and tactical decisions at the logistical level as well as operational decisions at the distribution level can be covered by modelling decentralized decision making of city logistics activities. Agent based modelling (ABM) is an approach where distributed decision making of the multiple stakeholders can be included by modelling each entity as an autonomous agent. This technique enables modelling the actors (i.e. roles) of the logistics chain as individual agents to capture the emerging system and analyse the effect of their decision making on the system.

Notwithstanding, in order to model the actors of the city logistics domain correctly, we need information about the type of stakeholders, activities, resources and relationships between all these. Thus, the first step is to build a ‘conceptual map’ that represents the city logistics domain by depicting the concepts and relationships in a comprehensive way. Such a map serves as the starting point in developing a model by providing the basic structure of relationships and communication between city logistics entities. Figure 3.1 shows the outline of multi-stakeholder agent based modelling approach.

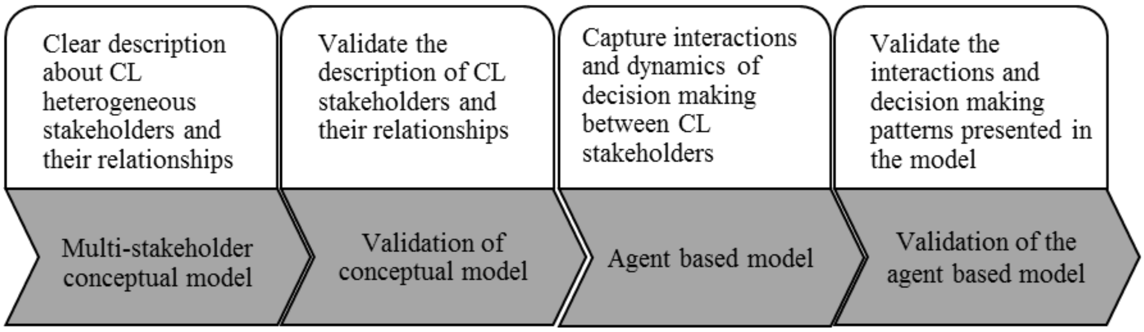


Figure 3.1 Outline of the multi-stakeholder agent based modelling approach

Since the conceptual map and the resulting model are representatives of real life, in the second step, the conceptual map must be validated. In the next step, a multi-perspective agent based model can be developed based on the information from the conceptual map. Validation of a conceptual map confirms the authenticity of a structure of the model; however we also must verify the interactions carried out by the agents in the model. Therefore, in the final step, validation of decision making patterns of the agents must be done. In the following sections, each step of the agent based modelling approach for multi-stakeholder analysis of city logistics solutions is described in detail.

3.2. Multi-stakeholder ontology – a conceptual framework for the city logistics domain

Problems related to city logistics are visible in urban areas, but their roots may relate to decision making of different stakeholders. As shown in Table 3.1 different stakeholders in the city logistics domain have different objectives and, thus, act autonomously without any centralized control. This situation often leads to non-cooperation in decision making, which in turn causes a lack of coordination in activities. Uncoordinated activities, ultimately, result in the non-optimal use of city logistics resources. For example, frequent trips to city areas and a lower loading rate of a freight delivery vehicle is the result of a lack of coordination between shops' ordering patterns and goods delivery scheduling by carriers. These types of situation make the city logistics domain a distributed decision making system causing inefficiencies (e.g. poor economic and environmental sustainability). Consequently, the model developed for the city logistics analysis must include distributed decision making of the stakeholders by including individual decisions and interactions between different stakeholders.

Table 3.1 Objectives of city logistics stakeholders

STAKEHOLDER	OBJECTIVE
Administrator (also represents residents)	Accessibility Governance and legislation Negative environmental impact
Suppliers	Market growth Profitability
Carriers	Congestion Cost effectiveness, minimum use of resources
Receivers	Competitiveness, profitability, On-time delivery

Among several modelling platforms available for the city logistics domain, agent based modelling is the latest addition. In an ABM, each entity (e.g. stakeholder, resource) can be modelled as an individual agent possessing objectives and decision making attributes. Thus, an ABM can be a valuable tool for city logistics domain researchers for its strong capability of capturing the dynamic behaviour of individual stakeholders and their interconnections[4] (Getchell, 2008). Although a powerful tool, the human effort required to develop an ABM is considerable, especially when multiple stakeholders have to be covered (Tamagawa et al., 2010).

The traditional modelling approach requires the modeller to develop a formal conceptual model by capturing users' view of the real world. Next, the modeller has to map, mentally, the

[4] It is also called social commitment among agents (Singh, 1999).

concepts acquired from the real world to instances developed in the model. This mapping is usually done informally or in an ad-hoc fashion, which often causes inaccuracies as well as inconsistencies between the users' concepts and the model developed by the modeller. These conflicts and inaccuracies can be attributed to the lack of an initial agreement between the users and modeller on the conceptual map of the real world. For instance, Roorda et al. (2009) proposed a conceptual framework for the agent based model of logistics services. The framework describes various roles of different stakeholders and representation of logistics service contracts in mathematical formats. However, the conceptual model is not explicitly rooted in observations and has not been verified against real world information. Furthermore, the knowledge represented in the conceptual model is not explicitly described in terms of concepts and relationships. As a result, the lack of semantic representation may limit its usefulness because the direct transfer of a stakeholder-agent or an activity to modelling is not possible.

According to Le Ber and Chouvet (1999), an ABM must be constructed upon a knowledge base that abstracts a specific domain into a world purely composed of agents and their relationships. In simple terms, before developing an ABM, the conceptual model must be developed covering all the important concepts of the domain and the relationships between them. Unfortunately, this kind of knowledge base is still built with little sharing or reuse – almost each one starts from a blank slate. ABM developers have to go through extensive literature reviews and data analysis to seek the terms of interest, sort the complex and usually implicit relations among terms and code the agents together with their properties. They have to search through the behavioural rules and communication protocols merely on the basis of what they subjectively learn, without a shared reference. This situation directly leads to a poor reusability of models and ultimately incurs repetitive work and extra developing time. For instance, a modeller wants to add a new agent to her model and is informed that there exist some models containing this agent. Unfortunately, after checking the models of interest, she finds that agents in these models are coded in a different way that is non-compatible or inconsistent with her model. Finally, a significant amount of time has to be spent on coding the agent.

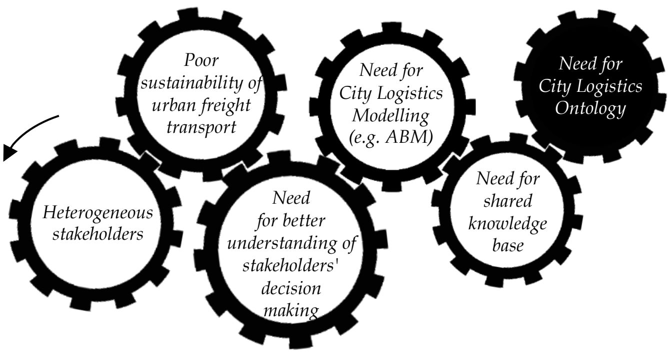


Figure 3.2 Need of a semantic database (i.e. ontology) for the city logistics domain

An intuitive problem forming mechanism for the need of an ontology is given in Figure 3.2. The figure describes that to improve the efficiency of the city logistics system and reduce negative impacts generated by city logistics activities, a better understanding of perspectives of different stakeholders is required. Also, their interactions and decision making during different city logistics related activities need to be understood. City logistics models can be used to mimic the domain and gather insights about the real causes of the problems. The model must be based on a knowledge base that includes different stakeholders, objective, activities, resources and other related details in order to create a conceptually correct city logistics domain. A knowledge base developed in the form of an ontology relates the domain concepts using semantic relationships. The ontology for the city logistics domain serves as a conceptual model that can be used as a necessary building block for an ABM. The introduction of the semantic knowledge data model – the ontology - can considerably reduce the problem of structural consistency and amount of effort needed to develop an ABM.

The term ‘ontology’ was coined by Aristotle as a branch of metaphysics and is the study of ‘the nature and structure of reality’. According to Gruber (2009), the traditional goal of ontological inquiry is to ‘divide the world at its joints, to discover those fundamental categories, or kinds, into which the world’s objects naturally fall’. Since the mid-1970s, researcher have been recognizing the great value of using an ontology for capturing knowledge, which is regarded as the key to building a large and powerful Artificial Intelligence (AI) system. In the 1980s, the AI community began to use the term ontology to refer to both a theory of a modelled world and a component of knowledge systems. In the early 1990s, Gruber (1995) further defined an ontology in a technical term in computer science as ‘a specification of a conceptualization’. That is ‘*ontology is a description (like a formal specification of a program) of the concepts and relationships that can exist for an agent or a community of agents*’. In other words, an ontology stipulates the potential agents and their rules of interaction in a given domain.

The ontology structure does not only represent groups of concepts as a vocabulary or terminology of the domain but also contains specific knowledge relationships among them. The concepts here are called ontology classes, and relations between these classes are called object properties. Thus, there is a clear distinction between “vocabularies” and “ontologies”. The latter is a more complex version of the former, as every term in the ontology is no stand-alone term but linked with other terms to characterise the knowledge about the domain it represents.

Following this discussion, it is conceivable that the city logistics ontology can abstract the city logistics domain into multiple concepts (i.e. classes). Some of these classes can directly be adopted as agents in the models, and their potential interactions have already been formally clarified in the ontology. Hence, city logistics ABM developers can have a shared and standardized template that specifies the data structure and initial data used within their models. Rather than building from scratch, they can assemble their knowledge bases with components drawn from the city logistics ontology. Furthermore, specific agents in an existing model can be directly reused in other models as long as their developers follow the same ontology (Keirstead and van Dam, 2010). All of these merits should greatly decrease development time while improving the robustness and reliability of the resulting knowledge bases.

3.3. Validation of the semantic data model

With the inclusion of a variety of domain entities and relationships between them, an ontology is a powerful way to express domain knowledge in a structured way. Nevertheless, to utilize this powerful method one needs to have confidence in its structural information model. Confidence in using the ontology can be built by assessing the ontology for its scope, structure and knowledge representation with respect to real-world concepts. The evaluation can reveal how much (quantity) and how good (quality) the ontology model is in representing the real world. Consequently, the next step after developing a city logistics ontology is to estimate its quantitative parameters and validate the information it represents.

In the quantitative evaluation, the task is to assess dimensional ontological parameters such as number of classes, attributes, and relations between classes. While in the qualitative validation, correctness of the information presented in the ontology is checked against the reference data from the real-world stories of the city logistics domain. The qualitative validation answers questions such as does the ontology cover topic related to the domain of interest and if yes, does it cover the relations between classes correctly?

Ontology validation is usually the only way to ensure the precision of the knowledge presented in the ontology. Seemingly, validation of the ontology requires close cooperation of domain experts and cannot be performed automatically due to the complexity of the domain and the data presented in the ontology. This complexity is one of the reasons for a lack of validated knowledge data model in many disciplines. Practitioners and researchers are reluctant to use such un-validated ontology. In the author's opinion, systematic evaluation and validation of an ontology can essentially generate confidence among researchers for its usage.

3.4. Agent-based model

The review done in *Chapter 2* indicates that a wide variety of modelling approaches is used for modelling the city logistics domain. Simulation is one of the widely used techniques for city logistics modelling. In a survey of simulation for supply chain, Terzi and Cavalieri (2004) conclude that simulation is very helpful technique as it provides a systematic quantitative and objective evaluation of the outcomes resulting from different possible planning scenarios. In essence, the survey agrees that the simulation technique is very powerful tool to understand the dynamics of the system. In the article about a tour-based micro-simulation of urban commercial movements, Hunt and Stefan (2007) state the essential characteristics of modelling techniques for urban commercial movements. They state them as; ability to model various aspects of choice behaviour explicitly; to aggregate results ex-post as desired; to provide an explicit representation of tours; to include specific constraints acting at the individual level. The authors believe that micro-simulation is very appropriate for such task. Similarly, Liedtke and Schepperle (2004) claim that a micro-simulation freight model could be a potential forecast tool and pave the way for more reliable policy assessments compared to currently available decision tools.

However, when decision making between independent actors or firms is to be modelled, traditional discrete-event simulation is not pragmatic for limited information exchange between actors in real life. For this purpose, the simulation technique should be able to represent many individuals with autonomous behaviour. The relatively new paradigm of parallel and distributed simulation, an agent based modelling technique, enables to capture these interactions between independent actors. It is a special type of discrete event simulation that does not rely on a model with an underlying equation but can nonetheless be represented formally. Although new to freight modelling, the agent based modelling (ABM) technique has been successfully implemented in many disciplines (Axelrod, 2006). One of the most important reasons for using this technique is that it can explicitly model the complexity arising from individual actions and interactions. Especially, those interactions that were either not possible or not readily accommodated using traditional modelling techniques, such as a discrete event or system dynamic modelling (Borshchev and Filippov, 2004).

Davidsson et al. (2005) give a survey of existing research on agent based approaches for transportation and traffic management. The survey evaluates the models based on domain, transport mode, time horizon, usage, control, agent structure, agent behaviour, maturity level of model, and evaluation comparison. It concludes that agent based modelling approach is very suitable for modelling transport and logistics domains.

The usefulness of ABM is visibly accepted among city logistics researchers as evidenced by an increasing number of agent based models found in the city logistics modelling literature. Nevertheless, developing an ABM remains a challenge due to the complexity of including multiple stakeholders and multiple interactions. To model a city logistics domain successfully using ABM, communications between heterogeneous stakeholders of the domain must be implemented accurately. For accurate communication, the agents should have common knowledge of different terminologies and the types of decisions they are making. From a semantic point of view, these agents should have a common view of the system and should have coordination in their activities. Furthermore, the abstraction of the stakeholders and their interactions presented in the model must match with the users' view of the real world.

To achieve this twofold objective - the structural consistency in the model and conceptual consistency with the real world, we propose to use the city logistics ontology for ABM development. The city logistics ontology contains concepts and relationships of the domain in a structured manner that allows the systematic transfer of domain knowledge. Multiple perspectives incorporated in the ontology promises that communication links between domain entities are correctly established. In addition, an ABM developed from the user-validated ontology possesses the validated structure.

3.5. Participatory simulation game for validation of ABM

For any modelling paradigm, validation is vital for the acceptance by the users of the model. Surprisingly, little research effort has been spent on the definition of specific methods and techniques for an ABM validation. It is clear that autonomy is an inherent characteristic of agents in an ABM which makes these agents capable of processing and exchanging information with other agents in order to make independent decisions (Bonabeau, 2002). The system model consists of such autonomous and heterogeneous agents is useful to describe the domain of interest in a natural and flexible way, to capture resulting emergence patterns (Farmer and Foley, 2009).

Nonetheless, the notable benefits of using an ABM are hampered due to the difficulties in its validation. The ABMs capture decentralized decision making of the domain where global behaviour is not defined but emerges from individual behaviours embedded in the agents present in the model. When multiple agents with different goals and rules interact in (close to) infinite ways, they create a complex emergent system that is difficult to track. An equally frustrating fact caused by the complexity is that in the absence of clear-cut a priori expectations about the results, the unexpected output raises confusion about the legitimacy of the result (Galán et al., 2009).

An ABM is developed using the ontology and therefore its components and relationships mirror the structure of the ontology. In consequence, the conceptual validation of an ABM can be done by validating the ontology. The traditional technique of model validation is to evaluate the model outcome. For an ABM, the outcomes represent the state of the system emerged due to interactions of the agents. Often, statistical validation techniques applied to other simulation paradigms are deemed equally suitable for an ABM without much questioning. Notwithstanding, often, the absence of relevant data is a serious issue for statistical validation (Kleijen, 1999). Furthermore, even though the system outcome might be relevant to the observed output, the events and/or their sequence may not have followed a logical process and could still be completely different from the real processes. Therefore, such validation techniques do not assess the accuracy of model behaviour. Therefore, an ABM must be validated for the processes represented in the model and executed by agents to perform various activities. Concentrating on the internal mechanism of the model, we argue that the system outcome is the result of interactions between the agents. Therefore, by aligning the decision making mechanisms of agents with that of a real-world system, we can assess the model behaviour. In essence, exploring the events that lead to a system outcome can be helpful to understand the system output and, thus, contribute to the validation of the model. One effective way of collecting information about the decision making mechanism of real stakeholders for validation is by putting them in the same decision making condition with the same set of assumptions. This can be done by allowing a stakeholder to take control of decision making of a specific agent of the model. This setting is called a participatory simulation game. One of the famous examples of such a setting is the beer distribution game designed by MIT (Sterman, 1989). A computerized version of this game is developed by (Kaminsky and Simchi-Levi, 1998). This game is mainly used for education purpose, but we argue that such a setting can be used to collect information about decision making parameters and behavioural attributes of the player to use as a validation reference.

3.6. Framework for agent based model development for the city logistics domain

To successfully use the potentials of agent based simulation technique for modelling the city logistics domain, the author proposes the following framework. Figure 3.3 shows the proposed framework depicting different stages. The framework starts with the review of the city logistics domain. It is imperative to have knowledge about the city logistics related research and modelling attempts in order to represent the domain sufficiently in the model. The city logistics domain is characterized by multiple stakeholders with heterogeneous characteristics who collaborate to carry out urban goods related activities. To understand the decision structure of these activities, we need to understand the knowledge relationships among domain stakeholders. To consistently represent relationships between different entities of the city logistics domain we propose to use the city logistics ontology. The city logistics ontology is, in fact, a knowledge database describing how different city logistics entities interact with each other.

Evidently, the ontology reflects the domain information from the viewpoint of the person or a group of people who developed it. Therefore, the ontology must be validated by checking whether the ontology information is correctly representing the domain. The ontological information (e.g. ontology classes) can be used as building blocks to develop an agent based simulation model. Therefore, by validating the ontology one can partially validate the agent based model.

The agent based simulation model uses information from the city logistics ontology (e.g. concepts, knowledge relationships) as basic building block to model ‘basic’ entities (e.g. agents, resources) and events (e.g. communication protocols). After adding additional behavioural attributes and decision making, one can develop a fully functional multi-agent system depicting micro details and behavioural aspects of the real world. Such a simulation system allows for the exploration of how the city logistics system evolves over a period under influence of different factors, such as policy measures and market situations.

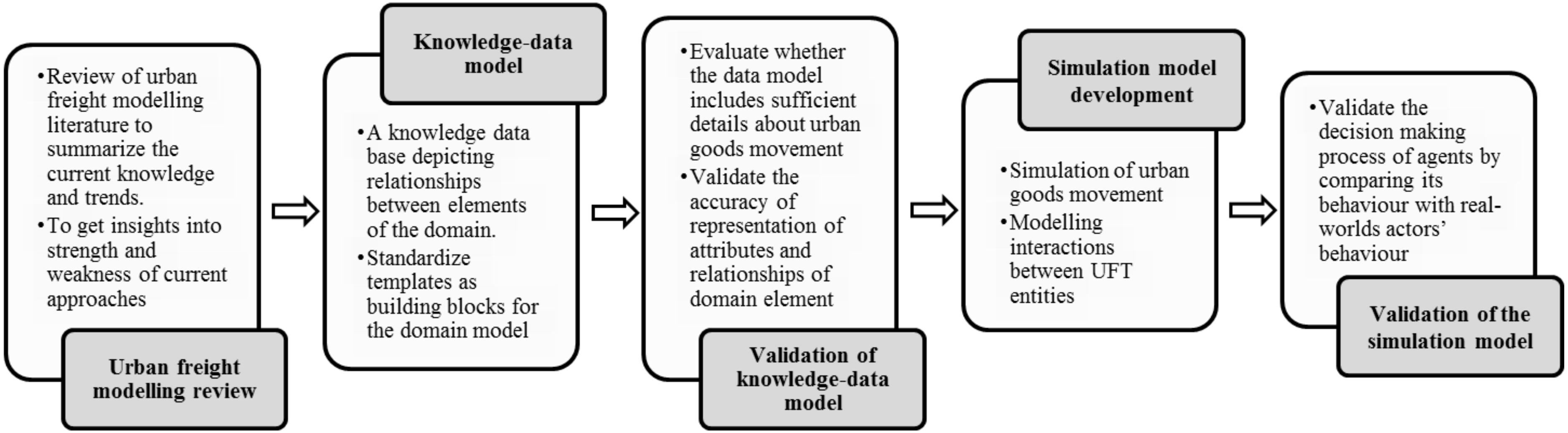


Figure 3.3 Methodology for developing an agent based model for the city logistics domain

The agent based simulation model uses information from the city logistics ontology (e.g. concepts, knowledge relationships) as basic building block to model ‘basic’ entities (e.g. agents, resources) and events (e.g. communication protocols). After adding additional behavioural attributes and decision making, one can develop a fully functional multi-agent system depicting micro details and behavioural aspects of the real world. Such a simulation system allows for the exploration of how the city logistics system evolves over a period under influence of different factors, such as policy measures and market situations.

The development of the knowledge relationship model and the simulation model is important to garner insights about decision making by stakeholders in the city logistics domain. However, since the model is to depict reality in an abstract way, one must check its authenticity in order to use it confidently. The resulting model is a simulation model and therefore the traditional validation methodology such as comparing the model output with the observed or hypothesized output can be applied. However, such empirical validation is not sufficient for the simulation model using agent technology. The reason for this is that agents do not behave in isolation. More often, their behaviours are affected by the behaviours of other agents or the environment and so the final state of the system can be achieved by following completely different patterns/paths. Subsequently, we consider validating an ABM not only from the aggregate system output but also based on agents’ behaviour. As a result, in the last phase we propose to develop a method to validate the agent based model to verify attributes and decision making process of the agents.

The outline of the remaining chapters is as follows. In *Chapter 4*, the formal ontology is introduced to specify the city logistics domain in terms of the concepts, attributes and relationships between concepts. In *Chapter 5*, the ontological parameters were determined for the city logistics ontology. Next, the ontology is validated using comparative information from the real world. An approach describing the use of the city logistics ontology for the development of an agent based model for the city logistics domain is described in *Chapter 6*. In *Chapter 7*, we propose a validation framework to validate decision making patterns of agents of city logistics ABM based on a participatory simulation game. Next, we describe a proof-of-concept game for validating the agent based model for city logistics. *Chapter 8* describes a policy scenario and respective analysis for the city logistics domain. Finally, *Chapter 9* concludes this research work summarising contributions, future research possibilities and recommendation for using this research.

References

Axelrod, R. (2006). Agent-based modeling as a bridge between disciplines. Handbook of computational economics 2: 1565-1584.

Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. Proceedings of the National Academy of Sciences of the United States of America 99(Suppl 3): 7280.

Borshchev, A. and Filippov, A. (2004). From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools. Proceedings of the 22nd international conference of the system dynamics society.

Davidsson, P., Henesey, L., Ramstedt, L., Törnquist, J. and Wernstedt, F. (2005). An analysis of agent-based approaches to transport logistics. Transportation Research Part C 13(4): 255-271.

Farmer, J. D. and Foley, D. (2009). The economy needs agent-based modelling. Nature 460(7256): 685-686.

Galán, J. M., Izquierdo, L. R., Izquierdo, S. S., Santos, J. I., Del Olmo, R., López-Paredes, A. and Edmonds, B. (2009). Errors and artefacts in agent-based modelling. Journal of Artificial Societies and Social Simulation 12(1): 1.

Getchell, A. (2008). Agent-based modeling. Physics 22(6): 757-767.

Gruber (1995). Toward principle for the design of ontologies used for knowledge sharing. International Journal Human-Computer studies.

Gruber, T. (2009). Ontology. Encyclopedia of database systems: 1963-1965.

Hensher, D. A. and Puckett, S. M. (2005). Refocusing the Modelling of Freight Distribution: Development of an Economic-Based Framework to Evaluate Supply Chain Behaviour in Response to Congestion Charging. Transportation 32(6): 573-602.

Holguin-Veras, J., Thorson, E. and Ozbay, K. (2004). Preliminary Results of Experimental Economics Application to Urban Goods Modeling Research. Transportation Research Record: Journal of the Transportation Research Board 1873(-1): 9-16.

Hunt, J. D. and Stefan, K. J. (2007). Tour-based microsimulation of urban commercial movements. Transportation Research Part B: Methodological 41(9): 981-1013.

Kaminsky, P. and Simchi-Levi, D. (1998). A new computerized beer game: A tool for teaching the value of integrated supply chain management. Global supply chain and technology management 1(1): 216-225.

Keirstead, J. and Van Dam, K. H. (2010). A comparison of two ontologies for agent-based modelling of energy systems.

Kleijen, J. (1999). Validation of models: statistical techniques and data availability. Simulation Conference Proceedings, 1999 Winter, IEEE.

Le Ber, F. and Chouvet, M. P. (1999). An agent-based model for domain knowledge representation. Data & knowledge engineering 29(2): 147-161.

Liedtke, G. and Schepperle, H. (2004). Segmentation of the transportation market with regard to activity-based freight transport modelling. International Journal of Logistics Research and Applications 7(3): 199-218.

Roorda, M., Cavalcante, R., Mccabe, S. and Kwan, H. (2009). A conceptual framework for agent-based modelling of logistics services. Transportation Research Part E: Logistics and Transportation Review.

Sterman, J. D. (1989). Modeling managerial behavior: Misperceptions of feedback in a dynamic decision making experiment. Management science 35(3): 321-339.

Tamagawa, D., Taniguchi, E. and Yamada, T. (2010). Evaluating city logistics measures using a multi-agent model. Procedia - Social and Behavioral Sciences 2(3): 6002-6012.

Terzi, S. and Cavalieri, S. (2004). Simulation in the supply chain context: a survey. Computers in industry 53(1): 3-16.

4 GenCLOn: an ontology for city logistics[5]

4.1. Introduction and literature review

Although so far there is no explicit contribution to ontology dedicated to the city logistics domain available in the literature, ontology is not something new in the domain of logistics/supply chain management. The domain of logistics/supply chain management has a close relationship with the city logistics domain. Several initiatives are reported in the literature formalising logistics domain knowledge in the form of an ontology. Lian et al. (2007) proposed an ontology that act as a logistics situation model that can help to specify a situation of a product and attach events that 'triggered' by this situation. Different from the company-oriented efforts, the main application of this ontology is to help construct scenarios of different logistics process. The 'trigger' concept here will probably make great sense for simulating the behaviour of agents in the city logistics domain. In an another attempt, Leukel and Kirn (2008) made a creative trail to build a logistics ontology with the knowledge contained in the famous SCOR (i.e. Supply Chain Operation Reference) model. Due to the partial focus of the SCOR model on logistics process and information flow, this ontology has a relatively poor representativeness of the physical/material aspects of the logistics domain. Examples of the physical/material aspect of the logistics domain include goods, infrastructure and vehicles.

[5] This chapter is based on the journal paper - Anand, N., Yang, M., van Duin, J. H. R., Tavasszy, L. (2012). GenCLOn: An ontology for city logistics. Expert Systems with Applications, 39(15), 11944-11960. doi: http://dx.doi.org/10.1016/j.eswa.2012.03.068

This research was carried out along with Mr. Mangchang Yang during his master thesis work.

Hoxha et al. (2010) also contributed an ontology for the semantic representation of the logistics domain. Their contribution offered solutions to the integration challenges among heterogeneous data and interoperability of logistics services from different providers. In this study, the authors divide the logistics domain into five top classes. These top classes are actors, logistics service, logistics process, logistics resource and logistics KPI, and each class has been further specified with multiple sub-structures. Similarly, Zhang and Tian (2010) designed a logistics domain ontology model to represent the relations among logistics domain concepts to facilitate integration of inter-enterprise logistics information system. This ontology contains 12 top classes, namely cargo, organization, supplier, customer, carrier, transport service, constraint, transport service standard, transport mode, vehicle, traffic line and information between actors. Compared to the previous case, classification asserted by Hoxha et al. (2010) tends to be more systematic as well as hierarchical and, thus, possess considerable referential value. Additionally, they also provide constructive insight in facilitating semantic web-based logistics service request and execution based on their ontology. Other interesting studies in developing ontology for logistics domain are (Liou and Chang; Smirnov and Chandra, 2000; Fayez et al., 2005; Ye et al., 2007; Huang and Lin, 2010; Yu-Liang, 2010; Xu et al., 2011). Conclusively, these previous studies lay a good basis for building the micro part (i.e. demand-supply pattern among private actors) of the city logistics ontology. Nonetheless, due to the different focus, the macro part (i.e. political, social and environmental issues) exclusively covered by the city logistics domain has to be constructed from almost a blank slate.

4.2. Generalization and conceptualization of the city logistics domain

The Institute of City Logistics defined city logistics as ‘the process for totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, the traffic congestion and energy consumption within the framework of a market economy’. According to this definition, the focus of city logistics lies in the company-driven logistics activities initiated by business between companies or even between companies and individual consumers. In this case, the possible patterns include[6]

- traditional direct B2B delivery from wholesalers/end goods producers/importers to independent retailers or other business parties located in the urban area;
- dedicated delivery organised by retail chains from DCs to outlets;
- B2C[7] delivery from retailers (outside or inside the same urban area) to urban inhabitants (i.e. home delivery) performed by freight vehicle;
- logistics activities involved that influence urban areas (e.g. (un)loading and (part of) return trips)

Correspondingly, some patterns become less important and can even be left out from the scope of the definition. For instance, scattered shopping trips generated by households with private cars are of less importance for that proactive participation from business parties are missing in this pattern. The congestion caused by private cars, however, is still needed to be

[6] Allen, et al. (2000) distinguished three urban freight demands as ‘core goods’ representing the goods that are essential for the main activity of an retail premise (e.g. commodity for a supermarket), ‘non-core goods’ representing goods that are not directly essential for the main activities of an retail premise and ‘service’ including maintenance, cleaning, etc. For its heterogeneity from freight transport, ‘service’ will not be taken into account here.

[7] C2B business is now emerging, but the popularity is still very low. Moreover, the ‘goods’ involved in C2B business is usually non-material like pure design scheme or software. In case the goods are material, the quantity of them tends to be very small. Thus, C2B business is left out from the scope.

taken into account since it influences the performance of city logistics activities. Mail (parcel) express consigned by individuals (including Customer to Customer (C2C) business) will not be taken into account. The reason for not including C2C is that the negative impact caused by C2C deliveries to the urban sustainability is low due to both the efficiently organized trips and the vehicles used are tend to be smaller as well as cleaner than the trucks used for B2B business (Ports, 2005).

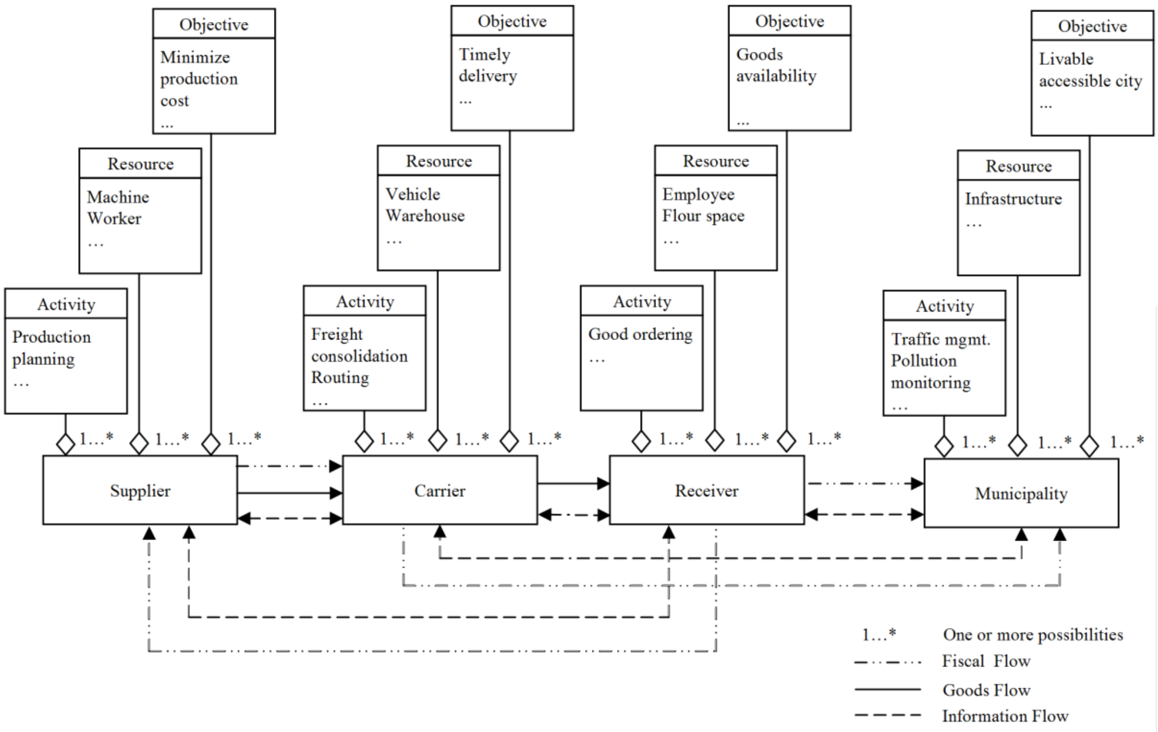


Figure 4.1 Scope of the city logistics ontology

Following the definition of city logistics, we can further scope out the upstream actors in the supply chains that do not have a direct demand-supply relationship with the receivers (i.e. retailers, inhabitants) situated in the urban areas. Figure 4.1 illustrates the domain of interest determined so far for developing the city logistics ontology. To sum up, deliveries from end depots to urban premises/homes by freight vehicles, deliveries from retail premises to home by freight vehicles and their return trip along with auxiliary logistics activities that influence city logistics performance are of interests in the following work. A series of assumptions will be given in the next section (along with ontology description) to refine the scope based on the conclusion derived above further.

4.3. Protégé – ontology development software

For the city logistics ontology building, an ontology building software Protégé is used. It is a free, open source ontology editor and a knowledge-base framework. The ontology created using Protégé can be exported into a variety of formats including RDF(S), OWL, and XML Schema. Protégé is based on Java programming language. This software comes with a plug-and-play environment making it a flexible base for rapid prototyping and application development. Using Protégé's user interface, once can easily create classes, assign properties to them as well as restrict the properties' features to certain classes (Abdolmohammadi and Wright, 1987).

Ontologies for a wide variety[8] of fields are developed using protégé. The reason for its popularity is due to that fact that the coding efforts needed for developing the ontology is much lower due to its user-friendly visual interface. Since Protégé is the most widely used software for ontology development, it is supported by a strong community of developers and academic, government and corporate users. Consequently, there are multiple independent plug-ins available to carry out a wide variety of operations (e.g. ontology visualization, UML and Java class extraction) for the ontology.

Furthermore, a unique benefit of using Protégé is its support for Java (and UML) code-generating. The ontology developed using Protégé can be exported into a code package where the whole ontology is parsed into separate Java documents. Thus, if the city logistics ontology is exported into this kind of package, documents as ‘Stakeholder.java’, ‘Objective.java’ and ‘Measure.java’ can be found there. Due to this facility, developers can create Java classes to develop a simulation model (e.g. Agent-based simulation model).

4.4. Formal specification of Generic City Logistics Ontology (GenCLOn)

4.4.1. Hierarchy of GenCLOn

According to Uschold and Gruninger (1996), the class hierarchy can be developed using three approaches:

- A *top-down development* process starts with the definition of the most general concepts in the domain and subsequent specialization of the concepts.
- A *bottom-up* development process starts with the definition of the most specific classes, the leaves of the hierarchy, with subsequent grouping of these classes into more a general concept.
- A *middle-out* development process is a combination of the both the methods mentioned above. It defines the most salient concepts first and then generalizes and specialize them appropriately.

None of these three methods is inherently better than any of others. A top-down approach results in better control of the level of detail, however, demands very systematic top-down understanding of the domain, which is not the best choice for highly dynamic and complicated systems such as city logistics. A bottom-up approach, instead, facilitates a quick start without imposing high-level understanding on the users. However, a bottom-up approach tends to involve a high level of detail that will easily arouse problems like incremental overall effort, difficulty in spotting commonality between related concepts and risk of inconsistency. Contrarily, both, (Uschold and Gruninger, 1996) and (Noy and McGuinness, 2001) believe that the middle-out approach makes it easier to relate terms in different areas more precisely. This approach avoids potential re-work since the concepts ‘in the middle’ tend to be the most descriptive concepts in the domain (Rosch, 1999). Considering its empirical[9] compliments together with the complexity, extensiveness and dynamics of city logistics system, the middle-out approach is thus adopted for the following hierarchy construction. Also, due to the

[8] For the examples of ontologies developed using Protégé, visit – http://protegewiki.stanford.edu/wiki/Protege_Ontology_Library

[9] The middle-out approach has been used successfully for many years as part of the BSDM, developed by IBM (Uschold, et al., 1996)

non-stipulated characteristic of various city logistics situations presented in the ontology, it will be called a Generic City Logistics Ontology – in short, GenCLOn.

4.4.2. GenCLOn classes

In this section, the hierarchical structure of the proposed ontology will be mapped out following the middle-out approach. We will at first create the most important classes and then expand them.

(1) Stakeholders

The middle-out approach advocates determining the most 'salient' terms at first and expanding the structure from it. The question arises 'which term is the core of the city logistics ontology?' From the city logistics literature review in *Chapter 2* and subsequent discussion in *Chapter 3*, it is clear that the city logistics ontology should provide sufficient understanding about the 'interests and decision making processes of heterogeneous stakeholders involved in the city logistics domain'. Variety of the stakeholders is at the heart of the distributed decision making in the city logistics domain (Browne et al., 2005; Taniguchi and Tamagawa, 2005) and therefore the core status is given to stakeholder class. The hierarchical structure of Stakeholder class in GenCLOn is presented in Figure 4.2.

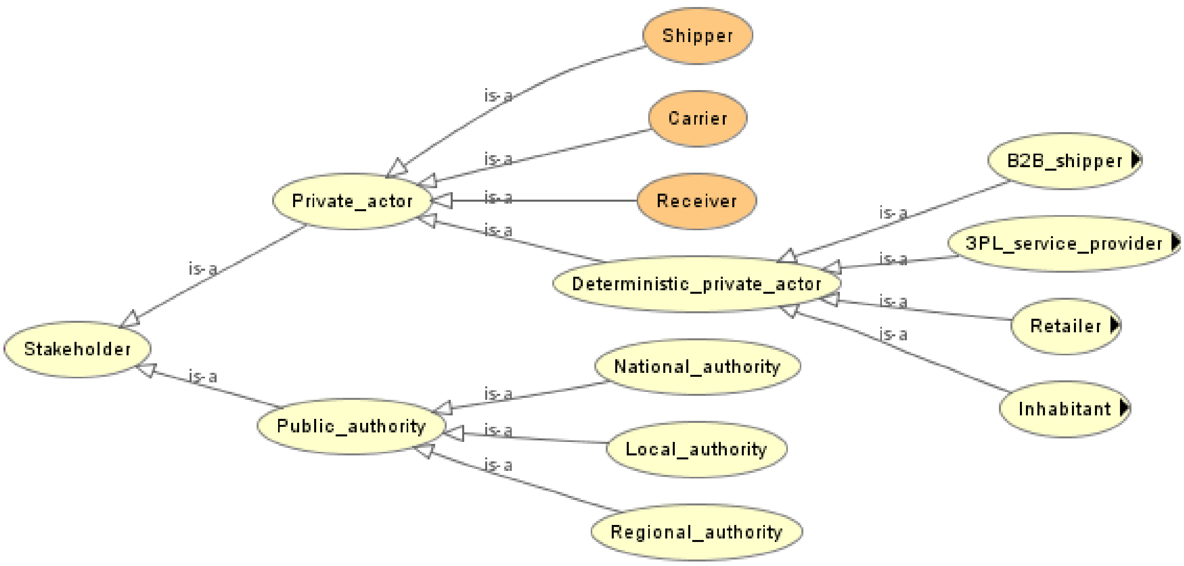


Figure 4.2 Hierarchical structure of class 'Stakeholder.'

The stakeholder can be further classified into two general categories as Private and Public stakeholder that is given naming convention as Private_actor and Public_authority in GenCLOn. Conventionally, a private actor in the city logistics domain is classified as a shipper, a carrier or a receiver (Taniguchi and Thompson, 2002). Nevertheless, this role-based classification cannot fit well here for its 'multiple inheritances' (i.e. a class has multiple super classes) it implies. For example, a retail chain organizing logistics activities on its own can play all the three roles (i.e. have three super classes) simultaneously (Quak, 2008). According to Horridge et al. (2004), this situation should be avoided in a manually constructed hierarchy (i.e. asserted hierarchy) to minimize the human effort and, to minimise errors in maintaining a multiple inheritance hierarchy. Thus, we would better start with a more 'deterministic' classification only implying a single inheritance. The hierarchy with multiple inheritances then can be generated afterwards by the logic-reasoner[10].

All the 'deterministic' stakeholders listed will be automatically assigned to the 'shipper', 'carrier' and 'receiver' in light of their unique attributes. The rationale for doing this seemly repetitive work is that the objectives/interests of private actors come from the role they are playing. For example, an independent retailer acting merely as a 'receiver' is less concern about traffic congestion because she does not consider the transport as her responsibility (Quak, 2008). While, a retail chain, on the other hand, knows and cares more about the transport issues because it also acts as a shipper who is well informed about the relation between congestion and logistics costs. Moreover, performable countermeasures and activities are also associated with the roles. Therefore, it is necessary to have a role-based view besides the deterministic categorization.

Thus, role-based stakeholder classes 'Carrier', 'Receiver' and 'Shipper' are added directly under 'Private_actor', where these classes are 'defined class' equipped with 'necessary and sufficient conditions'. This implies that other classes that meet the 'necessary and sufficient conditions' of the "defined class" will be automatically considered to be 'kind of' (i.e. sub-class of) the defined class in GenCLOn. For example, let us say a 'necessary and sufficient condition' for the carrier-class is to own at least a single goods delivery vehicle. Then any stakeholder with one or more goods delivery vehicles is automatically considered as a 'sub-class of' the carrier class. This reasoning is exactly the key to fulfilling the task stipulated above. That is, assigning the sub-classes of 'Deterministic_private_actor' (e.g. 3PL carrier, retailer, inhabitant, etc.) to role-based classes in the light of their intrinsic attributes.

(2) Objectives

The stakeholders in the city logistics domain are driven by their personal objectives. Accordingly, once stakeholders are identified, the next step is to categorize their objectives or interests that ultimately influence the city logistics activities. All stakeholders involved in the city logistics system have their particular or shared objectives/interests (Browne et al., 2007). Some of these objectives are consistent with others while others are contradictive with others. Generally, objectives within the city logistics domain can be classified into economic, environmental and social categories.

It is evident from Figure 4.3 that these three categories of objectives are interlaced. For example, 'competitive retail industry' is facilitated by congestion reduction, nuisance reduction, and valuable area protection. An additional point deserving a mention is that 'efficiency', a prevalent objective that can be found in many literatures, has not been included here for its ambiguity. In the logistics sector, the overall efficiency measurement includes a variety of variables including economic, environmental, energy, human, and operations. At the individual level inclusion of these variables as well as its magnitude varies (Sullivan et al., 2012). In a broad sense, for city logistics context, it can be defined as 'delivering the same amount of goods with fewer vehicles, less vehicle kilometre, and time'. For public sectors and citizens, this means better accessibility of cities, less fuel consumption as well as a reduction in negative influence on the environment and city inhabitants. For commercial private actors, on the other hand, it will be more related to monetary benefits such as transport or receiving cost reduction. It is thus convincing to assert that 'efficiency' has already been represented by other concrete objectives listed in this section.

[10] A semantic reasoner is a piece of software able to infer logical consequences from a set of asserted facts or axioms.

Figure 4.3 Hierarchical structure of class 'Objectives.'

In a tree-like structure of the class 'Objective' (see Figure 4.3), each link between a sub-classes and its super-class has been labelled 'is-a' with an arrow going from a sub-class to a super-class. This phrase explicitly indicates that in an ontology, a sub-class is 'kind of' its super-class and will inherit all the attributes of its parent. Confusion between 'kind of' and 'part of' must be avoided while constricting hierarchy.

(3) KPIs

KPI stands for Key-Performance-Indicator and is used as a measure to check at what extent to an objective of stakeholders is achieved. A KPI is closely connected with 'Objective'; therefore, it could be a part of the 'Objective' class. However, due to the above mentioned semantic implication (i.e. sub-class of a super-class), 'KPI' as a sub-class of 'Objective' cannot be defined. Therefore, we build 'KPI' as an independent class parallel to the 'Objective' class. The relation 'part of' is reclaimed via appropriate 'object property' – detail of which discussed in section GenCLOn Axioms. The hierarchical structure of class "KPIs" is presented in Figure 4.4. In contrast to expanded social objective (refer Figure 4.3), no further classification of social indicator is carried out. The reason being that an indicator for a health condition, a safety condition and liveability of city inhabitants is related to one of the sub-classes of environment and economic indicators. For example, decrease in 'Emission_indicator' can increase 'Social_indicator'. Thus, in an application using GenCLOn, a correlation among these indicators can be established to estimate the social indicator.

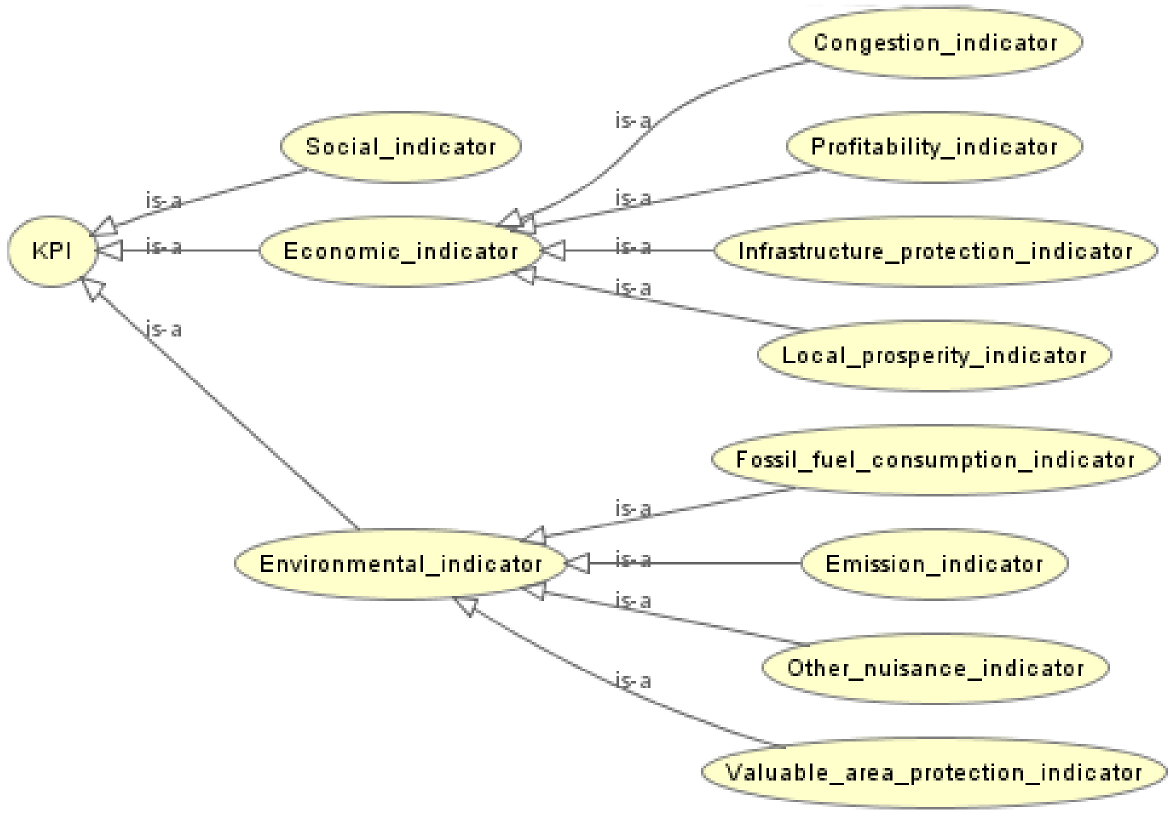


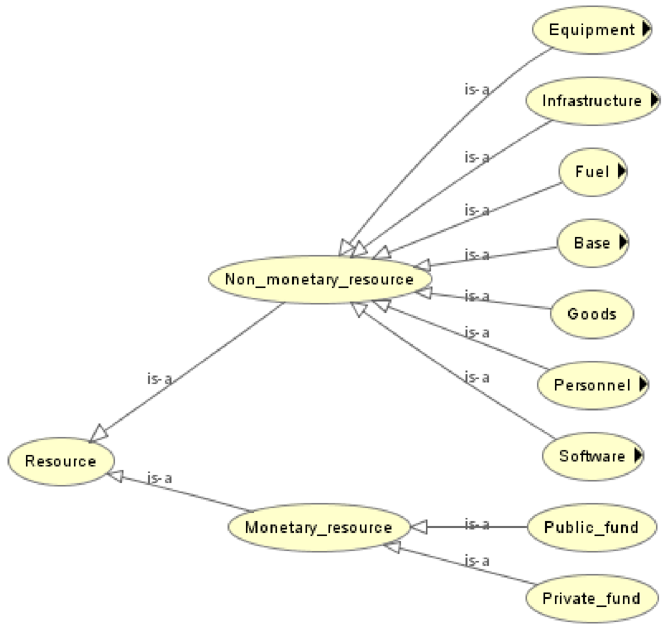
Figure 4.4 Hierarchical structure of the class 'KPI'

Mirroring the class 'Objective', the structure of 'KPI' is simpler and only contains two sublevels. The reason is just to respect the nature of terms. For example, the lower level components of 'Emission_indicator' are the concentration or mass of all kinds of emission, which can hardly be further classified and thus it should be created as an 'instance'.

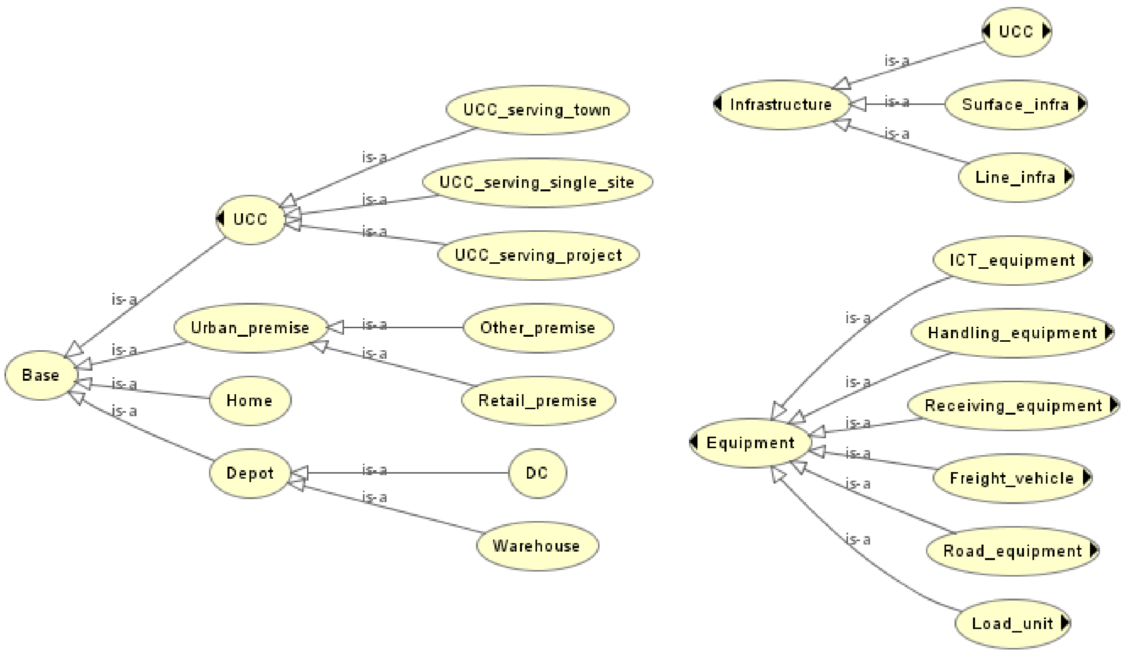
(4) Resources

Compared with the classes created before, 'Resource' involves many hierarchical levels (see Figure 4.5). Resource could be classified as 'Monetary_resource' and 'Non_monetary_resource' where the former comprises of 'Private_fund' and 'Public_fund', and all the remaining resources fall into 'Non_monetary_resource'.

'Non_monetary_resource' consists of seven sub-classes. Starting with "Base", a sub-class of "Base" mainly acts as the destination and origin of 'Transiting' in this ontology. Someone may argue that why not directly represent destination and origin by 'Private_actor' (i.e. create a slot 'address' for 'Privator_actor'). This action is tempting because it actually can simplify the ontology and simplifying is always something desirable. However, certain private actors, such as a retail chain playing multiple roles in the logistics chain, can simultaneously possess at least one depot and one retail premises. An implied problem will then be that a 'Transiting' can have the same stakeholder as both origin and destination (i.e. depart from address A to address A), which does not make sense. Hence, we have to separate the 'location' concept from 'Private_actor' and the introduction of 'Base' can exactly fulfil this task. Within the scope of this ontology, the concept of base is that shippers, receivers and UCC (Urban consolidation centre) operators must have certain physical locations where the goods can be stored, handled or delivered.



(a) Details of main class 'Resources.''



(b) Structure of sub-classes 'Base', 'Infrastructure' and 'Equipment.'

Figure 4.5 Hierarchical structure of class 'Resources.'

Notice that, under the class 'Depot', sub-classes 'Warehouse' and 'DC' are attached. Also 'Retail_premise' and 'Other_premise' have not been further classified because their sub-classes do not imply any functional differences (i.e. share the same attributes/properties). Moving to the class of 'Equipment', six sub-classes are defined under it, among which 'Freight_vehicle' takes a big share due to the special focus on it. Assuming that most urban goods deliveries are carried out using road freight vehicles, 'Road_freight_vehicle' is further categorized into seven sub-classes. It is obvious that these classes are not mutually exclusive, and the reason for grouping in this way is to provide various insights. For example, sometimes the users of the ontology care about multiple criteria of one object; then monotonous classification will weaken the instructive power of the ontology. All of these have been set as ‘defined’ classes’ and the corresponding ‘necessary and sufficient’ conditions are based on their key properties. It deserves a mention that a case of ‘multiple inheritances’ is present here as well, i.e. besides a sub-class of ‘Base’, ‘UCC’ is also a sub-class of ‘Infrastructure’. This situation exactly represents the fact that a ‘UCC’ can be considered both a base and a kind of infrastructure within the scope of this ontology.

(5) Measures

Different from all the classes given before, there is so far no clear classification of the city logistics measures. Thereofre, the hierarchical structure of class “Measure” has to be built from scratch. In the review framework, we categorised the measure (i.e. solution approach) in three broad categories 1) Technology 2) Policy and 3) Planning. Such a broad categorization serves purpose for the review where the focus is to classify the measures and get an overview of the popularity of the measures. However, while developing the city logistics ontology, the description of measures should be detailed. Therefore, a wide variety of existing measures as well as any possible, but have not yet been implemented, measure in the city logistics domain should be included in this ontology. Keeping this need in mind and following the consistency with other top classes, we take a stakeholder-based view to group measures according to their potential implementers. Three top classes are then mapped as ‘Governance_measure’, which can be implemented by public authorities; ‘Private_measure’ that can be implemented by private actors; and other measures that either need a joint effort of both sides (i.e. PPP) or can be performed by either side (i.e. ‘Using_ITS’ and ‘Using_alternative_mode’). Figure 4.6 shows the hierarchical structure of class “Measure” with its first-level sub-classes.

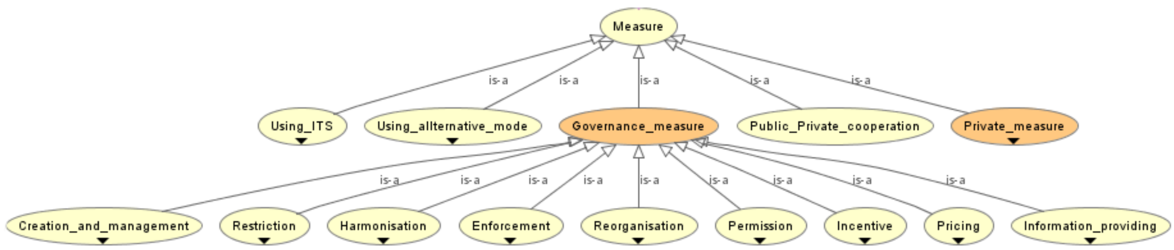


Figure 4.6 Hierarchical structure of class ‘Measures.’

Governance_measure: This class is defined as ‘measures that can be implemented by the public authority’. Nine sub-classes are formed beneath ‘Governance_measure’. Details about these measures can be found in (Visser et al., 1999; Taniguchi et al., 2004 ; Browne et al., 2007; Crainic, 2008).

Using_alternative_mode: This type of measure focuses on using non-tradition way (e.g. canal) for city logistics activities. This type of measure needs a strong involvement of all the actors that include both public and private actors from an activeness and regulatory viewpoint respectively. So, it is actually both a ‘Private_measure’ and ‘Public_measure’. The reason for listing it in parallel to its potential super-classes is again the implied multiple inheritance.

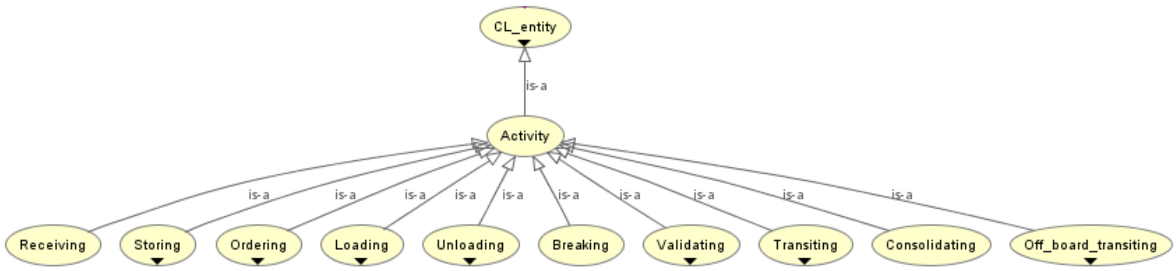
Public_private_cooperation: As suggested by its name, this type of measure will never work in the absence of either public or private sides. Thus, following the same principle as above, we isolate it from both ‘Private_measure’ and ‘Governance_measure’.

Using _ITS: This part can be completely assigned to 'Private_measure' and 'Public_measure' without any multiple inheritances. The reason for creating a separate class is to highlight the importance of the ITS concept in the city logistics domain. Moreover, due to its inheritance, with the assist of the logic reasoner, they can still be easily assigned into 'Public_measure' or 'Private_measure'.

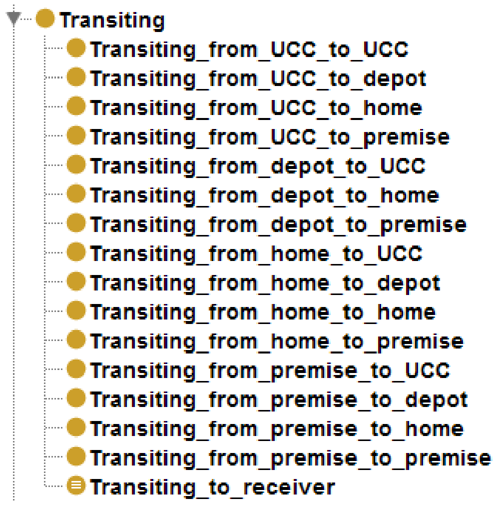
Private_measure: This class is defined as 'measures that can be implemented by private actors'. Different from 'Governance_measure', Private_measure enjoys many existing classifications provided in the literature. The structuring of 'Private_measure' is exposed to a lack of reference. A casual classification will negatively influence the accuracy of the ontology. Accordingly, the optimal solution will be directly putting all private measures collected from diverse literature under the class 'Private_measure' without any manually asserted hierarchies (except the ones that are very explicit and certain). When 'properties' or 'attributes' are attached to these measures, we can again use the logic reasoner to achieve various categorization. For example, a new class 'Congestion_reducing_measure' can be created under 'Private_measure'. It can then be given a 'necessary and sufficient condition' as 'Private_measures' that can help to achieve the 'Congestion_reduction' objective. In this way, all measures that meet this criterion will be automatically asserted as a kind of 'Congestion_reducing_measure'.

(6) Activity

Private actors involved in the supply chain perform a series of sequential logistics activities to achieve successful goods movements. The end of an activity could trigger a different or repeated activity depending on the particular situation. Thus, it is possible roughly to reproduce the typical process flow of city logistics transport with these activities, and this concept is deemed to be able to facilitate the relevant modeling work. All activities should be performed by at least one stakeholder with certain resources (e.g. equipment, personnel), and sometimes the corresponding infrastructure must be in place (e.g. road for 'transiting'). Main activities involved in a delivery trip within the scope of this ontology are depicted in tree-like structure below in Figure 4.7(a).



(a) Details about main class 'activity.'



(b) Details about 'transiting' class

Figure 4.7 Hierarchical structure of class 'Activity.'

Among these activities, 'Transiting' is highly specified with all the OD pairs within the scope. The reason for doing so lies in the various extents to which the importance of these 'Transitings' can be. For instance, the 'Transitings' to urban premises and homes deserve more focus than the ones between depots for the different geographical areas involved. Correspondingly, there is an extra 'defined' sub-class attached under 'Transiting', namely 'Transiting_to_receiver' (see right side of Figure 4.7 (b)). The 'necessary and sufficient condition' of it is, if expressed in natural language, 'transiting that has urban premise or home as its destination'. This class could be deemed as the 'VIP' of 'Transiting's and is highly relevant to the KPIs of congestion, nuisance and logistics costs. It also has an exclusive attribute as 'extra VKT (Vehicle kilometer travelled) for finding a parking area', which is of poor importance for other 'Transiting's. Besides, 'Loading', 'Unloading' and 'Storing' also get further classified in light of the various physical locations where they can be performed. The reason for doing this is twofold. At first, just like 'Transiting', the locations can determine the potential impact of these activities on the KPIs of city logistics. Secondly, activities with clarified location can facilitate defining the 'trigger' relations between each other. Thanks to this, a more unambiguous process flow can be represented by the ontology. 'Breaking' and 'Consolidating' are kept alone since they can only be performed in UCCs in the given scope of GenCLOn.

(7) R&D

The hierarchy of 'R&D' is derived in light of the classification proposed by Quak (2008). Although not very old, the city logistics research domain has been very active since the last decade and a half. A direct effect of this can be found in Figure 4.8 which depicts detail classification of R&D approaches available in the city logistics domain. Most of these 'R&D's can directly help to improve the measures or resources covered in this ontology. For instance, the 'Cooperation_R&D' is dedicated to improving the feasibility, as well as benefit from cooperation between 3PL carriers. Differently, 'Research_oriented_contribution' is exclusively aimed to facilitate the R&D work itself and has no immediate relation to certain measures or resources. The whole class of 'R&D' should act as a 'library index' where domain-specific literatures and other efforts can be recorded and categorized.

Figure 4.8 The structure of the class 'R&D.'

(8) Value partition

In GenCLOn, 'Fuel' is created as an 'object' rather than an attribute of the class 'Road_freight_vehicle' because we want to specify it in detail by attaching attributes to it as well as further classifying it. It is the same case for 'Base' that is created as an independent object rather than an attribute of 'Private_actor'. In an ontology, properties/attributes can only be attached to an 'object' (i.e. class and instance/individual). This rule implies that all the concepts that require further specification or will be used to describe other objects (e.g. 'KPI' is used to describe 'Objective') must be created as objects. However, some objects to be created do not enjoy positions under the top seven classes defined so far. For example, we want to create a class 'Inventory_policy' to address the inventory policy adopted by a shipper. However, this new class cannot be associated with any of the top seven classes. That is, 'Inventory_policy' is not a 'kind of' 'Stakeholder' or 'Objective' or 'KPI' or 'Resource' or

'Base' or 'Activity' or 'Measure' or 'R&D'. It is different from the case of 'Fuel' which can be located under 'Resource' because it is actually a 'kind of' resource in the given context. On the other hand, the ontology can easily lose its hierarchy and deviate from the real world (Noy and McGuinness, 2001) if all those 'homeless' classes are created in the same way as 'KPI' and 'Base', regardless of their relative importance in the domain. To cope with this problem, the class 'Value_partition' is created especially to take in those 'homeless' classes without implying too much structural change. The reason for name 'Value_partition' is that all the members of this class act as certain 'value' used to specify another object via the corresponding 'object property'. This reasoning will be addressed in detail in the next section. These homeless classes are mutually exclusive, and each partition of this top class depicts separate feature used for other classes of GenCLOn[11]. Figure 4.9 shows the hierarchical structure of class "Measure" with its first-level sub-classes.

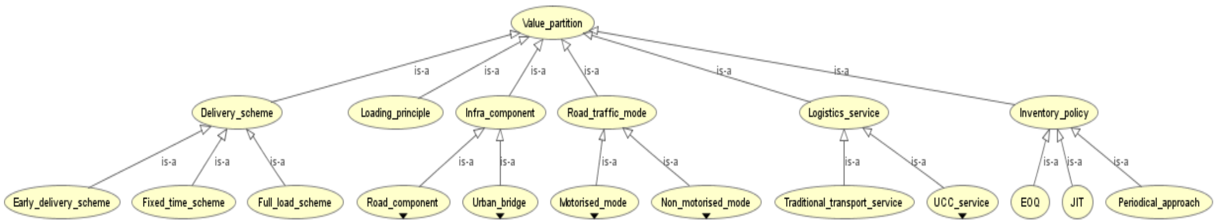


Figure 4.9 Hierarchical structure of class 'Value_partition.'

4.5. GenCLOn axioms

The hierarchical city logistics classes and their instances alone cannot provide sufficient information needed to understand the city logistics domain. Thus, the properties describing the attributes of individuals must be defined in the ontology. Classes, typically, have two kinds of properties, namely 'object property' and 'data property'. The former could be considered a bridge connecting classes/individuals and the latter is a defined slot where data value can be filled in. Together with the customized facet and quantifier/cardinality of properties, we can define axioms that stipulate the relationships among classes/individuals. In simple terms, an axiom is a first-logic expression comprising of subjects, objects and predicates (i.e. properties) in the form of Subject-Predicate-Object. Thus, these axioms are used to associate class and property identifiers with either partial or complete specifications of their characteristics and give other logical information about classes and properties. Additionally, axioms place constraints on sets of individuals (i.e. classes) and the types of relationships permitted between them. In doing so, the axioms provide semantics by allowing systems to infer additional information based on the data explicitly provided.

4.5.1. GenCLOn axioms: naming conventions

We follow the same naming convention as we did for defining classes in the previous section. Moreover, in case of naming the object property, we use the name of the class associated with a small modification. For example, we can simply create an object property, named as 'has_objective' or 'is_objective_of' to show the connection between 'Stakeholder' and 'Objective'. Then we have two (software-specific) first-order-logic expressions as below:

[11] See discussion on naming http://www.w3.org/TR/swbp-specified-values/

```
Stakeholder has_objective Objective
Objective is_objective_of Stakeholder
```

With these definitions, the ‘Stakeholder’ object and ‘Objective’ object are now connected. Notice that there could be various alternative ways to name the object properties mentioned above, such as ‘own_objective’ instead of ‘has_objective’, ‘belong_to’ rather than ‘is_objective_of’. Despite that how the property is named will not imply any semantic changes; we are still inclined to adopt a unified naming manner as depicted below to avoid confusion:

- For object property specifying the proactive relations from ‘Stakeholder’ to other classes (e.g. ‘Objective’, ‘Resource’), naming it in the manner of ‘has_object’ as much as possible, and name the corresponding inverse property as ‘is_object_of’ as much as possible
- For data property, directly naming it (e.g. address)

4.5.2. Top-level hierarchy of GenCLOn

There are general relations (object property) among the seven classes (excluding value partition) described in section 4.4.2, and each of them has its own properties that are more specific. Figure 4.10 illustrates the main possible relations among the seven classes. Notice that the naming of these properties has been simplified for readability. Figure 4.11 and information from Table 4.1 gives an idea about GenCLOn’s extent and extension. In the following sections, description of properties of ‘Stakeholder’ together with part of its sub-classes will be given stepwise so as to throw light on some basic axiomatic syntax. Some over-complicated syntactic issues will be weakened or skipped to make the content easily understandable.

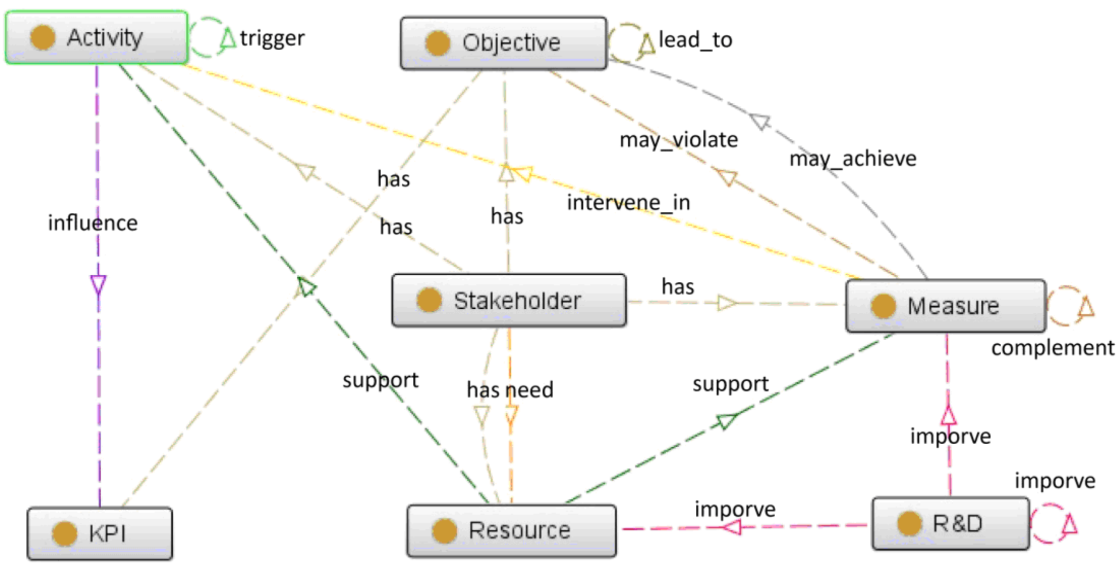


Figure 4.10 Top-level hierarchy of GenCLOn

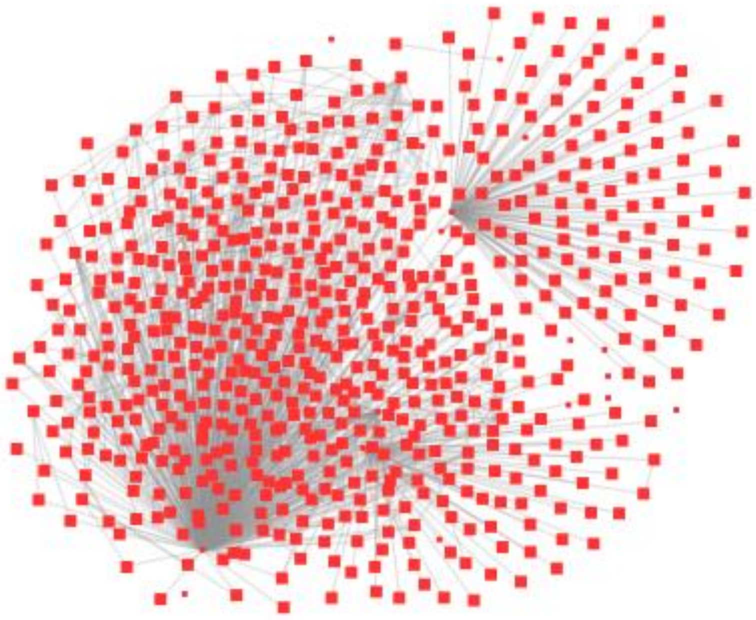


Figure 4.11 Visualization of depth and width of GenCLOn

Table 4.1 Quantitative information of GenCLOn

Ontology detail	Count
Class	443
Object property	63
Data property	108
Individual	170
Class axioms	805
Object property axiom	73
Data property axiom	56
Individual axiom	175
Annotation axioms	751

4.5.3. Properties of GenCLOn classes

(1) Property of top level – 'Stakeholder.'

The properties of the top-level class are the most generic ones and will be inherited by its descendant classes with no exception. In other words, the sub-classes of 'Stakeholder', namely Private_actor and Public_authority will have all the properties of 'Stakeholder'. It is a primary rule of the ontology and is also a reflection of real world.

We start with the property has_objective and give more detailed explanation. At first, each member of the ‘Stakeholder’ class must have at least one ‘Objective’. Thus, it is rational to assert that

```
Stakeholder has_Objective some Objective
```

Where, the object property ‘has_objective’ indicates the proactive relationship from the individuals in class ‘Stakeholder’ to the ones in class ‘Objective’. It is clear that in this ontology, only ‘Stakeholder’ can have an ‘Objective’. Thus, there is no problem setting the ‘domain’ of the property ‘has_objective’ as ‘Stakeholder’ and the ‘range’ of it as ‘Objective’ (see Figure 4.12). Notice that the word ‘some’ here is the so-called ‘existential quantifier’, which indicates that ‘any’ instance of the class ‘Stakeholder’ participates in at least one relationship with the specified object property ‘has_objective’ to instances that are members of the class ‘Objective’. The common mathematic expression of the existential quantifier is the symbol ‘$\exists$’. Its natural expression exactly equals to ‘each stakeholder has at least one objective.

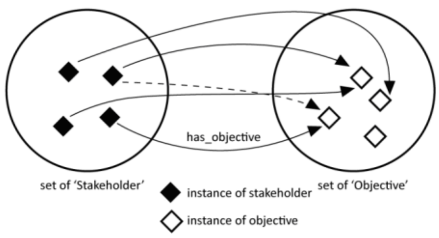


Figure 4.12 Visualization of the axiom ‘stakeholder has_objective some Objective.’

Driven by the same principle, we will similarly derive another stakeholder-related object property as ‘has_measure’. An axiom built with the property and the appropriate subject, object and quantifier can then be written as:

```
Stakeholder has_measure some Measure
```

Though here the object property ‘has_measure’ is created and attached to ‘Stakeholder’, it is just used to indicate the generic relation between ‘Stakeholder’ and ‘Measure’. The detailed relations between specific stakeholders and their specific measures will be built via its inverse property ‘is_measure_of’. The reason is that if the object property ‘has_measure’ is adopted, then for each sub-class of ‘Stakeholder’ we have to go through all sub-classes of ‘Measure’ in order to choose the ones the specific stakeholder can perform. It is very likely to miss certain measures due to the large number of options (i.e. sub-classes of ‘Measure’). However, if we do it the other way around, the possibility of missing out will decrease a lot since there are fewer sub-classes of ‘Stakeholder’.

‘Stakeholder’ must have a ‘name’ with which other stakeholders can interact with her. In reality, a ‘Stakeholder’ can have multiple names. Thus, the quantifier of ‘name’ could be ‘some’. Then we have to think about the data type of the slot ‘name’. In Protégé, there is a complex set of pre-defined data types and some of them (e.g. time, Name) cannot be read by the logic reasoners. To ensure a high compatibility and meanwhile avoid work beyond the scope, we hereby only use common data types like ‘integer’, ‘float’ and ‘string’. In case all of these three do not fit, the data type ‘PlainLiteral’ will be adopted, and it is compatible with all text typed manually. Obviously, here ‘string’ should be the one that best fits a ‘name’. Then an axiom is carried out as below

```
name some string
```

Besides ‘name’, the class ‘Stakeholder’ does not have any more fundamental data properties in this ontology.

(2) **Property of the second level – ‘Private_actor.’**

In an ontology every sub-class automatically inherit all properties from their super-classes and possesses specific properties that their parents do not have. The only constraint is that these properties must be consistent with the properties of their super-classes. For example, we can only assert ‘a wine must contain alcohol’ and cannot assert the ‘color’ of all wines must be red or white because ‘color’ is a specific property of the children of ‘Wine’. Again, since it has been asserted ‘all wines must contain alcohol’, then it is forbidden to have a wine ‘without alcohol’ as the sub-class of ‘wine’. Due to the highly heterogeneous nature of private actors (e.g. different objective, different resource), there is hardly any shared attributes that can be generally asserted to ‘Private_actors’. For the same reason, we avoided asserting constructive properties that could be inherited by all members of ‘Private_actor’.

(3) **Property of the second level – ‘Public_authority.’**

Compared with the heterogeneous nature of individuals of ‘Private_actor’, properties of members of ‘Public_authority’ are highly homogeneous and can thus be generally asserted.

No matter local, regional or national authorities, all want to improve the life quality of urban inhabitants and it is thus rational to assert

```
Public_authority has_objective some Emission_reduction
Public_authority has_objective some Other_nuisance_reduction
Public_authority has_objective some congestion_reduction
Public_authority has_objective some Safety_objective
Public_authority has_objective some Health_objective
Public_authority has_objective some Liveability_objective
```

‘Fossil_fuel_consumption_reduction’ is not included above because it is a higher-level objective that only belongs to national and even international (e.g. EU) authorities. Roads with different hierarchies are managed by the public administrators on different levels. For example, the backbones of a national road network should be managed by the national administrators while local streets are under control of municipalities. Thus, it is rational to assert

```
Public_authority has_resource some Road
```

Surface infrastructures such as parking lots or loading zones in urban areas are managed only by local authorities; therefore, it will not be set as a property of Public_authority (the super-class of ‘Local_authority’). Each level of public authorities should have some governable fiscal revenue that could be used to invest in city logistics projects or to subsidise private actors’ initiatives. It is thus rational to assert

```
Public_authority has_resource some Public_fund
```

(4) **Property of the third level – 'Carrier', 'Shipper', 'Receiver.'**

Carrier: 'Carrier' is the sub-class of 'Private_actor' and is also one of the three role-based stakeholders. All carriers have certain homogeneous attributes which can thus be generally asserted. As mentioned in the description of 'Stakeholder' class, 'Carrier' has been set as a 'defined class' with a sufficient and necessary condition as below

```
(has_resource some Road_freight_vehicle) and (has_resource some Driver)
```

Notice here the term 'and' is used to build a 'composite' axiom. It can be simply read as its natural meaning, i.e. denoting a coordinative relation. With this axiom, all the private actors that have a road freight vehicle and a driver as their resources will be automatically assigned to 'Carriers' by the logic reasoner. Within the city logistics context, object properties for carrier are mentioned below.

```
Carrier has_activity some Transiting
Carrier has_activity some Loading
Carrier has_activity some Unloading
Carrier has_activity some Off_board_transiting
Carrier need_resource some Road
Carrier need_resource some Surface_infrastructure
Carrier has_objective some Congestion_reduction
Carrier has_objective some Transport_cost_reduction
Carrier has_objective some Logistics_quality
```

Given the context of city logistics, carriers are featured by their unique resources as drivers and road freight vehicles. Hence, it is necessary to know their available transport capacity. Transport capacity is defined, as a combination of available drivers and available vehicles capacity in terms of volume or mass for *specific types* of goods[12] in this ontology. For instance, given a specific type of goods, a carrier has two trucks available with a capacity of five tons each and only one driver available. Then we can only say that the carrier just has a capacity of five tons available for the time being. The static overall capacity of a carrier may be high while only the available part makes sense. Thus, it is necessary to assert

```
available_transport_capacity exactly 1 float [>=0.0f]
```

Notice here the term 'exactly' is used. It is the so-called cardinality restriction that specifies the exact number of relationships that an individual must participate in (Horridge et al., 2004). Accordingly the axiom above could be read as 'there must be exactly one value for the slot 'available_transport_capacity'. The following '[>=0.0f]' is a software-specific syntax that constrains the range of the filler. Since it is possible for a carrier to have no vehicles or drivers temporarily at hand, '0' should be included in the range.

Carriers (and also shippers and receivers involved in the logistics chain) must provide contact information such as phone number or e-mail address. Thus, it is rational to assert:

```
Contact_info some PlainLiteral
```

[12] For different types of goods, the transport capacity may vary. For example, a carrier may have trucks available for goods with no temperature demand, while have no trucks available for frozen or chilled goods.

Shipper: 'Shipper' is the second 'role-based' stakeholder and also has some common attributes to be asserted. Similar to 'Carrier', 'Shipper' has also been set as a 'defined class' with definitive axioms as below

```
has_resource some Goods
```

The rationale behind this assertion comes from the essential attribute of a shipper. Within the scope of this ontology, a business party is deemed a shipper when it has goods to be delivered. Although some inhabitants may also have goods to be delivered, they have been excluded from the scope. Object properties of shipper are listed below.

```
Shipper has_objective some Logistics_quality
Shipper has_objective some Transport_cost_reduction
Shipper has_activity some Validating_goods_order
Shipper has_inventory_policy exactly 1 Inventory_policy
```

Notice that here 'Inventory_policy' is created as an 'object' rather than a data slot. It is put under the class 'Value_partition' with three sub-classes under it, namely 'EOQ', 'Fixed_period_approach' and 'JIT'. The reason for doing so is just the same as mentioned before: 'Inventory_policy' is considered an important concept in the city logistics domain and deserves further specification with more attributes. For example, 'EOQ' now has data properties as 'inventory_level', 'order_quantity' and 'reorder_point' which are the three key parameters for this policy. The users of the ontology then can be well informed about this knowledge.

Receiver: 'Receiver' is the third 'role-based' stakeholder and mainly includes 'Premise_retailer' and 'E_shopper'. The essential attribute characterising a member of 'Private_actor' as a 'Receiver' is different from the ones for 'Shipper' and 'Carrier'. A receiver does not have any unique resource such as the road freight vehicle and drivers monopolised by carriers or the goods monopolised by shippers. Thus, we have to consider it differently. Apparently, among the three roles involved in the final distribution of a supply chain, only 'Receiver' demands the goods to be delivered. It is thus rational to define all individuals that meet the condition below as the members of 'Receiver'.

```
need_resource some Goods
```

The most important object properties of a receiver are listed below.

```
Receiver has_objective some Logistics_quality
Receiver has_objective some Transport_costs_reduction
Receiver has_objective some Receiving_cost_reduction
Receiver has_objective some Other_nuisance_reduction
Receiver has_activity some Ordering_goods
Receiver has_activity some Receiving
```

Premise retailers have clear inventory policies while it is tricky to define the way individual consumers order goods via e-commerce. They order goods whenever they want, and this behaviour pattern resembles the 'JIT' concept (i.e. small or zero inventories, order when need). Thus, if we take a broader definition of 'inventory policy', all receivers then could be deemed to be driven by certain inventory policies. This concept will lead to the assertion below:

```
Receiver has_inventory_policy some Inventory_policy
```

(5) Property of third level – 'Local_authority', 'Regional_authority', 'National_authority.'

Local authority: 'Local_authority' is the sub-class of 'Public_authority' and only has three specific object-property- based axioms as below

```
Local_authority has_objective some Competitive_retail_industry
Local_authority has_objective some Creation_of_job
Local_authority has_objective some Infrastructure_protection
```

Each local authority wants that the retail industry in its area can attract more shoppers, say, mainly from its adjacent areas. It is thus a very local-specific (i.e. selfish) objective that cannot be attached to the higher-level authorities. This rule also applies to the second objective 'Creation_of_job' that need to be based on the fulfilment of the first one. For the third axiom, the 'infrastructure' refers to the road in a specific urban area.

Regional _authority: From the standpoint of a regional authority, it is essential to find collaboration for city logistics activities among cities of a region. Thus, important property for this class would be

```
Regional_authority has_objective some logistics_quality
```

National_authority: Different from lower-level authorities, national administrators have to consider sustainability from a global perspective. Accordingly the preservation of non-renewable resources comes into agenda. It is thus rational to assert

```
National_authority has_objective some
Fossil_fuel_consumption_reduction
```

So far, the relations occurring most frequently in this ontology have been illustrated with the axioms of 'Stakeholder' along with its top two layers of sub-classes. The construction of other axioms follows more or less the same rules and can be understood by browsing through the ontology.

4.6. Application of city logistics ontology

An ontology can be used passively as a database where users can acquire knowledge of interest or be informed about the knowledge structure of the domain. It may also be used actively as a component of models and interact as a modelling part and thus it can help to analyse the knowledge it contains. The following sections describe different ways of using the city logistics ontology.

4.6.1. Knowledge sharing

The most basic application of an ontology is to share the domain knowledge with its users as the ontology contains information in a highly structured. Users can search for the terms of interest, check their attributes as well as annotations providing highly refined information. For example, using GenCLOn a user can easily start exploring information about a UCC. After selecting the class 'UCC', (see Figure 4.13), the user can immediately get the definition of 'UCC' via the corresponding comment of the class (see Figure 4.14). Besides this, a list of axioms will also be visible under the annotation (see Figure 4.15). Important attributes of

‘UCC’ are summarized into these axioms, and each of them is equipped with a dedicated explanation. A straightforward classification of the main three types of ‘UCC’ is visible after a click on the small triangle (see the right side of Figure 4.13).

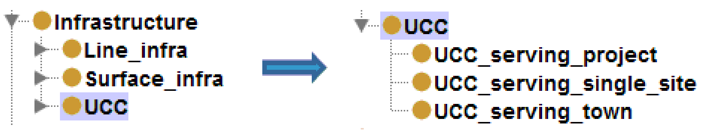


Figure 4.13 Expanding the class ‘UCC.’

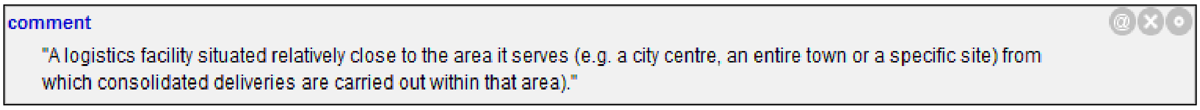


Figure 4.14 Annotation on class 'UCC.'

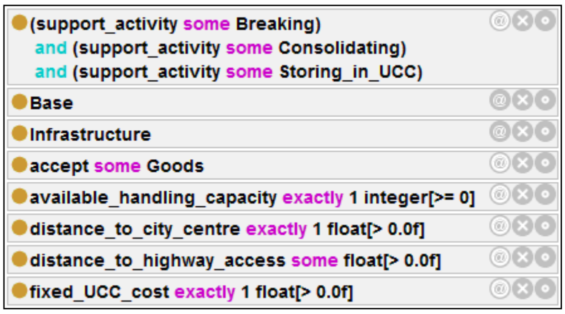


Figure 4.15 The list of axioms of UCC

Based on the features mentioned above, the user can easily get information about city logistics concepts. It is also possible to access other related terms via the corresponding axiom. For example, the ‘UCC_operator’ is connected to ‘UCC’ via the object property ‘is_resource_of’, and then a systematic learning course is practiced subconsciously. What is more, for ABM developers, the function discussed above provides an easy interface to sort out the relationships between different objects. The developers can in turn add their object instances for a specific case studies (i.e. data entry) (Keristead and Dam, 2010).

4.6.2. Analysing and reasoning

Another important application of the ontology is to analyse and reason the knowledge it contains, and this can be achieved mainly via two ways, namely automated categorization and query.

(1) Automated categorisation

The logic reasoner (e.g. Protégé - in this case) can restructure the manually asserted ontological hierarchy and in turn infer or discover new/hidden relations based on the manually asserted ones. Such an action is especially useful when an ontology becomes too large as well as complex to maintain it. It has been mentioned in the description of the ‘Stakeholder’ class that deterministic stakeholders such as retailer, B2B shipper, 3PL carrier and inhabitant would be assigned to the role-based classes ‘Shipper’, ‘Carrier’ and ‘Receiver’ respectively in light of their relevant attributes. This operation is exactly a typical automated categorization suitable to be performed here as an example.

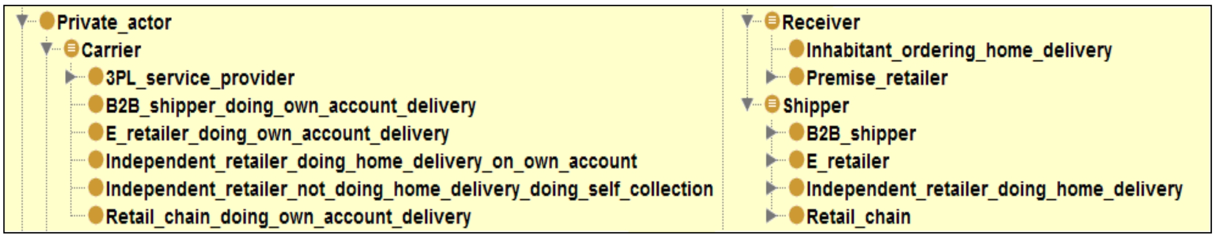


Figure 4.16 The automatically inferred sub-classes of 'Carrier,' 'Receiver' and 'Shipper.'

To illustrate the changes caused by the automated categorization, a recap of the original hierarchical structure of the class 'Private_actor' is necessary before running the reasoner. In Figure 4.2, it is evident that all the three role-based stakeholders do not have any sub-classes at that time. However, after running the reasoner, it can be immediately perceived that there are new sub-classes attached to 'Shipper', 'Carrier' and 'Receiver'(i.e. there are ► marks in front of them). If we expand these new inferred classes by clicking on the ► marks, their sub-classes will look like as shown in Figure 4.16. It is self-evident that the classification achieved by the reasoner is more complicated and involves several multiple inheritances. For example, classes such as 'Retail_ chain' and 'Independent_retailer' are simultaneously (completely or partly) assigned to different role-based stakeholders. With this automatically asserted hierarchy, the roles stakeholders can play in the city logistics chain becomes intuitive.

(2) Query and Answering

A well-constructed ontology can help to analyse domain knowledge by answering domain queries. When the objects (classes or instances) in an ontology are specified with attributes, then a series of queries based on those attributes can be posed by users. These queries can be answered by the ontology with the help of an appropriate software platform (e.g. Protégé – as, in this case). One example query in natural language is:

"To achieve a specific objective, what measures can be performed by the stakeholders?"

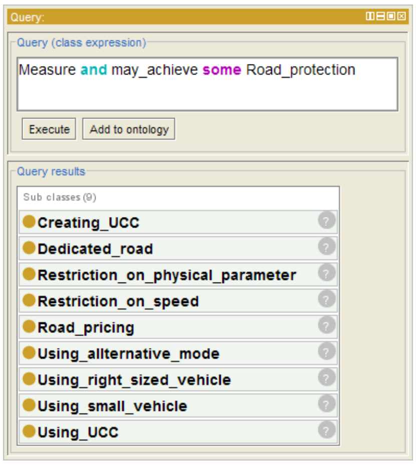


Figure 4.17 Formal query and the corresponding result for the measure that may help to protect the road.

Let's use the objective 'Road_protection' as an example. To answer the first sub-question the 'DL query' function provided by Protégé will be used to avoid manual effort (i.e. manually checking each sub-class of 'Measure'). The only premise for using this function is that the input question must be given in the formal language that can be understood by the program. The first sub-question can then be formally expressed as,

```
Measure and may_achieve some Road_protection
```

After clicking on the 'Execute' button, (see Figure 4.17) the 'DL query' will execute this question automatically on the basis of the predefined properties of each descendant class of 'Measure'. A list of competent measures will then be displayed as lower part of Figure 4.17. The essence of this operation is to pick out all the sub-classes of 'Measure' that have a 'may_achive' relation with the class 'Road_protection'.

4.6.3. Modelling and simulation

The ontology can be used as a knowledge sharing platform to understand the concept, its properties and relationships. While this is – indeed – useful but might not be sufficient for the modelling purpose. In fact, it would be much more useful if the model can access this information as the building blocks of the model and also query the information it requires directly from the ontology during simulation. There are multiple Java libraries available for this purpose[13]. Information from the ontology can be used for modelling purpose in two ways: code generation and annotation-based binding.

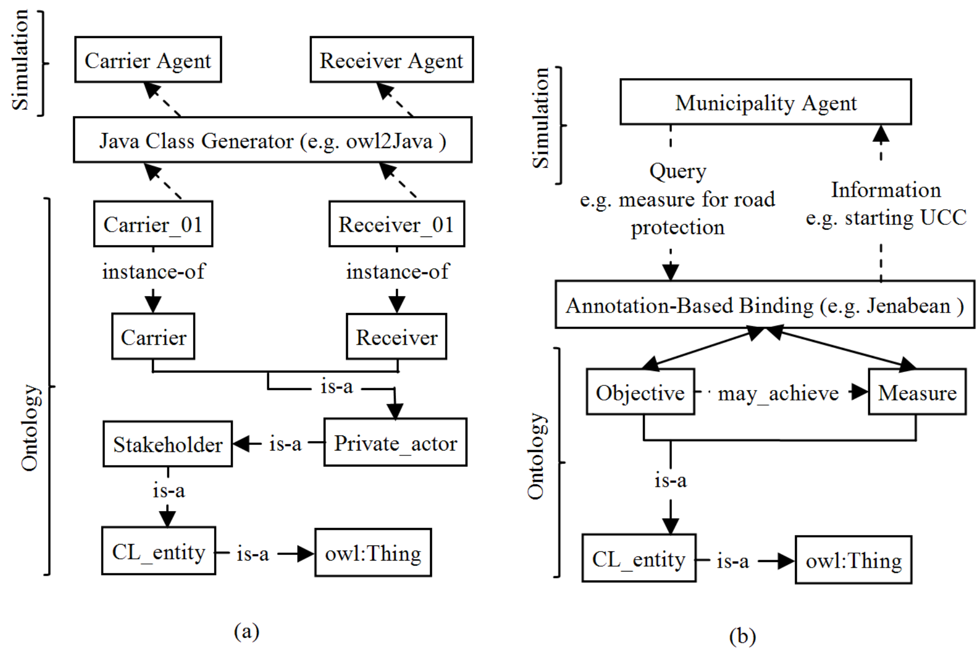


Figure 4.18 Use of Ontology for modelling (a) Code generation (b) Annotation-based binding

Java code generator generates Java classes using ontology classes, properties and relationship attached with ontology. Thus, classes generated from the city logistics ontology can be used to represents agents in an agent based simulation model for the city logistics domain. A code generator can be tremendously useful, and time-saving, provided the ontology is properly

[13] Check here for more detail - http://wiki.yoshtec.com/java-owl-api

detailed with specific property ranges (Cowan, 2009). In annotation-based binding approach, annotations of Java classes are linked with ontology data that allows the instantiated object to acquire relevant data from ontology – class or property. Unlike, code generation approach, the ontology is always connected with the model and works as graph database. Here, the acquiring of relevant data is done using a query language (e.g. SPARQL) in Java class of the agent. Figure 4.18 gives an overview of these approaches. Examples with detail description about both of this method can be found on the web (Giudici, 2009) and literature (Quasthoff and Meinel, 2009). For this research, we use code generation method to develop stakeholder agents. In *Chapter 6*, we will describe this procedure in detail.

4.7. Conclusion

In this chapter, we introduced a formal ontology aimed to systematically as well comprehensively specify the domain of city logistics in terms of the concepts involved along with their relations to each other. Extensive information and knowledge have been collected from relevant literatures as the theoretical foundation of the ontology. After a series of information processing, including sorting, refining and summarizing, the domain of city logistics is classified into eight classes. These eight classes are; 'Stakeholder', 'Objective', 'KPI', 'Resource', 'Measure', 'Activity', 'R&D' and 'Value_partition'. Together with the large number of sub-classes attached afterwards, these classes represent the city logistics domain with a hierarchical structure that abstracts the real world. Most classes are interconnected with others via defined relations and are noted for specific attributes that can help to build corresponding instances.

Conceivably, there will never be a perfect ontology since it is just a representation of knowledge that is something ever-growing and thus infinite. A manually constructed ontology has to be improved and enriched continuously. For example, in the city logistics ontology presented in this chapter, some important concepts such as public transport, individual shopping trips and service-oriented traffic are weakened considerably due to the delimitation of GenCLOn. Only their ultimate influences on freight traffic are shallowly represented in the ontology via data properties as instant traffic load of roads and demand rate of goods. Also detail logistics concepts (e.g. supplier contract, transportation contract) are not included as the purpose of GenCLOn is to represent daily activities of urban goods movements. Nevertheless, it should be noted that these concepts are very important as they decide pattern of urban goods movements. Further effort is required to specify these factors in detail. It can be achieved possibly via the introduction of a new stakeholder (e.g. service provider), new activities (e.g. choosing suppliers, consuming goods) and new measures (e.g. enhancing or starting a public transport service). It is also possible to combine these details from other ontological efforts mentioned in a literature review.

Besides the inevitable delimiting, the content covered by the ontology can also be further refined as well as enriched. At first, the ontological restrictions on classes and properties have been deliberately simplified. Such action was vital to facilitating reasoning and debugging that had been heavily burdened by the large number of objects (i.e. classes and instances) along with their properties in the ontology. For instance, some object properties can be further defined as 'functional', 'symmetric', 'transitive'. Moreover, their domains and ranges can be strictly constrained. All of these operations will definitely make the ontology more precise while imposing high hardware requirements, as well as more exposure to inconsistency caused by strictly ontological commitments among objects. These inconveniences should be avoided by a newly-developed ontology that has to be debugged from time to time. If competent hardware is in place, further work can be done to reclaim these restrictions.

Besides, some data properties such as ‘engine’ of vehicles can be converted into object properties to further classify and specify relevant data properties along with comments. This kind of conversion can even introduce new semantics. Intuitive examples are terms, such as ‘reputation’ and ‘address’ that can be connected to a new activity ‘Choosing_supplier’ via a new object property ‘depend_on’. This formulation will explicitly indicate that reputation and physical location (the distance between the bases of shippers to the receivers’ sites) are two important criteria during supplier-choice. Similarly, almost all the classes can be enriched continuously, and sometimes it is even possible to import directly an external ontology. For example, if an ontology dedicated to road is accessible, we can just download it and import it into the city logistics ontology and substitute it for the current class ‘Road’ as long as the new one is more competent. Similarly, part of this ontology can also be directly combined with other relevant ontology (e.g. an ontology for the holistic domain of logistics).

Moreover, due the limitation of the current ontology editors, some dynamic/stochastic relations among objects can hardly be represented. Accordingly, relations defined by default can deviate more or less from the real world. For example, the relation between stakeholders and objectives are quite uncertain and must be asserted in a deterministic way in the ontology nowadays. Encouragingly, there are now some initiatives on introducing randomness with the assist of approach like ‘fuzzy logic’ (Tho et al., 2006; Bobillo et al., 2009). These concepts, nevertheless, are still in a juvenile age and demand much further development. It is believable that an ontology will be able to reflect the world in a more realistic way when these technologies are mature enough.

Finally, this ontology is still at a generic level due to the extensiveness of the domain it tries to represent as well as the relatively low importance of instance creating at the current phase. As a result, many classes just end up with sub-classes rather than specific individuals that are addressed with concrete data. For example, in the ontology we only have classes such as ‘Goods’ or ‘Retail_premise’ and do not have a specific type of goods such as ‘Coca-Cola 330ml’ or a specific shop like ‘Wal-Mart 88th Street’. Fortunately, the ontology itself can act as the template for instance building since all the attributes that an instance should possess have already been stipulated. Accordingly, the work left revolves around only collecting and assigning data to the corresponding slots. This is exactly one of the most important merits of an ontology, namely facilitating instance-building.

References

Abdolmohammadi, M. and Wright, A. (1987). An examination of the effects of experience and task complexity on audit judgments. Accounting Review: 1-13.

Bobillo, F., Delgado, M., Gómez-Romero, J. and López, E. (2009). A semantic fuzzy expert system for a fuzzy balanced scorecard. Expert Systems with Applications 36(1): 423-433.

Browne, M., Piotrowska, M., Woodburn, A. and Allen, J. (2007). Literature Review WM9: Part I-Urban Freight Transport.

Browne, M., Woodburn, A. and Allen, J. (2005). Urban freight consolidation centers - final report.

Cowan, T. (2009). Binding Java Objects to RDF. from http://semanticweb.com/binding-java-objects-to-rdf_b10682.

Crainic, T. G. (2008). City Logistics. CIRRELT-2008-25.

Fayez, M., Rabelo, L. and Mollaghasemi, M. (2005). Ontologies for supply chain simulation modeling. Proceedings of the 37th conference on Winter simulation. Orlando, Florida, Winter Simulation Conference**:** 2364-2370.

Giudici, F. (2009). Elmo, a Semantic Entity Manager. from http://weblogs.java.net/blog/fabriziogiudici/archive/2009/10/26/elmo-semantic-entity-manager.

Horridge, M., Knublauch, H., Rector, A., Stevens, R. and Wroe, C. (2004). A Practical Guide To Building OWL Ontologies Using The Protégé-OWL Plugin and CO-ODE Tools Edition 1.0. The University Of Manchester, August 27.

Hoxha, J., Scheuermann, A. and Bloehdorn, S. (2010). An Approach to Formal and Semantic Representation of Logistics Services.

Huang, C.-C. and Lin, S.-H. (2010). Sharing knowledge in a supply chain using the semantic web. Expert Systems with Applications 37(4): 3145-3161.

Keristead, J. and Dam, v. K. (2010). A comparison of two ontologies for agent-based modelling of energy systems.

Leukel, J. and Kirn, S. (2008). A Supply Chain Management Approach to Logistics Ontologies in Information Systems, Springer.

Lian, P., Park, D. W. and Kwon, H. C. (2007). Design of Logistics Ontology for Semantic Representing of Situation in Logistics, IEEE.

Liou, W. C. and Chang, J. Y. Multi-view Ontology Based Logistical Management System.

Noy, N. F. and Mcguinness, D. L. (2001). Ontology development 101: A guide to creating your first ontology, Citeseer.

Ports, C. (2005). City Ports–project interim report. Emilia-Romagna, Bologna, Italy.

Quak, H. J. (2008). Sustainability of Urban Freight Transport: Retail Distribution and Local Regulations in Cities.

Quasthoff, M. and Meinel, C. (2009). Design Pattern for Object Triple Mapping, IEEE.

Rosch, E. (1999). Principles of categorization. Concepts: core readings: 189–206.

Smirnov, A. and Chandra, C. (2000). Ontology-based knowledge management for co-operative supply chain configuration.

Sullivan, J., Aultman, L. and Watts, R. (2012). The Challenges of Measuring Transportation Efficiency.

Taniguchi, E. and Tamagawa, D. (2005). Evaluating city logistics measures considering the behavior of several stakeholders. Journal of the Eastern Asia Society for Transportation Studies 6: 3062-3076.

Taniguchi, E. and Thompson, R. G. (2002). Modeling city logistics. Freight Transportation 2002(1790): 45-51.

Taniguchi, E., Thompson, R. G. and Yamada, T. (2004). Visions for city logistics. Logistics Systems for Sustainable Cities: 1-16.

Tho, Q. T., Hui, S. C., Fong, A. C. M. and Cao, T. H. (2006). Automatic fuzzy ontology generation for semantic web. Knowledge and Data Engineering, IEEE Transactions on 18(6): 842-856.

Uschold, M. and Gruninger, M. (1996). Ontologies: Principles, methods and applications. Knowledge engineering review 11(2): 93-136.

Visser, J., Binsbergen, V. A. and Nemeto, T. (1999). Urban freight transport policy and planning.

Xu, D., Wijesooriya, C., Wang, Y.-G. and Beydoun, G. (2011). Outbound logistics exception monitoring: A multi-perspective ontologies' approach with intelligent agents. Expert Systems with Applications 38(11): 13604-13611.

Ye, Y., Yang, D., Jiang, Z. and Tong, L. (2007). An ontology-based architecture for implementing semantic integration of supply chain management. International Journal of Computer Integrated Manufacturing 21(1): 1-18.

Yu-Liang, C. (2010). Rule-based ontological knowledge base for monitoring partners across supply networks. Expert Systems with Applications 37(2): 1400-1407.

Zhang, X. K. and Tian, T. (2010). Logistics Domain Ontology Model and Its Application. Advanced Materials Research 108: 1403-1408.

5 Ontology metrics and validation

5.1. Introduction and literature review

The consequential issue after developing an ontology is its validation. Confusion prevails in distinguishing evaluation and validation for the ontology. Often these words - "evaluation" and "validation" - are used synonymously. In our opinion, validating an ontology is *'a process of determining the degree to which the content and knowledge relations of the ontology are accurate representations of the real world from the perspective of the intended user(s)'.* Thus, the validation of the ontology involves comparison of the ontology data with the domain data. On the other hand, the evaluation of the ontology is a process of computing quantitative information of key characteristics of the ontology. Most ontology validation literature deals with the evaluation of the ontology by assessing ontological parameters such as depth, breadth. We prefer to call it ontology metrics which represent ontology parameters indicating details such as number of related classes, number of attributes.

In an article from 90's, Gómez-Pérez (1995) explored the idea of evaluating an ontology. The article states that the most important features for the evaluation of the ontology are its structure, contents, syntax, and a set of semantic properties that guarantee the coherence, completeness, consistency and conciseness of the definitions. Most of the literature on ontology evaluation suggests this theme but present many different approaches. For instance, Fox et al. (1996) proposed various set of criteria for manually assessing an ontology. Guarino and Welty (2002) proposed various notions such as identity, unity, essence, rigidity to define a set of meta-properties to evaluate different properties, classes, and relations of the ontology. Brewster et al. (2004) introduced a data-driven approach, which compares the ontology with a given text corpus[14] in order to determine how appropriately knowledge of a domain is

[14] text corpus is a large and structured set of texts electronically stored and processed

presented in the ontology. The data-driven approach uses probabilistic settings to evaluate the "best fit" between a corpus and the ontology.

A task-based approach, which usually applied to ontologies that are tightly integrated with an application, suggested by Porzel and Malaka (2004) explore the ontology quality for insertion, deletion and substitution features. Gangemi et al. (2005) presented a framework that considers depth, breadth, tangledness as quantified parameters measuring the quality of the ontology. Similarly, Tartir et al. (2005) introduced an evaluation framework called OntoQA. In this framework, the author evaluates the ontology based on schema metrics and knowledge metrics. The schema metrics evaluate richness, width, depth, and inheritance of ontology and the knowledge metrics evaluate the effectiveness of the ontology design and the amount of real-world knowledge represented by the ontology. The approach is effective for measuring the quality of the ontology in terms of quantified information. However, it cannot evaluate the knowledge representation error since the knowledge metrics only calculate how many relations are present in the ontology and do not check if these relations are correctly embedded in the ontology.

A survey by Brank et al. (2005) gives an overview of different approaches to ontology evaluation. According to the survey, an ontology can be evaluated at different levels and each layer can be separately evaluated by the application of a different approach. Table 5.1 shows the overview of the approaches.

Table 5.1 An overview of approaches to ontology evaluation (Source: (Brank et al., 2005)

	Approach to evaluation			
Level	Golden standard	Application based	Data driven	Assessment by humans
Lexical, vocabulary, concept, data	x	x	x	x
Hierarchy, taxonomy	x	x	x	x
Other semantic relations	x	x	x	x
Context, application		x		x
Syntactic	x			x
Structure, architecture, design				x

- Golden standard: comparing the ontology to a “golden standard”, which may itself be an ontology (Maedche and Staab, 2002)
- Application based: using the ontology in an application and evaluating the results (Porzel and Malaka, 2004)
- Data driven: comparing the ontology with source of data (e.g. a collection of documents) of the domain (Brewster et al., 2004)
- Assessment by humans: evaluation is done by humans who try to assess how well the ontology meets a set of predefined criteria, standards, requirements (Lozano-Tello and Gómez-Pérez, 2004)

Another review by Obrst et al. (2007) divides an ontology into three levels: language level, concept level and instance level. The review discusses issues and problems in ontology evaluation, describes current strategies and suggests some further approaches. Giving an example of gene ontology (Ashburner et al., 2000), the review concludes that the ultimate evaluation of the ontology is in terms of its adoption and successful use, rather than its consistency or coverage. The literature review about ontology validation suggests that there are multiple approaches existing for ontology evaluation where each has some pros and cons. Therefore, the usability of the approach depends on its use and user(s). For instance, if the domain does not have any standard ontology to compare with then the ‘Golden standard’ approach cannot be adopted. Similarly, an ‘application based’ approach is not possible if the ontology is generic and covers a wide range of details. In that case making a single model to cover all the details of the ontology is technically challenging. The city logistics ontology is a generic one, and so the data-driven approach is more suitable. Data collected from different sources can allow assessing the ontology from different perspectives.

In this chapter, two objectives are aspired to. First, we seek to make ontology metrics that list numerical properties of the city logistics ontology. The metrics give information about physical properties of the ontology such as number of classes, relationships, attributes. The frameworks proposed by Gangemi et al. (2005) and Tartir et al. (2005) are used to calculate metrics for evaluation since they compute all important parameters helpful to comment on the numerical structure of the ontology. The ontology metrics can give the prospective users information about the ontology coverage and expressiveness of ontology classes, attributes and relationships. Apart from the numerical information, city logistics ontology’s validity and soundness, its consistency, the sort of inferences for use in the applications, or its ability to be adapted and reused for wider purposes also must be clear. Therefore, the second objective is to validate the city logistics ontology – GenCLOn - by comparing it with information from the real world. We assert that ontology validation is usually the only way to ensure the precision of the knowledge presented in the ontology. We also believe the validation often cannot be performed completely automatically due to the complexity of the domain and the data presented in the ontology. Therefore, validation requires close cooperation of domain experts.

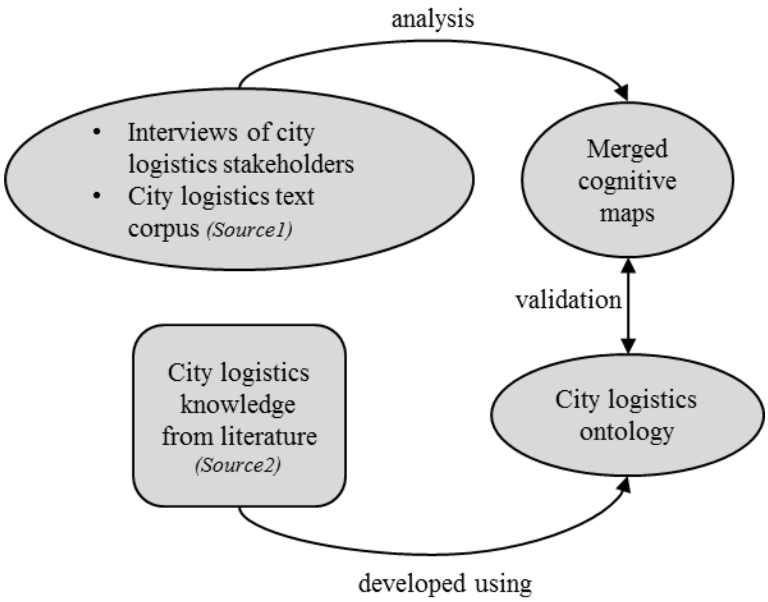


Figure 5.1 Schema for qualitative validation of city logistics ontology

Figure 5.1 represents the schema for validation of GenCLOn. In the case of city logistics, we incorporate information on real-world stakeholders from in-depth personal interviews and domain text corpus to generate cognitive maps. These maps are used to examine the precision of the ontology (i.e. quality validation) by manually checking the details (e.g. system component, knowledge representation) of the ontology.

5.2. Generic city logistics ontology (GenCLOn)

Fundamentally, an ontology consists of classes, its attributes and relationship between the classes. The classes represent system components of the domain for which the ontology is being developed (city logistics, in this case), and the relationships portray knowledge relationships among the system components (see Figure 5.2).

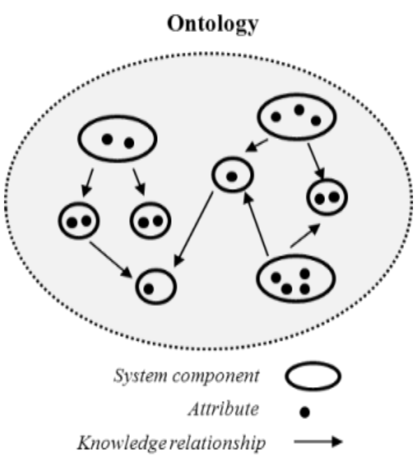


Figure 5.2 Representation of an ontology structure

Ontology can be divided into two broad categories from the point of view of its scope, 1) Generic ontology and 2) Case specific ontology. Figure 5.3 gives an indication of the difference between a generic and a case specific ontology.

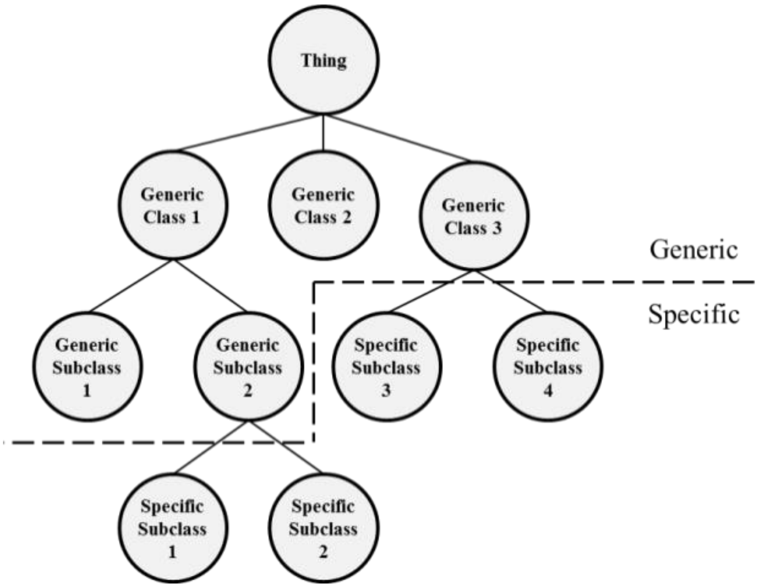


Figure 5.3 Generic versus Specific ontology (source: (van Dam and Lukszo, 2006))

The generic ontology includes general or basic concepts and relations necessary for knowledge representation and modelling the physical world (Martin and Eklund, 1999). Unlike a generic ontology, a case specific ontology describes more detailed sub-classes representing information about a specific case. For instance, a generic ontology for a production system includes machinery as an entity at an abstract level. A case specific ontology for a certain production system includes information about the machinery at very detail level by including machine type, size, design, speed, brand name as sub-classes. As per van Dam and Lukszo (2006) “The case specific ontology is a specialisation of the generic one and, on the other hand, the generic ontology is a generalisation of all underlying case specific classes”.

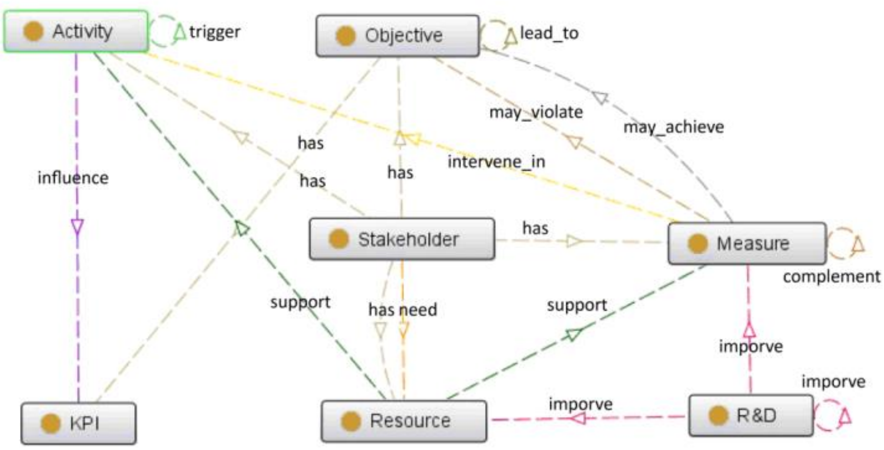


Figure 5.4 Top level hierarchy of GenCLOn

GenCLOn is a generic ontology as it includes the city logistics related concepts and relationships at a generic level. The generic level of GenCLOn is due to the extensiveness of the domain it tries to represent as well as the relatively low importance of instance creating. GenCLOn is developed to cover important and fundamental concepts of the city logistics domain and incorporate relation among each other. The schema depicting key classes and main possible relations for GenCLOn is reproduced in Figure 5.4.

The objective of developing GenCLOn at a generic level is to express the case specific parts of the domain in terms of the generic description. This generic-ness of the GenCLOn creates a strong framework that can form the foundation for flexible modelling platform for the city logistics domain (van Dam and Lukszo, 2006). To use information from GenCLOn for modelling purpose, it is essential to ensure that the coverage and quality of the content of the ontology are adequate. For this purpose, we prepare ontology metrics to comment on ontology's physical properties and validate it using information collected from city logistics stakeholders.

In preparing ontology metrics, the task is to assess dimensional ontological parameters (e.g. depth, breadth) using frameworks developed by Gangemi et al. (2005) and Tartir et al. (2005). These parameters answer questions such as: *How big is the ontology? How many relations are covered? How many attributes the classes of the ontology contain?* Section 5.3 describes calculation of GenCLOn metrics. The validation of GenCLOn includes the checking the system representation and knowledge representation in the ontology with respect to the domain information. The validation answers questions such as: *does the ontology covers topic related to the domain of interest?* and if yes, *does it covers the relations between classes correctly?* Section 5.4 describes the validation of GenCLOn by checking system representation and knowledge representation.

5.3. Quantitative evaluation of GenCLOn

Ontology metrics includes information about numerical properties of the ontology. Ontology primarily consists of classes and relationships between these classes. Each class in the ontology has certain attributes. By using methods based on the framework proposed by Gangemi et al. (2005) and Tartir et al. (2005), we calculate following parameters of ontology metrics for GenCLOn.

- Depth: describes what detail level the main concepts are explained (i.e. is-a relationships)
- Breadth: describes at what level the relevant concepts of the domain are covered (i.e. coverage of the domain)
- Relationship Richness: describes the diversity of the types of relations in the ontology
- Inheritance Richness: describes the generic (i.e. shallow) or specific (i.e. deep) nature of the ontology
- Attribute Richness: describes (on an average) at what level each class is described (e.g. a truck has engines versus a truck has engine, tires, driver cabin)

In remaining of the section, we describe each ontology parameter in detail and explain how it is calculated.

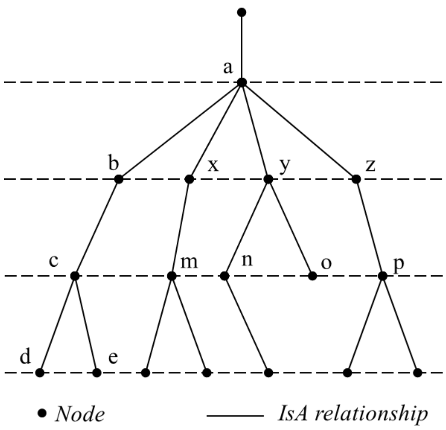


Figure 5.5 An example of ontology

5.3.1. Depth

Depth of an ontology is a property related to the cardinality of the paths of the ontology tree. Gangemi et al. (2005) describe the average depth of an ontology as

$$D_{Avg} = \frac{1}{n_{P\subseteq g}} \sum_{j}^{P} N_{j\in P} \qquad \ldots(5.1)$$

Where $N_{j\in P}$ is cardinality of each path j from the set of path P in a graph g and $n_{P\subseteq g}$ is the cardinality of P. In simple terms, the depth of an ontology is the ratio of sum of cardinality of all paths to the number of paths.

A path in the ontology is links of nodes from the top node to a leaf node. In the example ontology shown in Figure 5.5, a-b-c-d is one of the paths. The cardinality of each path can be calculated as a sum of number of nodes in each path. Thus, the cardinality of path a-b-c-d is 4 as it has 4 nodes. Accordingly, the sum of cardinality of all paths for the ontology represented in Figure 5.5 is 31, and total number of paths is 8.

5.3.2. Breadth

Similar to dimension depth, breadth of an ontology is a property related to the cardinality of the levels of the ontology tree. Gangemi et al. (2005) describes the average breadth of an ontology as

$$B_{Avg} = \frac{1}{n_{L\subseteq g}} \sum_{j}^{L} N_{j\in L} \qquad \ldots(5.2)$$

Where $N_{j\in L}$ is cardinality of each level j from the set of level L in a graph g and $n_{L\subseteq g}$ is the cardinality of L. In simple terms, the breath of an ontology is the ratio of sum of cardinality of all levels to the number of levels.

A level in the ontology can be described as an inheritance level from the top node. For example, in Figure 5.5, nodes b, x, y and z are at the first inheritance level from the top node a. The nodes c, m, n, o and p are at level 2 from the top node a and so on. The cardinality of each level can be calculated by summing all the IsA relationship nodes in the level. Note that as the level number increases, the number of IsA relationship also increase. For example, b has only one IsA relationship - b IsA sub-class of a. However, c has two IsA relationships – c IsA sub-class of b and c IsA sub-class of a. Accordingly, the sum of cardinality of all levels for the ontology represented in Figure 5.5 is 35, and total number of levels is 3.

5.3.3. Relationship Richness (RR)

Relationship richness reflects the diversity of the types of relations existing in the ontology. If the ontology contains only inheritance relationships, then it conveys less information compared to the ontology that contains a diverse set of relationships. The relationship richness is represented as the percentage of the non-inheritance relationships (e.g. non-IsA) between classes compared to all the possible connections that include inheritance and non-inheritance relationships. Tartir et al. (2005) describe relationship richness (RR) as the ratio of the number of non-inheritance relationships (P), divided by the total number of relationships defined in the schema (the sum of the number of inheritance relationships (IsA) and non-inheritance relationships (P)).

$$RR = \frac{|P|}{|IsA| + |P|} \qquad \ldots(5.3)$$

P = Number of non-IsA relationships, IsA = Number of IsA relationships

An IsA relationship is the relationship represented as a sub-class. For the ontology represented in Figure 5.5, we can see that the class b is a sub-class of a. Similarly, the class c is a sub-class of b and classes d and e are sub-classes of c. Thus, total IsA relationships for this ontology are 35. If total non-IsA relationships (not shown in the figure) in the ontology is 10 then the relationship richness can be calculated as (10/(10+35)).

5.3.4. Inheritance Richness (IR)

Classes in the ontology can be grouped in several styles and details. The grouping of classes can be a good indicator of how the information is dispersed (or clustered) within the ontology, which in turn gives the indication whether the ontology is deep (which covers specifics of domain) or shallow (which covers the generic concepts of the domain). OntoQA (Tartir et al., 2005) describes inheritance richness (*IR*) as the average number of sub-classes per class. Formally inheritance richness can be evaluated as

$$IR = \frac{|IsA|}{|nonLeaf\ node|} \qquad \ldots(5.4)$$

A leaf node is a node that does not have any sub-class and thus all the classes that have sub-class are nonLeaf nodes. In Figure 5.5, there are 10 nonLeaf nodes and accordingly, the IR can be calculated as 35/10.

5.3.5. Attribute Richness (AR)

Each class of the ontology has some attributes, e.g. data properties. Attributes attached to the class indicate the amount of information the class provides about the domain. OntoQA (Tartir et al., 2005) defines attribute richness (AR) as the average number of attributes per class. It is computed as the number attributes for all classes (att) divided by the total number of classes (C).

$$AR = \frac{|att|}{|C|} \qquad ...(5.5)$$

Where $|att|$ is the number of attributes for all classes

Table 5.2 shows ontology metrics for GenCLOn where the ontology parameters for GenCLOn are calculated based on the formula explained above.

Table 5.2 Ontology metrics for GenCLOn

A	Value - A	B	Value – B	Parameter	Formula	Value
Cardinality of paths	1672	Number of paths	312	Average Depth	A/B	5.36
Cardinality of levels	443	Number of levels	8	Average Breadth	A/B	55.36
Non-IsA relationships	49	IsA relationship	443	Relationship richness (RR)	A/(A+B)	0.099
IsA relationships	443	nonLeaf node	123	Inheritance richness (IR)	A/B	3.6
Total number of attributes	109	IsA relationship	443	Attribute richness (AR)	A/B	0.246

GenCLOn has an average depth of 5.56. Depth of the ontology indicates at what detail level the domain concepts are explored. In the case of GenCLOn, this can be interpreted as, on an average, each path of this ontology is expanded by 5.36 sub-class structure. For example, top-level class “Resource” is further classified as → Non-monetary resource Infrastructure → Line infrastructure → road →urban road and so on. Breadth of the ontology indicates "how many unique classes are included at each level of the ontology?”. It demonstrates the span of the domain covered in the ontology. GenCLOn has an average breadth of 55.36, which mean on an average, each level (GenCLOn has eight levels) of the ontology contains 55.36 classes.

If the reference ontology (or a similar structure) exists for the domain that can be taken as a standard for the comparison, one can compare the average depth and the average breadth of the ontology to comment on the relative size of the evaluated ontology. In absence of such standard, these numbers indicate only quantitative information and do not specifically say if it is a good or bad ontology. However from the average depth and the average breadth, we can state whether the ontology is a shallow or a deep ontology. If the average breadth is greater than the average depth, then it is a shallow otherwise it is a deep ontology. In the case of GenCLOn, the average breadth is greater that implies that GenCLOn is a shallow ontology and contains a wide (breadth) variety of concepts from the city logistics domain. However, these concepts are not expanded in much detail (depth) due to its generic nature.

In GenCLOn, 49 different object properties are listed that connect different classes by non-IsA relationships whereas the total number of IsA relationships is 443. Thus, GenCLOn has a relationship richness of 0.099. Here, low RR score of 0.099 (the range of RR is between 0 and 1) for GenCLOn implies that the ontology classes are connected by fewer non-IsA relationships and thus the ontology provides less information about how different classes of the city logistics domain are interrelated with each other. It should be noted that the objective of GenCLOn is to cover important concepts and relationships between them. There are many different types of relationships possible between different classes of the ontology out of which some are fundamental and necessary for domain representation and others are not. 49 unique relationships are used to define total 880 relationships over the GenCLOn classes. Thus, since GenCLOn represents the city logistics domain at an abstract level low score of RR is expected; however GenCLOn classes are connected by necessary relationships to represent the domain at an abstract level.

For GenCLOn, IR of 3.6 implies that, on an average, each GenCLOn class has 3.6 sub-classes. Ontology with high IR indicates shallow nature of the ontology (Liu and Gruen, 2008) The score of IR for GenCLOn indicates that the ontology covers the city logistics domain at the generic level and covers wide verities of city logistics details. The definition of attribute richness implies that more attributes express more detail knowledge in the ontology. Accordingly, with 0.246 distinct attribute per class, GenCLOn gives limited details about the domain. Looking at the generic nature of GenCLOn this can be explained as each class in GenCLOn has few attributes that belong to a specific class. However, it contains a higher total number of attributes that belong to many different classes. For example, each shop (e.g. receiver) has goods ordering activity and shelf space. However, a small-time shopkeeper storing some goods at his house is a very specific detail and such details should be incorporated in the system while using the ontology for a specific application (e.g. modelling effect of storage space on ordering quantity). Thus, GenCLOn integrates generic attributes that explain its low AR.

5.4. Validation of GenCLOn

The ontology metrics presented in the previous section suggest the numerical structure of the ontology but do not evaluate the general quality of the ontology for real usage. To confirm whether the classes, its attributes and relationships correctly represent the domain, we must validate the concepts and relationships of the ontology. The ontology concepts can be validated by the system component validation and relationships can be validated by the knowledge representation validation (refer Figure 5.2). Since the ontology represents domain knowledge, it is apparent that domain experts/users should be involved directly or indirectly in validation. Knowledge of any particular domain is not an expertise of any single expert but is distributed among many groups of people. However, involving a number of people requires plenty of resources (e.g. time, money). Likewise, it is also very time-consuming to compile knowledge of these experts into one bundle and compare it with the ontology at stake. Thus, scarcity of validated ontologies is largely attributed to lack of resources (e.g. time, money) and reference databases.

5.4.1. The validation approach

Ontology must be validated with respect to information needs of various users of the ontology (Kim, 2010) which, essentially, generates confidence among its users. There are mainly three groups within the domain of city logistics who are potential users of this ontology: 1) City logistics experts 2) City logistics modeller and 3) City logistics stakeholders from the real-world. Incorporating the diversity of the groups also assures validation of relational orchestration among the classes presented in the ontology. Considering this, we use information collected from stakeholders' interviews and the text corpus of city logistics literature for the validation purpose.

(1) The interview

For the interview part, we are using information gathered from in-depth personal interviews[15] with four trucking firms and eight administrative authorities associated with the city logistics domain (Kawamura and Sriraj, 2012). Each interview was digitally transcribed, and afterwards information from interviews was analysed using cognitive mapping technique called Strategic Options Development Analysis – SODA (Eden and Ackermann, 2001). For each stakeholder, a cognitive map is developed using the mapping software Decision Explorer[16] (Explorer, 2002). Quotes from stakeholder interviews are included in the cognitive map. Theses individual cognitive maps are combined to make a merged cognitive map, which reflects the central viewpoint of the entire stakeholder group. The relationships among the concepts are analysed and mapped by linking these concepts using the statistical scoring techniques available in the tool. Figure 5.6 shows the merged cognitive map of the carrier stakeholder.

(2) The Corpus

The interview approach for collecting information is important to include real life stakeholders from the city logistics domain. To capture the perceptions and knowledge of city logistics modellers and experts, we compiled a text corpus for the city logistics domain. This corpus consist of reviews, city logistics models, articles describing part(s)of the city logistics domain, reports of projects aiming at improving city logistics activities and literature surveys of city logistics projects sources. Similar to the collection of quotes from interviews, details related to particular stakeholder are collected from the literature corpus to create individual cognitive maps. Finally, a merged cognitive map of the stakeholder is created following the procedure analogous to the processing of interview data.

(3) Cognitive map

Cognitive mapping is a causality based mapping technique and is based on Personal Construct Theory (Kelly, 1955). It consists of "concepts" that are short phrases giving a sense of action and direction of the process (in this case, city logistics activities). Here, these phrases are quoted from stakeholders' interviews and the text corpus. Most links are directional, representing causal relationships and are read as "may lead to" (Explorer, 2002). This cognitive map can be seen as a parallel ontology for a specific stakeholder of the city logistics domain. Accordingly, a concept of a cognitive map represents class(es) of the ontology, and the links between classes suggest the axiom(s) of the ontology.

---

[15] The interviews and analysis were done as a part of CFIRE project (Kawamura and Sriraj 2012). For this research final outcome – the merged cognitive maps of stakeholders - were used

[16] For more information go to: www.banxia.com/dexplore/

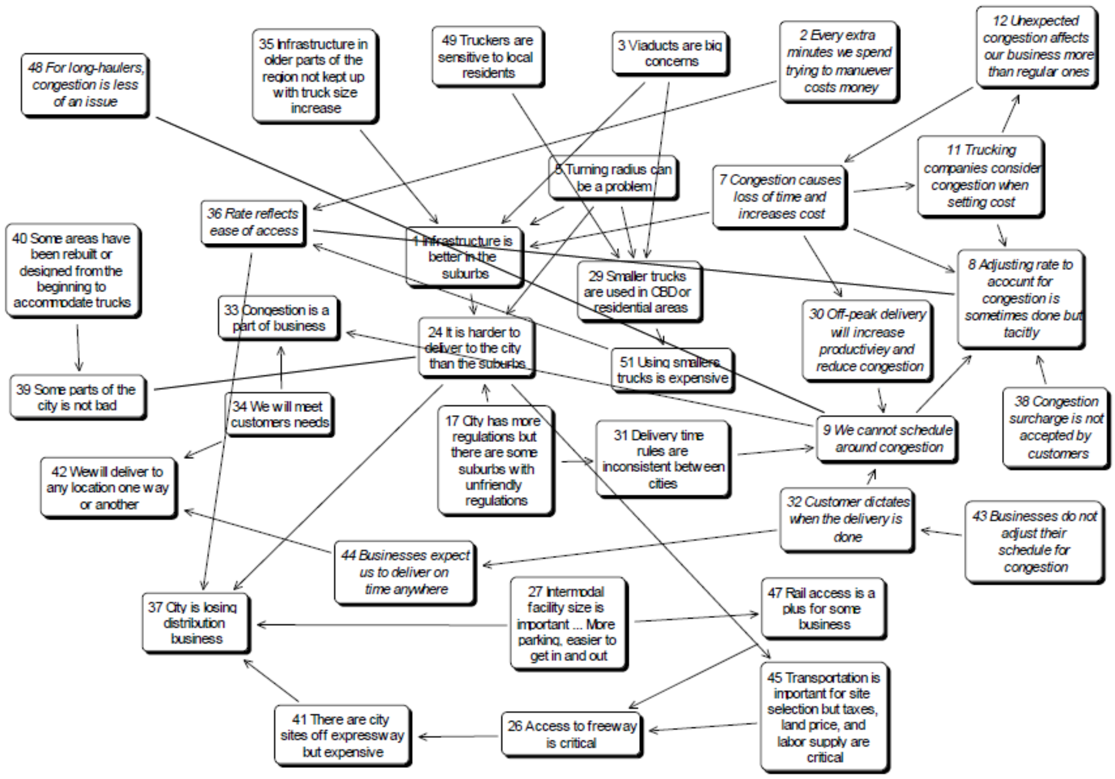


Figure 5.6 Merged cognitive map of the carrier (i.e. trucking firm) (Source (Kawamura and Sriraj, 2012))

5.4.2. System component validation

The ontology can be used in various ways. However, before using the ontology it is important to know whether the ontology is (sufficiently) complete – that is whether the ontology contains all important classes of the domain. Next, it is important to check whether those classes and their attributes are correctly presented in the ontology. If both criteria are not satisfied, then the use of ontology may lead to incorrect knowledge representation and application.

(1) System component validation approach

The core of system component validation is to check first its presence and then its presentation. It checks and confirms whether all-domain people understand and utilize the class in the same manner. For system component validation, first we collect different concepts from the merged cognitive map of stakeholders. Next, we use the query function (provided in Protégé) to query for those concepts to check their existence in city logistics ontology. It is possible that some concepts are present in the ontology but with slightly different naming convention. For example, no class with the name *'vehicle'* exist in GenCLOn but a more specific *'Freight_vehicle'* class exists. However, we can safely assume that this class should be available under the class 'Resources'. Therefore, we can query class '*Resource*' and can browse that specific class to check the presence of the vehicle class. Figure 5.7 shows an example of a query function for querying the *'UCC'* (i.e. urban consolidation centre) class using the ontology software Protégé. The query function also allows the user to see other connected classes such as sub-class, super-class and variants of classes.

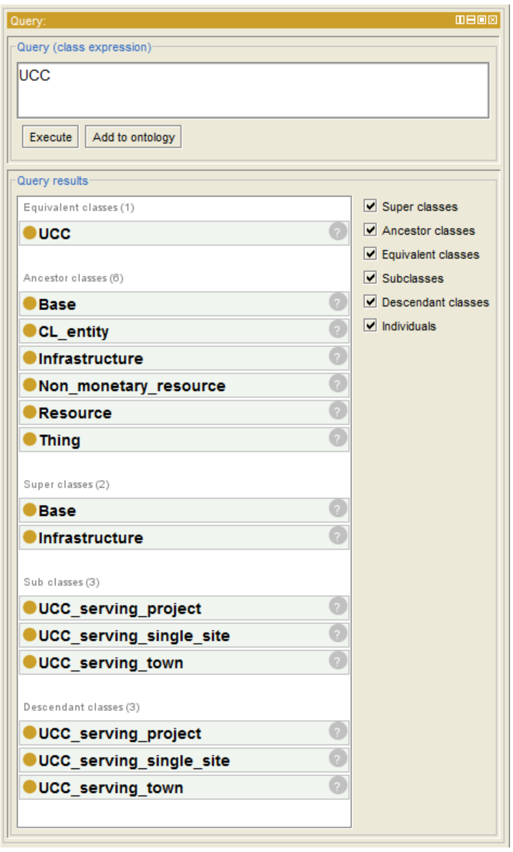


Figure 5.7 Example of query in Protégé

Once the concept is found in the ontology, a further analysis is performed to check whether the concept has appropriate attributes. Figure 5.8 shows the framework for component validation.

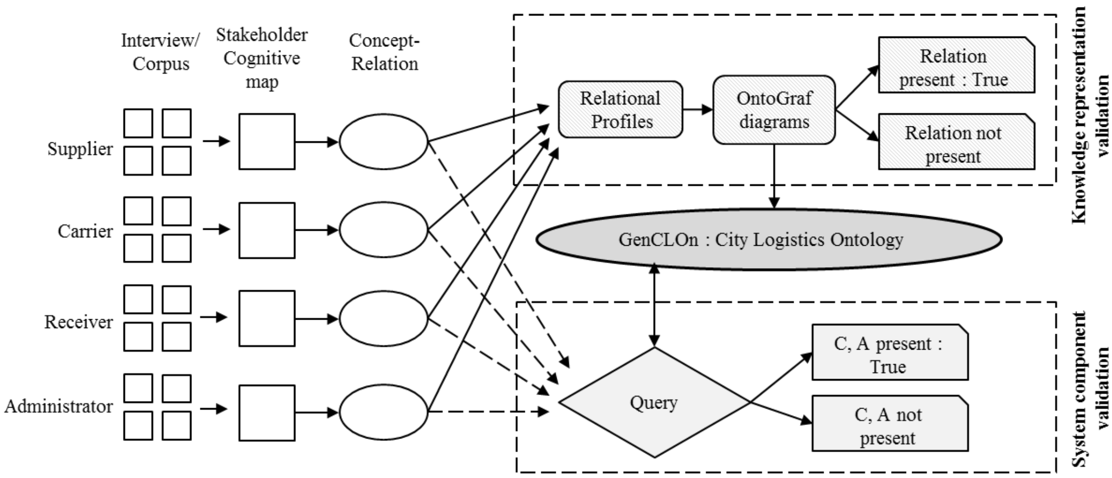


Figure 5.8 Schema for system component and knowledge representation validation

(2) Validation of system component of GenCLOn

The cognitive maps give information about the city logistics concepts and relationships between them. A single phrase in the cognitive map consists of multiple concepts. For example, in the phrase from the point 30 in Figure 5.6, we can identify concepts such as *'off-peak delivery'*, *'productivity'* and *'congestion'*. Similarly, in point 29, the phrase mentions '*small truck'* as one of the concepts, which is a type of vehicle. Thus, using phrases of cognitive maps we collect concepts to validate the city logistics ontology by querying for similar classes in GenCLOn. One important aspect of the validation is the perspective of the concept description as it can help in deciding the querying location in the ontology. For example, point 7 states *'congestion causes loss of time and increases the cost'*. In GenCLOn, there are eight main classes and all sub-classes fall under these classes. One can assume here that congestion is a problem and should have an indicator. By querying KPI class in GenCLOn, we found that congestion is represented as *'Congestion_indicator'* class which has the property *'Avarage_delay'*. Thus, the concept 'congestion' from the cognitive map (i.e. congestion) is present in GenCLOn as *'Congestion_indicator'* class and also represents the same effect in the city logistics ontology. Table 5.3 shows some concepts identified in the cognitive map of the carrier and the respective classes found in the city logistics ontology.

Table 5.3 Comparing system component of GenCLOn and the cognitive map

Concept from Cognitive map	Class found in GenCLOn	Type
Road	Road	Class
Off peak delivery	Off_peak_time_window	Class
Small truck	Road_freight_vehicle, LGV	Class
Congestion	Congestion_indicator	Class
Delivery Time	Delivery_time	Attribute
Customer	Receiver	Class
Regulation	Restriction	Class
Rail	Rail	Class
Tax	Road_pricing	Class

5.4.3. Knowledge representation validation

The complexity of knowledge relationships between the ontology classes requires knowledge representation validation to eliminate any undesirable outcome upon the use of the ontology. Knowledge representation validation checks the structural integrity of the process and ensures that entity-relationship is properly constructed from a knowledge representation point of view. Thus, the knowledge representation validation confirms that the concept is being related to another concept in the real world the way it is presented in the ontology. Importantly, this validity is a stringent measure to build confidence in using the ontology as a knowledge database for further use.

(1) Knowledge representation validation approach

Validating the relationships between different classes is much more complicated compared to the validation of classes because the domain ontology maps a wide variety of classes that have multiple relationships with other classes. With multiple connections, the task of validating becomes increasingly difficult. Imagine that there are only 50 classes in the ontology and each class has just one relation with other classes then the total relations will be combinatorially high (2450 relations). This phenomenon is also true in the case of GenCLOn as it represents the city logistics domain at a generic level and, thus, maps a wide variety of classes and their relations. Even the visual representation of all the classes and their relationships presents quite convoluted structure. Figure 5.9 shows the UML-diagram generated for GenCLOn using a plug-in called OWLGrEd[17]. We can see that validating the entire relationship structure of GenCLOn is extremely difficult considering multiple connections. Note that each box in the Figure 5.9 is a class and a line connecting two boxes is the relation between two classes. Unfortunately, this plug-in does not allow selecting specific classes to see the relationship between them. Thus, if the ontology contains hundreds of classes and object properties, the UML-diagram becomes very difficult to follow.

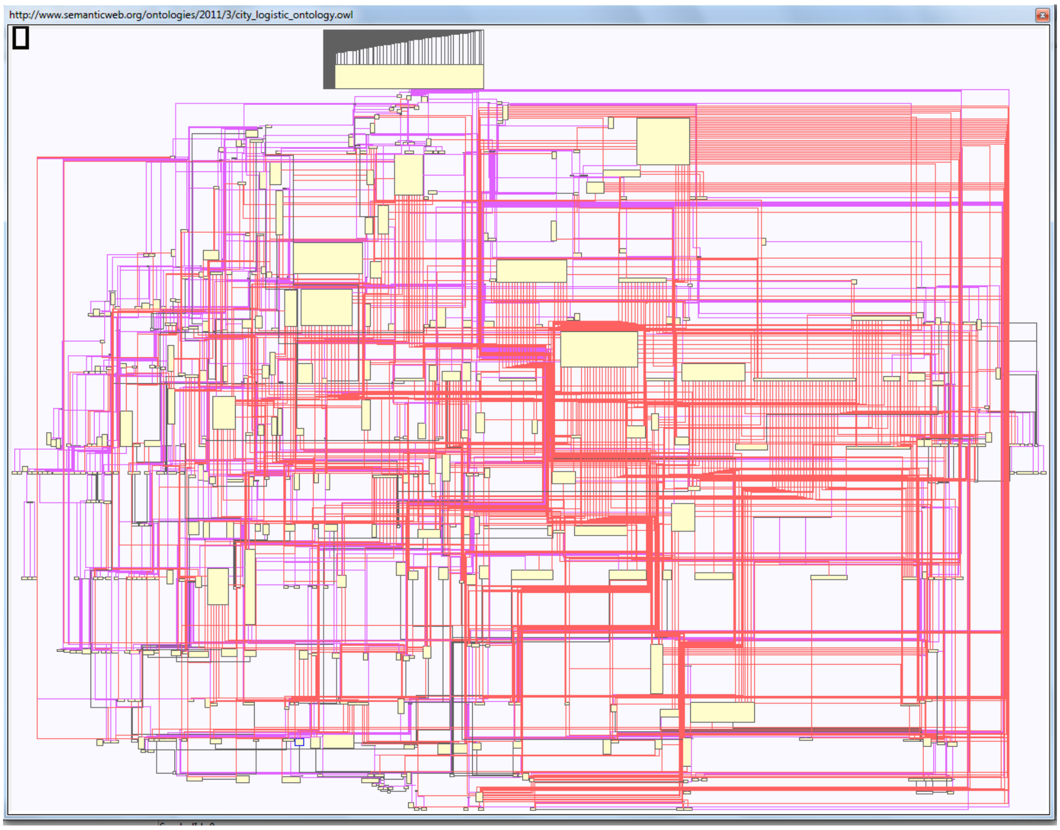


Figure 5.9 UML-diagram generated using OWLGrEd for GenCLOn

Fortunately, another plug-in called OntoGraf[18] can serve the purpose here. OntoGraf allows navigating interactively through different classes and object properties of the ontology. It allows browsing through sub-classes, individual, and domain/range object properties. Using the plug-in, one can explore the neighbourhood of specific classes to check the relationships of the specific classes with other classes. Thus, for example, if we want to know how road pricing is connected to other classes of city logistics ontology, we can explore the neighbourhood of *'Road_pricing'* class of the city logistics ontology. From Figure 5.10 we can see that *'Road_pricing'* is connected to class *'Transiting'* by object property *'intervene_in'*. Thus, road pricing affects the transiting activity in city logistics ontology.

[17] OWLGrEd is a UML style graphical ontology editor for OWL (http://owlgred.lumii.lv/)
[18] OntoGraf is plug in for interactively navigating the relationships of OWL ontologies (http://protegewiki.stanford.edu/wiki/OntoGraf)

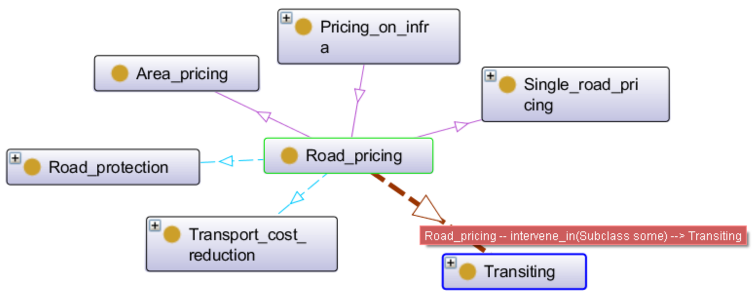


Figure 5.10 Example of relational diagram of OntoGraf

Thus, for knowledge representation validation, we use OntoGraf to check whether the relation existing in the real life also exist in the city logistics ontology between specific classes. The entire schema for knowledge representation validation is presented in Figure 5.8. Similar to system component validation framework, we use the cognitive maps of different stakeholder. From the cognitive maps, we get the relation between different concepts of the city logistics domain, which in turn will be used to create relational profiles of different concepts. Set of relational profile represents the relation between different concepts of the city logistics domain. Thus, using OntoGraf we explore the relationships between the classes to check the completeness and consistency of relationships of ontological classes.

(2) Validation of knowledge representation in GenCLOn

The relationships between different concepts are used to derive different relational profiles. Following the merged cognitive map of carriers in Figure 5.6we can see that,

- Point 7 and 30 shows that off-peak delivery is one of the solutions to loss due to congestion.
- Relations between point 34 and 42 states that truckers are willing to make deliveries that customer expect and to stay in the business, it is necessary to be able to do so.
- It is difficult to make deliveries to the destinations in the city boundary (point 25). It is explained by the fact that the unfriendly regulations in the city centre affect transiting activity (point 17). At the same time, inconsistent time windows for different cities makes routing and scheduling inefficient (point 31).

In Table 5.4 we can see the list of some of the important concept-relations found from the merged cognitive map of carriers. On the right of the list, we can see the axiom(s) found in the city logistics ontology that represents the similar relationship. It is to be noted that statements in the cognitive map are derived from verbatim. A single statement of the cognitive map can be a combination of multiple axioms and may take a complicated form in ontological representation. For example, a statement "*Carrier delivers goods to the receiver at any location*" can be folded down into:

- Carrier delivers goods
- Receiver orders goods
- Goods are delivered to the location
- Goods are delivered at some time

If we find these multiple axioms in GenCLOn, then we can safely assume that the relation profile from the cognitive map is present in GenCLOn.

Table 5.4 Comparison of relational profile and axiom

Relation profile from Cognitive map	Axiom found in GenCLOn
Carrier has to deliver within time-window	intervene_in some Ordering_transport_service
Time-window influence the delivery of goods (31,32)	intervene_in some Transitting
Measures influence logistics quality (9,17,31)	Permission on infra may achieve some LQ
Carrier delivers goods to the receiver at any location (34,42)	Transitting_is_activity_of_carrier, ordering_goods is_activity_of some Receiver, transitting has_destination some base, transitting has_start_time and has_end_time
Infrastructure is important for goods delivery (1,24)	Transitting performed_at road, permission_on_infra may_achieve some Logistics_quality
Congestion influence logistics quality/ time-window (7)	Congestion_reduction lead_to Logistics_quality
Truckers are sensitive to local residents (49)	Carrier has_objective some Congestion_reduction
Regulation affects delivery (21, 17)	Restriction_on_vehicle intervene_in transiting
Off-peak delivery will increase productivity and reduce congestion (30)	Off_peak_time_window may_achieve some Congestion_reduction and transport_cost_reduction

5.4.4. Validation results and discussion

The result of the system component validation and knowledge representation validation is displayed in Figure 5.11 and Figure 5.12. The charts compare the absolute number of outcomes found in GenCLOn against the outcome identified in the respective cognitive map.

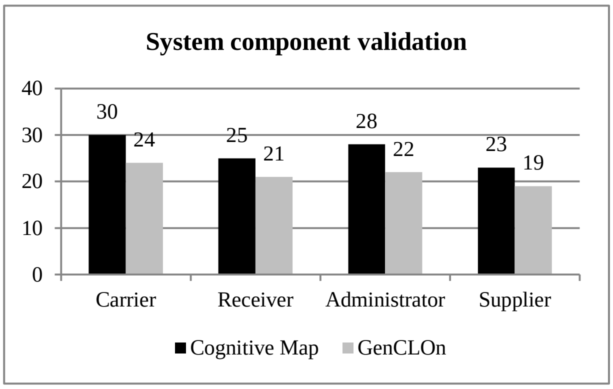


Figure 5.11 System component validation of the city logistics ontology

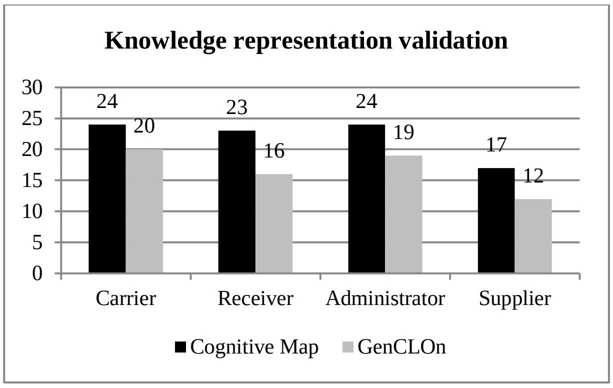


Figure 5.12 Knowledge representation validation of the city logistics ontology

It should be noted that we are not validating representation of only stakeholders in GenCLOn; instead this validation is for entire city logistics ontology. Here, we are using perspective of different potential users (e.g. real-world stakeholders, modellers, city logistics experts) of the city logistics domain to carry out the validation. Thus, while validating GenCLOn using information from the cognitive map of the carrier we are validating the city logistics ontology classes and its relationship that belongs to or connected to the carrier. Result from Figure 5.11 asserts that 24 concepts, out of 30 identified from the cognitive map of the carrier stakeholder, are present in GenCLOn in form of ontological classes. For knowledge representation validation, we can conclude that 20 relation profiles, out of 24 identified from the cognitive map of carrier stakeholder, exist in GenCLOn. Result for other stakeholders is displayed in Table 5.5 and can be interpreted in similar manner.

Table 5.5 Validation of GenCLOn

	System component validation			**Knowledge representation validation**		
	Cognitive Map	**GenCLOn**	**%**	**Cognitive Map**	**GenCLOn**	**%**
Carrier	30	24	80,00%	24	20	83,33%
Receiver	25	21	84,00%	23	16	69,57%
Administrator	28	22	78,57%	24	19	79,17%
Supplier	23	19	82,61%	17	12	70,59%
Total	106	86	81,13%	88	67	76,14%
Standard deviation			2,13%			5,79%

Analysis of graphs and results presented in Table 5.5 show that overall 81% of concepts and 76% of relationships identified from the cognitive maps are present in GenCLOn. At individual stakeholder level, detail related to administrator and carrier is slightly well covered for both, component and knowledge, representation levels. Nonetheless, the standard deviation for system component and knowledge representation shows that all fours stakeholder types are representing the ontology mostly at an equal level. Conclusively, the results of the validation indicate that the city logistics ontology covers concepts and relationships of main stakeholders at a satisfactory level.

The missing concepts and relationships in the GenCLOn can be largely attributed to the generic level of ontology. For example, specific such as “*congestion charges are not accepted by customers*” (Figure 5.6 - point 10) is not found in GenCLOn and can be included while using the ontology for specific purpose (e.g. modelling city logistics activity for particular city). However, some generic relationships such as “*Rate reflects ease of access*” (Figure 5.6 - point 36) is found omitted in GenCLOn. Such relationships are important and commonly prevail in real-world practice. This indicates that GenCLOn still needs to include more classes, attributes and relationship. Nonetheless, ontology development is an on-going process and with other stakeholders from the city logistics domain start using and editing it, the ontology shall get richer in quantity and quality.

5.5. Validation of GenCLOn using case studies

Apart from its application in knowledge sharing, the promising area of utilising city logistics ontology is modelling. Validating the city logistics ontology with respect to an existing model further builds trust in using it. Consequently, in this section we validate GenCLOn by comparing it to the existing model of city logistics. The amount of overlap between the concepts, attributes and relationships presented in the model and the terms appearing in the ontology (e.g. as names of concepts) can then be used to measure the fit between the ontology and the model. Furthermore, we also consider two real-life case studies on city logistics for validation purpose.

We use an agent based model by Kolck (2010) to check the compatibility of the city logistics ontology for modelling purpose. This comparison checks as to what extent the ontological structure mirrors the model structure. Next, two city logistics projects from real life are used to check if the ontology can comprehensively represents the city logistics concepts from real world. Two criteria proposed by Yin (1994) for case selection are used here. Each case needs to offer an extreme and/or unique situation and must be researched by the same study protocol, namely the city logistics ontology here. Besides, two customized criteria are also followed. The model case should cover major stakeholders and activities of the city logistics domain. For the real-life cases, it is better to have cases carried out in different countries so as to ensure a high commonality.

The agent based model used for the validation is based on cost-valued choices by individual agents and presents results in terms of financial and environmental KPIs. There are six types of agents (i.e. 3PL carrier, UCC operator, truck, shopkeeper, municipality and road) with specific attributes present in this model. For the validation, agents and their attributes in the model are compared with their counterparts in GenCLOn.

Table 5.6 Agents ‘road’ and its attributes (part) in the Multi-Agent Model for UCC (Kolck, 2010)

Agent	Properties in the model	Relevant content in the city logistics ontology		
		Class	Axiom	Top class
Road	has speed limit	Road	speed_limit some float[> 0.0f]	Resource
	has real speed per time phase	Road	instant_road_speed exactly 1 float[> 0.0f]	Resource
	can estimate toll collected	Road	toll_collected exactly 1 float[> 0.0f]	Resource
	can estimate NOx	Transiting	performed_at some Road emission_during_transiting exactly 1 float[> 0.0f]	Activity
	has different colours to indicate crossing	Road	has_infra_component some Junction	Resource
	can change the speed to account for traffic conditions	Road	instant_road_speed exactly 1 float[> 0.0f]	Resource
	can charge toll from trucks	Road	tariff some float[>= 0.0f]	Resource

Table 5.6 shows the results of overlap of GenCLOn with an agent based model. The results indicate that all six agents can find their equivalents in the city logistics ontology. More conclusive evidence is gathered while checking attributes of these agents. Out of 38 attributes represented by the agents of the model, 35 are found integrated with the city logistics ontology. A large number of them (24 out of 35) are directly represented by the ontological classes (e.g. tariff, toll collected and speed limit of ‘Road’). The remaining 11 are present in the ontology indirectly. For example, km and toll count in the model are deemed the properties of a truck while in the ontology they are defined as the attributes of a ‘Transiting’ activity. The only part that can hardly be represented by the city logistics ontology is the routing related property, which happens to be the most model-specific. Clearly, a routing algorithm is very specific to the model (e.g. Tabu search or Genetic) and is related to the modelling choice or a case specific ontology development. The results of validating GenCLOn against an ABM conclude that GenCLOn lays promising base for its use as a competent conceptual template.

Table 5.7 Validation of GenCLOn for Binnenstadservice, The Netherlands

Content in the case	Corresponding content in the city logistics ontology		
	Corresponding class	Axiom of the class	Top class
BSS provides value-added service: storage.	UCC_operator	provide_service some UCC_service	Stakeholder
	Storage_service	UCC_service tariff exactly 1 float [>= 0.0f]	Value_partition
BSS provides value-added service: (large) home delivery service.	UCC_operator	provide_service some UCC_service	Stakeholder
	UCC_home_delivery	UCC_service	Value_partition
	Return_management	UCC_service tariff exactly 1 float [>= 0.0f]	Value_partition
BSS provides the possibilities for e-retail in Nijmegen.	UCC_operator	provide_service some Last_mile_delivery_service	Stakeholder
	Pickup_point_for_outbound_B2C_ delivery	UCC_service tariff exactly 1 float [>= 0.0f]	Value_partition
	Transiting_from_UCC_to_UCC	Transiting	Activity

Table 5.8 Validation of GenCLOn for Copenhagen case, Denmark

Content in the case	Corresponding content in the city logistics ontology		
	Corresponding class	Axiom of the class	Top class
Municipality of Copenhagen	Local_authority		Stakeholder
Improving environmental quality in the Medieval City of Copenhagen	Environmental_objective		Objective
	Public_authority	has_objective some Emission_reduction has_objective some Other_nuisance_reduction has_objective some Valuable_area_protection	Stakeholder

Next, two real-life case studies are used to validate the city logistics ontology in order to investigate at what extent the city logistics ontology reflects the real world. The results for these two cases are presented in Table 5.7 and 5.8. The first case is the Binnenstadservice (BSS); a UCC-based city logistics project started in April 2008 in the Dutch city Nijmegen

(Rooijen and Quak, 2009). The second case is City Goods by Municipality of Copenhagen: 1998 – 2003 (Ports, 2005). Both validations are steered by the same approach used in the previous modelling case. Project descriptions in the relevant papers are summarized in a series of topics that are in turn associated with the elements in the ontology. Encouragingly, 18 out of 20 topics in the first case, and 17 out of 19 topics in the second case can be either directly or indirectly represented by the ontology. The results of the validation process for these case studies bolster the ability of the city logistics ontology to represent the real world comprehensively.

5.6. Conclusion

Ontology is a powerful way to express domain knowledge in a structured way. To utilize this powerful structural information model, one must have confident that classes and relationships presented in the ontology are accurately representing the domain. Confidence in using the ontology can be built by evaluating and validating the ontology for its scope, structure and knowledge representation.

Generic ontology for city logistics (GenCLOn) is developed to specify the domain of the city logistics in terms of the classes and relations between the classes. In order to use GenCLOn as a knowledge database or a modelling platform, it must be validated to assure its credibility. In this chapter, we fulfilled the objective of preparing ontology metrics listing the numerical properties of the GenCLOn. The information from the city logistics ontology metrics indicates that GenCLOn is a shallow ontology and covers a wide scope of the city logistics domain. Validation of GenCLOn using information from city logistics stakeholders and literature indicates that GenCLOn includes overall 81% of classes and 76% relationships. Finally, validation of GenCLOn against the city logistics model and projects also reiterates that GenCLOn includes most generic concepts and relationships presented in the models. Thus, the results conclude that GenCLOn represents the city logistics domain at an acceptable level. With this validation, we can suggest that GenCLOn is a valid ontology and includes all important generic stakeholders, activities and relationships between different concepts of the city logistics domain. Validation using information from different stakeholders' also suggests that GenCLOn expresses multi-stakeholder perspectives in representing the city logistics domain.

Notwithstanding, there are still some gaps found in terms of inclusion of common concepts from the city logistics domain. Nonetheless, the majority of missing classes and relations in GenCLOn are due to the fact that many points assembled in the cognitive map are very specific to a situation while GenCLOn is built as a generic ontology. To create a complete generic ontology is more a direction than a goal since as the domain evolves new concepts and new relationships becomes contemporary and old may become obsolete. Finally, we do not claim GenCLOn is fully representative of the city logistics domain as the validation is done by only part of people who could use the ontology. However, with other city logistics stakeholders and experts start using and adding more generic classes will make GenCLOn more powerful in terms of content and details. Furthermore, the validation approach presented here has its limitations. The approach is time consuming since it involves the collection of data, classification and finally exploring ontological properties manually. One reason for this is the query technique that is available is not sophisticated enough to eliminate manual work. Additional techniques (e.g. plug-in) can be developed to explore the semantic data properties using more sophisticated queries. However, we strongly opine that the domain experts must actively be involved in the validation to check the quality of the ontology.

References

Ashburner, M., Ball, C. A., Blake, J. A., Botstein, D., Butler, H., Cherry, J. M., Davis, A. P., Dolinski, K., Dwight, S. S. and Eppig, J. T. (2000). Gene Ontology: tool for the unification of biology. Nature genetics 25(1): 25.

Brank, J., Grobelnik, M. and Mladenić, D. (2005). A survey of ontology evaluation techniques.

Brewster, C., Alani, H., Dasmahapatra, S. and Wilks, Y. (2004). Data driven ontology evaluation.

Eden, C. and Ackermann, F. (2001). Strategic options development and analysis: The principles.

Explorer, D. (2002). An Introduction to Decision Explorer. Banxia Software LTD.

Fox, M. S., Barbuceanu, M. and Gruninger, M. (1996). An organisation ontology for enterprise modeling: preliminary concepts for linking structure and behaviour. Computers in Industry 29(1): 123-134.

Gangemi, A., Catenacci, C., Ciaramita, M. and Lehmann, J. (2005). A theoretical framework for ontology evaluation and validation. Semantic Web Applications and Perspectives (SWAP)–2nd Italian Semantic Web Workshop, Citeseer.

Gómez-Pérez, A. (1995). Some ideas and examples to evaluate ontologies. Artificial Intelligence for Applications, 1995. Proceedings., 11th Conference on, IEEE.

Guarino, N. and Welty, C. (2002). Evaluating ontological decisions with OntoClean. Communications of the ACM 45(2): 61-65.

Kawamura, K. and Sriraj, P. (2012). Effect of the Built Environment on Urban Freight Movement and Operations. Transportation Research Board 91st Annual Meeting.

Kelly, G. A. (1955). A theory of personal constructs. New York: Norton. Nellie Ismail, Tan Jo-Pei and Rahimah Ibrahim pre-to postnatal period. Journal of Reproductive and Infant Psychology 19(2): 83-110.

Kim, H. G. (2010). SEDE: An ontology for scholarly event description. Journal of Information Science 36(2): 209-227.

Kolck, A. (2010). Multi-agent model for the urban distribution centre Master Thesis, Delft University of Technology.

Liu, J. and Gruen, D. M. (2008). Between ontology and folksonomy: a study of collaborative and implicit ontology evolution. Proceedings of the 13th international conference on Intelligent user interfaces, ACM.

Lozano-Tello, A. and Gómez-Pérez, A. (2004). Ontometric: A method to choose the appropriate ontology. Journal of Database Management 2(15): 1-18.

Maedche, A. and Staab, S. (2002). Measuring similarity between ontologies. Knowledge engineering and knowledge management: Ontologies and the semantic web: 15-21.

Martin, P. and Eklund, P. (1999). Embedding knowledge in Web documents. Computer Networks 31(11–16): 1403-1419.

Obrst, L., Ceusters, W., Mani, I., Ray, S. and Smith, B. (2007). The evaluation of ontologies. Semantic Web: 139-158.

Ports, C. (2005). City Ports–project interim report. Emilia-Romagna, Bologna, Italy.

Porzel, R. and Malaka, R. (2004). A task-based approach for ontology evaluation. ECAI Workshop on Ontology Learning and Population, Valencia, Spain, Citeseer.

Rooijen and Quak (2009). Binnenstadservice.nl-a new type of urban consolidation centre. Association for European Transport and Contributors.

Tartir, S., Arpinar, I. B., Moore, M., Sheth, A. P. and Aleman-Meza, B. (2005). OntoQA: Metric-based ontology quality analysis. IEEE Workshop on Knowledge Acquisition from Distributed, Autonomous, Semantically Heterogeneous Data and Knowledge Sources.

Van Dam, K. H. and Lukszo, Z. (2006). Modelling energy and transport infrastructures as a multi-agent system using a generic ontology. Systems, Man and Cybernetics, 2006. SMC'06. IEEE International Conference on, IEEE.

Yin, R. (1994). Case study research: Design and methods . Beverly Hills, CA: Sage publishing.

6 Ontology based multi-agent system for the city logistics domain[19]

6.1. Introduction and literature review

As discussed in *Chapter 2*, a wide variety of modelling approaches is used in the city logistics domain, including operations research techniques, differential equation modelling and system dynamics. Simulation is one of the most widely used techniques for city logistics modelling. In a survey of simulation of supply chains, Terzi and Cavalieri (2004) conclude that simulation is very helpful as it provides a systematic, quantitative, and objective evaluation of the outcomes resulting from different possible planning scenarios. In essence, the survey agrees that simulation is a very powerful tool for understanding the dynamics of the system. In the article ‘a tour-based micro-simulation of urban commercial movements’, Hunt and Stefan (2007) state the essential characteristics of modelling techniques for urban commercial movements. They see these as; 1) its ability to model various aspects of choice behaviour explicitly; 2) to aggregate results ex-post as desired; 3) to provide explicit representation of tours; and, 4) to include specific constraints acting at the individual level. The authors believe that micro-simulation is very appropriate for such task. Similarly, Liedtke and Schepperle (2004) claim that a micro-simulation freight model could be used as a potential forecast tool and pave the way for more reliable policy assessments than are currently available.

However, when decision making between independent actors or firms must be modelled, traditional discrete-event simulation is not pragmatic it cannot model a variety of information exchange happening between actors in real life. For this purpose, the simulation technique should be able to represent many individuals with autonomous behaviour. The relatively new paradigm of parallel and distributed simulation, an agent based simulation, allows us to

[19] This chapter is based on the journal paper - Anand, N., van Duin, R., & Tavasszy, L. (2014). Ontology-based multi-agent system for urban freight transportation. International Journal of Urban Sciences, 18(2), 133-153

capture interactions between independent actors. It is a special type of discrete event simulation that does not rely on a model with an underlying equation but can nonetheless be represented formally. Although new to freight modelling, the agent based technique is successfully implemented in many disciplines (Axelrod, 2006). One of the most important reasons for using this technique is that agent based models can explicitly model the complexity arising from individual actions and the interactions that arise in the real world, that were either not possible or not readily accommodated using traditional modelling techniques, like discrete event or system dynamic modelling (Borshchev and Filippov, 2004).

Introduction of agent based models in supply chains is more than a decade old - e.g. (Swaminathan et al., 1994). Since then, the field of supply chain management has produced a number of supply chain models with varying types and extents of supply chains using agent technology - for the overview refer (Kumar and Srinivasan, 2010). These models aim to capture the decision making processes and interactions between entities of the supply chain, and mainly capture the dynamics of the product flows instead of the transport flows. The focus of modelling a supply chain is different from modelling freight activities, as the former is customer-driven while the latter is the result of macroeconomic activities depending upon the scope of the model (i.e. international, national, regional or urban). The decision making processes incorporated in a supply chain model represents the firm (or at the most partner firms) involved in a supply chain, which does not give insight into goods movement generated due to activities of multiple supply chains – the general focus of freight models. Davidsson et al. (2005) give a survey of existing research on agent based approaches for transportation and traffic management. The survey evaluates the models based on the domain, transport mode, time horizon, usage (i.e. automation system, decision support system), control (i.e. centralized, distributed), agent structure (i.e. static, dynamic), agent behaviour (i.e. benevolent, selfish), maturity level of model and evaluation comparison (i.e. qualitative, quantitative, none). The author concludes that ABM is a suitable technique for a system marked by modularity, dynamic changes and complexity due to decentralized decision making of multiple entities. Notably, city logistics echoes such a system.

In city logistics modelling, only a few agent based models have been developed previously. The multi-agent model by Taniguchi and Tamagawa (2005) considers five agent types in the model: freight carriers, shippers, residents, administrator and motorway operators. The model captures the interactions between these stakeholders and establishes a good base of agent technology for the city logistics domain. Bergkvist et al. (2005) developed a model for testing the effects of government policies on transport chains. The model includes a variety of information exchanges - i.e. from the case where agents share no information to where information flows freely among the actors. A small test case was employed as a proof of concept. The development of the model is ongoing, and it aims at studying cooperation between actors. The model takes a logistics chain perspective for modelling agents to represent firms, customers, and a transport coordinator. However, the behaviours of the agents need to be extended to take advantage of the agent structure. The model by Donnelly (2007) uses a hybrid modelling approach based on aggregate macroeconomic interactions, discrete event micro-simulation, and agent based modelling. The model uses data from Portland region and can be seen as the first agent based model with real-life data. However, due to its vastness the model must make a trade-off while including the number of independent agents (i.e. firm, importer & exporter – which are generalizations of the firm and carrier) and, therefore, models a limited number of interactions. Another interesting approach was considered in the agent based model developed by Marcucci et al. (2013). The model studies influence of agents' attributes on the decision making processes while performing city logistics activities. Information about attributes was gathered from around 250 city logistics stakeholders. The stakeholders were asked to make choices about city logistics policies and schemes (e.g. urban consolidation centre). The model adds behavioural research to ABM design and suggests that different stakeholders have different objectives and priorities. In this view, each stakeholder should be considered as a specific agent with unique attributes instead of considering homogeneous preferences for all stakeholder types.

Usefulness of ABM is visibly accepted among city logistics researchers as evidenced by an increasing number of agent based models found in the city logistics modelling literature. Thus, ABM is certainly a useful methodology. However, the effort to develop an ABM is not trivial when multiple stakeholders must be included (Tamagawa et al., 2010). An ABM is developed based on domain specific knowledge base (Le Ber and Chouvet, 1999), abstracted into agents and their relationships. Often such knowledge bases are conceptual and constructed by the modellers using sources like literature, surveys and project reports. Such individually constructed knowledge bases are subjective and, often, are built with little sharing or reuse – almost everyone starts from a blank slate. In this situation use of an ontology for the development of an agent based model can be really rewarding in terms of time and precision. According to Gruber (1995) “an ontology is a description (like a formal specification of a program) of the concepts and relationships that can exist for an agent or a community of agents”. Accordingly, the city logistics ontology is a structured knowledge base of the city logistics domain which represents potential agents and their relationships with other agents. Such ontology can be used as a knowledge sharing document, and parts of it can be automatically transferred as components of an agent based model. In this chapter, we use this novel approach for developing an agent based model using the city logistics ontology.

6.2. Agent-based model architecture using city logistics ontology

To model the city logistics domain using the agent based simulation technique successfully, communication between heterogeneous stakeholder-agents of the domain must be implemented accurately. For accurate communication, the agents of the model should have common knowledge of different terminologies and the types of decisions they are making. From a semantic point of view, these agents should have a common view of the system and should have coordination in their activities. For this purpose, we developed the city logistics ontology GenCLOn. It can work as a common platform for communication and information exchange between agents.

GenCLOn is a multi-stakeholder ontology where multiple stakeholder types existing in the city logistics domain are represented as the ontology components. These stakeholder components are associated with their respective objectives, resources, KPIs and activities. Thus, the GenCLOn represents the system model of individual stakeholder which is important for developing individual stakeholder-agents in the ABM. Furthermore, the individual system model of each stakeholder is connected to the system model of other stakeholders by appropriate links. Thus, the GenCLOn represents multi-stakeholder perspectives in the ontology. Developing an ABM from such a model gives consistency in the relations and communications between the agents.

Figure 6.1 shows a representative sketch of the system model of a carrier and a shopkeeper. Here, the shopkeeper is associated with its shop, goods, and cost via different links. Similarly, the carrier is associated with its respective attributes and components. These individual models represent the functioning of the individual stakeholder and at the same time the link connecting both stakeholders’ system models indicates how they are connected in the domain of urban goods movements. Similarly, all the city logistics concepts are connected by the appropriate link. Thus, one can imagine that all such individual models together comprehensively capture the city logistics domain in an abstract way in the form of GenCLOn.

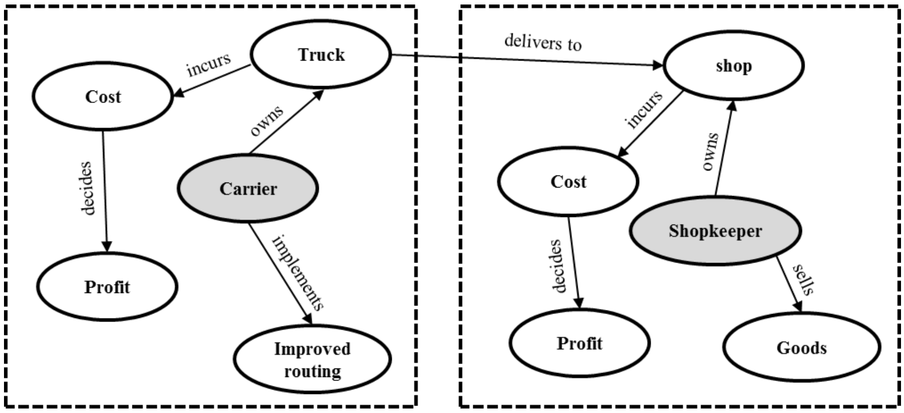


Figure 6.1 Representative sketch of multi-stakeholder ontology for the city logistics domain

One way of using the multi-stakeholder city logistics ontology for an ABM development is as a knowledge sharing document. In this case, one can use this structural document to browse through different stakeholders, their objectives and resources to see how these different concepts are connected. Also, one can see how the interactions can take place during the decision making for urban goods movements. Since the GenCLOn is a generic ontology, it contains the basic concepts of the city logistics domain at a broad level with limited details of each concept. For instance, the ontology may contain the information that a carrier stakeholder owns trucks but does not include the details of the truck such as the engine type, tire size or load capacity. Conversely, it may contain many other concepts and relationships that are of no use for a specific model case. Keeping the useful concepts and relationship, one can derive a structural conceptual model that can work as a guiding document for the agent modelling and interaction design.

As explain in *Chapter 4*, the ontology can be used in two ways for creating a simulation model. In first instance, the ontology components (i.e. Classes and relationships) can be extracted to be used as building blocks of the ABM. The city logistics ontological classes already contain attributes and relationships that exist between stakeholder-agents of the agent based simulation system. Using a code generation method one can extract (Java) classes from the city logistics ontology. These classes can be used as agents representing stakeholders (or activities, resources) in the model. It should be noted that these classes do not represent fully functional agents, but rather act as building blocks of the agent based model. With additional code representing the specific communication protocols in the class, the agent is ready for simulation. Secondly, one can also connect the ontology with simulation, where the relevant information needed for the agent to perform a certain action is obtained directly from the ontology during the simulation run. The information can be obtained by querying using the query language (e.g. SPARQL). Thus, the ontology is connected with the model throughout the simulation, unlike in the code generation method.

In this chapter, we use the ontology to create Java classes from ontology components as well as a guiding document. We aim to develop a model depicting fundamental aspects of urban goods movements using city logistics ontology. Therefore, we extracted classes from the GenCLOn to create stakeholder-agents such as carriers, shops, shippers, municipality and inhabitants. These classes have attributes that are needed for the specific stakeholder. For instance, the shop class of the ontology has ID number, area, stock level and is connected to the shipper by the 'goods ordering' method. There are multiple ways the Java code can be generated. We used protégé plug-in 'Protge-OWL API'. Figure 6.2 gives an overview of the process for Java code generation from GenCLOn. For technical detail refer (Guyot and Honiden, 2006; Stevenson and Dobson, 2011).

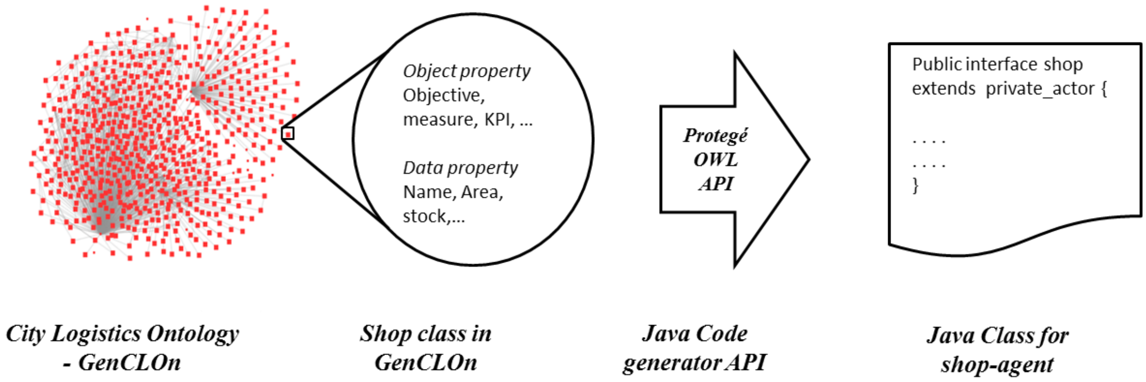


Figure 6.2 Java code generation from the city logistics ontology

Until now the structure of the model represents the 'skeleton' of an agent based model where individual agents and its plans are defined, so the agents know '*what to do*'. Next, we add additional communication and interactions between the agents that are not available in the classes extracted from the ontology. These strategies for agent interactions give agents information about '*what to do when*'. Communication and interactions between agents follow certain protocols that vary depending on the platform of software. Here, we use Repast Simphony for developing the model. In section 6.3.1 we explain the architecture of the software and interaction protocols. In the following section, we discuss the main agents of the model and their interactions with other agents.

6.2.1. Stakeholder agents and interactions

The agent based model developed for the city logistics domain has multiple agents with 'situated' or 'local' knowledge about the system, so it is called SMUrFS – Situated Multi-agent Urban Freight System. The key stakeholders involved in the generation and movements of urban goods are represented as agents in SMUrFS. Considering the bottom-up approach for the simulation processes, city inhabitants start the process by demanding goods from shops. The shops, in turn, contact shipper-firms that produce and supply goods. The shippers buy transportation service from the carriers who transport goods from the shippers' locations to the shops. The administrator plays a vital role by providing infrastructure for freight vehicle movements and is also responsible for creating an economic and environmentally friendly city area. We have the following types of agents in SMUrFS.

- Customer-agent
- Shop-agent
- Shipper-agent
- Carrier-agent
- Administrator-agent (e.g. municipality)

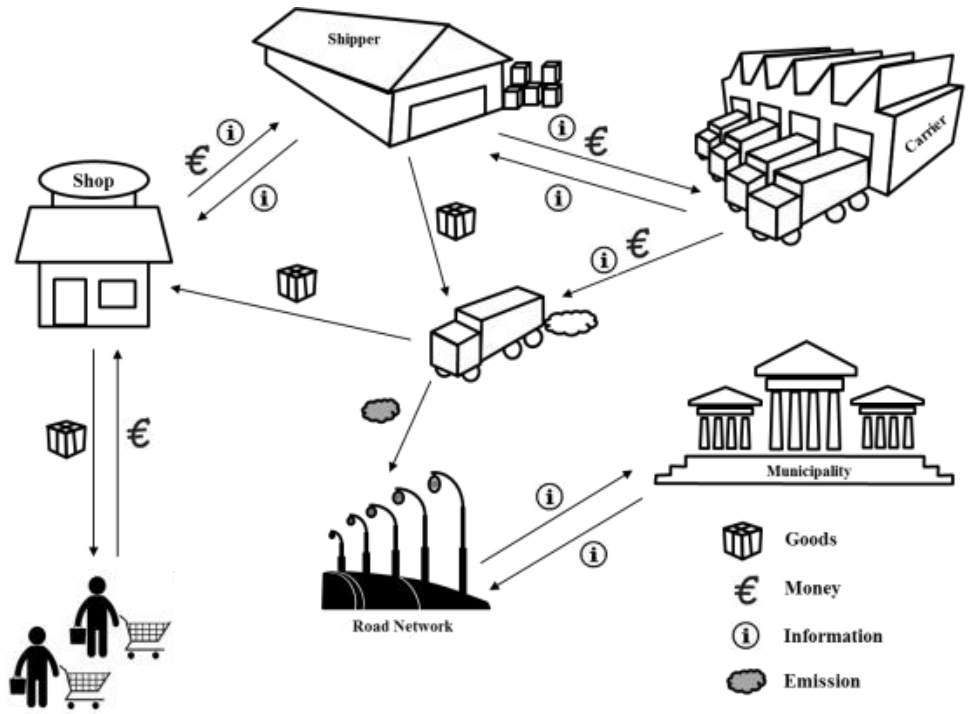


Figure 6.3 Agents and interactions in SMUrFS

Figure 6.3 shows the role of these agents in the model and how these agents interact with each other in terms of goods, money, information and harmful effects.

(1) Customer-agent

The customer-agent represents the inhabitant (e.g. consumer) in the city who buys goods from the shops. The activity of the customer agent starts with a decision about a shopping trip, which is based on the Bernoulli distribution. If the agent decides to shop, the number of units bought is decided based on the Poisson distribution. The selection of the shop for buying goods is based on three factors. 1) the size of the shop, 2) the profit-margin of the shop and 3) the on-shelf availability of the shop (the service level). There are many other factors customers consider during shopping in real life, such as the quality of the goods or the ambiance of a shop. Because we are modelling customers as entities that shop and not investigating shopping behaviour, only the first three factors are considered. Additionally, the decision about the shop selection is not affected by distance to the shop as all the shops are located in the radius less than a kilometre.

Accordingly, first the utility of every alternative (i.e. shop) is calculated using these three factors. Next, a probability is assigned to every shop using the multi-nominal logit (MNL) model. Based on this probability, the customer agent decides on a single shop as a shopping destination.

$$P(Shop\ i\ ) = \frac{e^{U_i}}{\sum_{i=1}^{n} e^{U_i}}$$

Where, U_i = utility of shop j,

$$U_i = f_1 \times \frac{Area_j}{Max\ area} + f_2 \times \frac{Service\ Level_j}{Max\ Service\ Level} - f_3 \times \frac{Profit\ Margin_j}{Max\ Profit\ Margin}$$

Customers are the end-users of the city logistics systems, and they are also the ones who experience the nuisances of freight transportation in the city, such as noise, pollution and congestion. Often, customers complain about these problems and change their shopping behaviour (e.g. shopping time). However, in the SMUrFS, the customer agents are non-reactive to such nuisances and their concern for the safe and non-polluting city is taken into account by the administrator-agent. Here, the administrator-agent (described later in the section) acts as the customer's representative and takes action to solve problems of congestion, pollution, noise by implementing various policy measures.

(2) Shop-agent

Shopkeepers are one of the most important stakeholders in the city logistics domain. They have a big influence on the city logistics transportation system. In the end, they decide when to order, how much to order, and when they want to have the order delivered. In the SMUrFS model, every shop-agent takes certain decisions during the setup phase and the simulation phase.

Setup phase decisions are:

- Shipper selection
- Maximum stock level
- Monthly demand of shop
- Minimum stock level (i.e. safety stock)

The setup phase decisions are made only once during the simulation (in the beginning), whereas the simulation phase decisions are repeatedly made under certain conditions. The decision about the shipper-selection is made based on the distance between the shop and the location of the shippers. The area of the shop, maximum stock level and safety stock are the function of their respective distribution functions. At the beginning of the simulation, a monthly demand is estimated as a function of the shop area using the given total demand for the city. During simulation, each shop-agent calculates the monthly demand using a simple moving average formula using demand of the last three months.

The simulation phase involves mainly two decisions:

- Re-Ordering Point (ROP)
- Ordering quantity (OQ)

The reordering point is estimated using the following formula:

*Re-order point = (Average Daily demand * Lead Time in Days) + Safety Stock*

Since the lead time is one day (i.e. goods are delivered next day) the reorder point is equal to the sum of the average daily demand and safety stock. The objective of the shop-agent is to maximize profit. This objective is closely connected to the number of units purchased and inventory cost associated with the stock. Furthermore, customer-agents are attracted to shops with higher stock availability. In this situation, shop-agents must optimize their ordering quantity while achieving multiple objectives - minimizing ordering costs and inventory costs and keeping sufficient stock to attract customers.

Since the ordering costs increases with the number of orders placed, the number of orders should be as less as possible. On the other hand, the inventory cost increases if many units are ordered. Furthermore, total units in the shop should not exceed the physical space of the shop.

Figure 6.4 shows the representative graphs indicating how costs are varying with change in order quantity. The demand rate is assumed constant in this case. From the graph it is apparent that the total cost is high when the order quantity is very low, and it reduces as the ordering quantity increases and reaches lowest point, and then start increasing again. Thus, shop-agents need to find ordering quantity level where the total cost is lowest. The order-quantity at this point is called economic order-quantity (EOQ) because at EOQ the total cost is lowest. If order-quantity is more than EOQ then ordering cost reduces but inventory cost increase. Since the increase in inventory cost is more than the reduction in ordering cost, the total cost is not lowest at non-EOQ point. Thus at any point other than EOQ, the total cost higher than the total cost at EOQ.

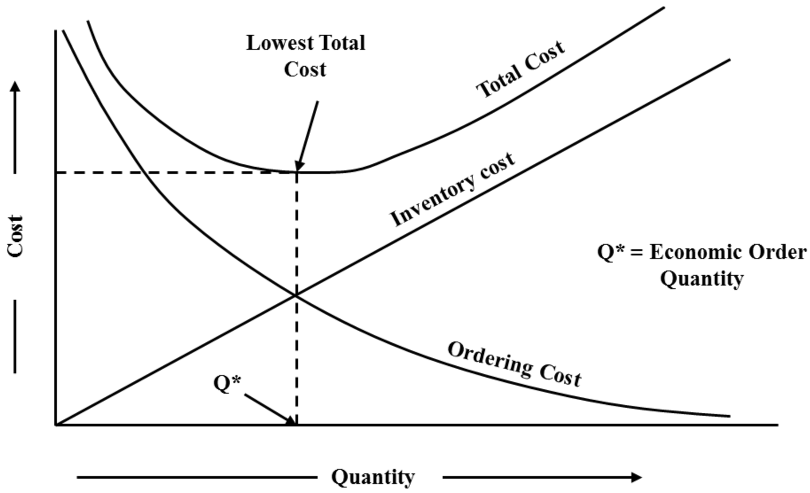


Figure 6.4 Economic order quantity

By differentiating the total cost, the formula for EOQ point can be derived (Tersine, 1994). The Economic Order Quantity formula is stated as

$$Q^* = \sqrt{\frac{2OD}{I}}$$

Where, Q^* = Order quantity, O = Ordering costs per order, D = Demand per month, I = Inventory costs per item per month

The demand by customers is the function of shop area, profit margin and stock level, where the first two factors are constant during the simulation. Although the demand is assumed constant for EOQ, in reality the demand deviates in reference to stock level. To tackle this deviation, the shop-agent uses 'adjustment factor' to adjust the EOQ. This factor is calculated as moving average of standard deviation in demand against the estimated demand.

(3) Carrier-agent

It is not uncommon that a shipper owns a private fleet for goods delivery. In that case, the shipper also acts as a carrier. If a shipper does not own goods delivery vehicles, the shipper buys a delivery service from an independent carrier. The independent carrier collects goods from different shippers and delivers to retailers. The selection of a carrier is mostly done by the shipper but sometimes a retailer can also influence the selection of a carrier. In the SMUrFS model, a shipper-agent uses an independent carrier for delivery of goods to the shops (i.e. receivers). The selection of a carrier is done by the shipper, based on the minimum cost for delivery. Carriers play an important role in the city logistics framework as they plan the tours for goods delivery which affect traffic level in urban areas. Together with their ability to improve the scheduling of the trucks, the carriers can improve the efficiency of city logistics transport considerably.

The total transportation cost incurred by the carrier is the sum of the fixed costs (e.g. depreciation of trucks, insurance) and variable costs (e.g. driver cost, fuel cost). The variable costs are associated with the truck usage that depends on the average length of a tour, the average number of stops on a tour, the speed of the trucks and driver's hourly wage. During the auction for the carrier selection, the carrier-agent adds its profit margin to the calculated cost and sends the final price as a bid to the shipper. As every carrier has a limited number of trucks, a carrier stops bidding in the auction once the total demand won from shippers exceeds the total capacity of the trucks. During the simulation phase, a carrier receives the order from one or more shippers for goods delivery. The carrier collects goods from warehouse of the shippers and creates tours using vehicle routing. Finally the trucks are dispatched to deliver goods to the shops.

For vehicle routing of carrier vehicles, we have implemented Tabu-search heuristics based routing using a Java-based tabu search framework OpenTS (Harder, 2001). The framework helps to implement the tabu search meta-heuristic (Gendreau et al., 1994) in a well-defined, object-oriented design. In the SMUrFS model, carrier wants to minimize the distance travelled by each truck delivering goods to the city. Therefore, the objective function for vehicle routing minimizes distance. The initial solutions for the tours are generated using simple greedy algorithm where tours are generated by filling each truck by adding order quantity by the shop until the truck cannot accommodate any more orders. At this stage, only the total capacity of the truck is considered and not the tour distance.

Based on the provided initial solution, the move manager generates a list of moves for the iteration. A move means reshuffling of orders to create a new set of tours. OpenTS use the objective function to determine the value of the solution that would result from each of these moves. With the help of the tabu list, OpenTS determines which move is the best, and that move operates on the initial, or current, solution that results in a new current solution. The Figure 6.5 below shows this process graphically.

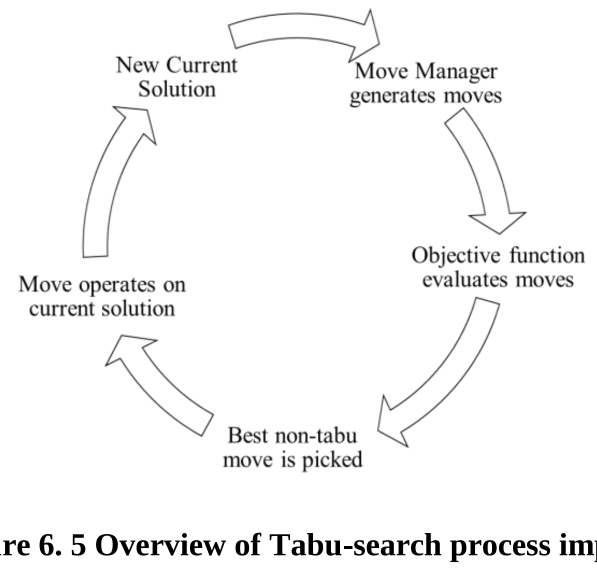


Figure 6. 5 Overview of Tabu-search process implemented in OpenTS

Once the initial solution is ready, the above mentioned process starts. Here, the move manager creates different moves (e.g. shuffle, replace) for shifting orders within the same tours and to other tours. Example of possible moves generated by the move manager is shown in Figure 6.6.

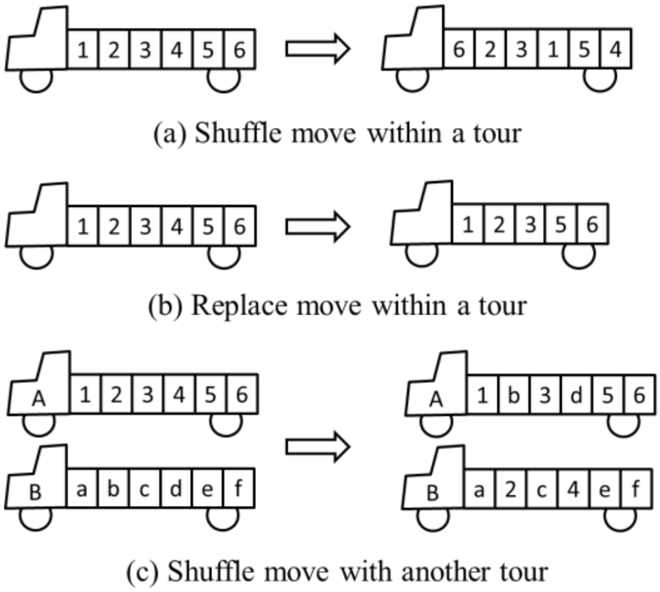


Figure 6.6 Example of move for tabu search heuristic used in SMUrFS

The iteration process continues for the number of iteration mentioned in the code. In this case, the iteration was done for 100 times. With some experiments we realized that 100 iterations are sufficient for average number of tours as 5 and average stops on a tour as less than 10. At the end of the 100 iterations, carrier gets final tours for delivering goods to the shops.

(4) Shipper-agent

The shipper is responsible for supplying goods to the retailers. There are different types of supply chains with different echelons and thus there can be more than one type of shipper. For this model, we assume only one type of shipper, who has goods available in the warehouse and is located outside the city area. We also assume that the goods are always available when a shop is ordering. In the SMUrFS model, a shipper-agent first decides its monthly demand by estimating the demand for its customer shops. Next, the shipper-agent starts the auction to hire the carrier-agent for goods delivery. In this auction, the shipper-agent sends the estimated demand to the carriers. The carriers calculate the costs of transportation for the auctioned demand and send the price to the shipper-agent. The shipper chooses the carrier with the lowest bid and uses this price to calculate the ordering costs for the shops. During the simulation phase, the shipper-agents collect orders from the shops and send the orders to their hired carrier.

(5) Administrator- agent

The municipality is the administrator in the city and can influence the city logistics activities by implementing various policies, measures and regulations. The administrator is also responsible for the economic and environmental sustainability of the city and, thus, must consider the effects of policies on businesses as well as inhabitants. For example, improving conditions for businesses may lead to more freight related transport activities. The subsequent increase in air and noise pollution and safety related issues affects the livelihood of city inhabitants. Conversely, implementing strict restrictions on freight vehicle movements reduces business activities in cities and, therefore, also jobs and supply of goods to city inhabitants. Thus, the objective of the administrator is to find policies that strike a balance between economic and environmental goals. In the SMUrFS model, the administrator-agent represents the municipality. The administrator-agent gathers information about the number of trucks entering the city, the pollution level based on total truck-km travelled as KPIs for an environmentally sustainable city.

In contrast to the detailed categorization of various stakeholders in the ontology, in the SMUrFS model, we combine different sub-types of stakeholders under one main stakeholder type. For example, instead of modelling different types of receivers (e.g. hotels, supermarkets, offices, and individuals) we consider a single type of receiving agent as a shop-agent. Furthermore, the different stakeholder types exhibit simple and mostly homogeneous behaviour. For example, each shop agent orders goods using the ROP and EOQ formulas.

Admittedly, these are strong assumptions that will limit the range of possible outcomes of the model. Nonetheless, the main objective of this research is to demonstrate the use of an integrative ontology in the development of an agent based model. Subsequently, we want to prove that such integration provides structural consistency in the relationships between the agents of the model. Such a methodology provides an innovative way to develop a valuable decision support tool that, by allowing autonomous decision making by stakeholders, explicitly incorporates distributed decision making in the city logistics domain. Table 6.1 shows the overview of the stakeholders, their objectives, decision activities and parameter used for decision making.

Table 6.1 Overview of stakeholders in SMUrFS

Stakeholder	**Objective**	**Decisions Activities**	**Parameters**
Customer	Lower price, Goods availability	Goods shopping	Stock level in the shops, Goods price, Shop size
Shop	Goods availability, Maximum customers, Maximum profit	Selling goods, Goods ordering	Ordering cost, Stock level, Demand, Inventory cost
Supplier	Supplying goods to the shops	Carrier hiring, Deciding ordering cost	Average order size, Transportation cost
Carrier	Maximize profit, Minimum cost	Freight delivery price bidding, Scheduling and routing	Fix cost, Running cost, Vehicle loading rate, Average tour distance, Average number of stops
Administrator	Congestion and pollution reduction	KPI analysis, Policy implementation	Total truck-kms, Total number of trucks,

In the light of this objective, assuming simplistic behaviour is justified at this stage of model development. Once the model is extended to evaluate real life situations and scenarios, the inclusion of more complex behaviour of stakeholders becomes important. It should be noted that an increase in the behavioural space also increases the complexity of the model and, consequently, the complexity of the analysis of the emergence of the model outcomes.

6.3. SMUrFS – an agent based model for city logistics system

6.3.1. Repast Simphony[20] – the agent based modelling platform

For the development of SMUrFS using agent based modelling technique, a free and open-source agent based modelling and simulation toolkit Repast Simphony (*Repast S*) (Cooper et al., 1999) is used. It is one of the most widely use agent based modelling tool among researchers. *Repast S* is based on Java programming language and uses the Eclipse Java runtime environment (JRE). It simulates events based on its priorities and the unit of time is a *Tick.* The time unit 'tick' is used to sequence the execution of events relative to each other. A tick – unit of time can be a day, a month or a year and is to be conceptually selected by the modeller. In SMUrFS, one tick is equal to one day and 30 ticks make a month. One of the inviting features of *Repast S* is its use of protocols and functionalities. These protocols and functionalities are very helpful in easily organizing interactions of agents based on time of events from other agents. Below we list three important protocols. Details about other features can be found in (Mavor and Pew, 1998; Fréchette, 2011).

Context-protocol

Context in *Repast S* is a data structure that holds components of the model that can be agents, objects or other contexts. A context holds all agents belonging to a specific type. However, a context can contain multiple contexts containing different types of agents. Figure 6.7 shows the structure of contexts for the SMUrFS model. It is apparent that a city context holds four sub-contexts and its respective agents. The road and junction context together makes a road network for the city in the model.

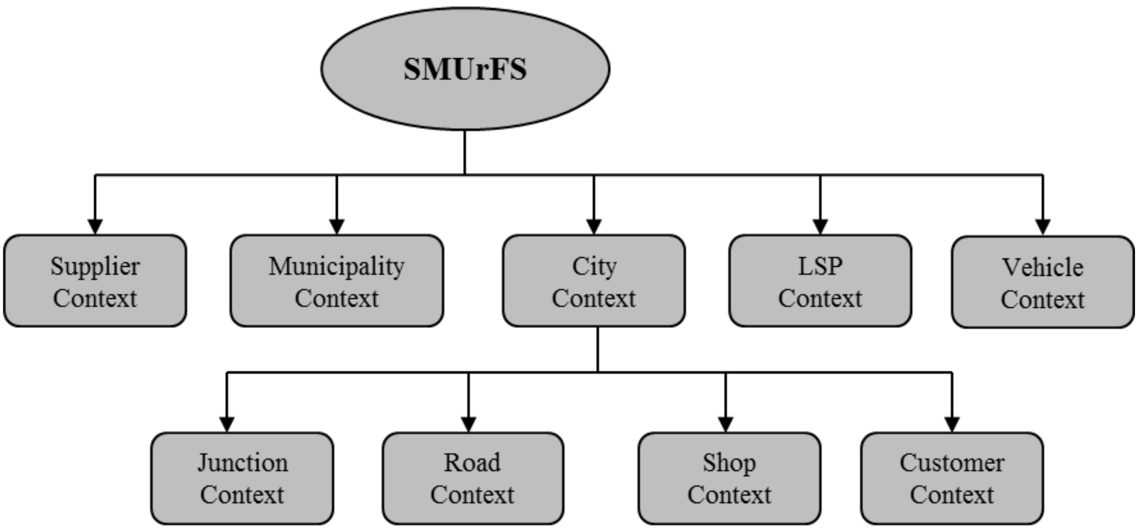


Figure 6.7 Contexts in the city logistics agent based model SMUrFS

[20] For more detail visit - http://repast.sourceforge.net/

The communication between agents is realized by projections. Projections give the modeller the ability to define the relationships, which can be social or spatial. The available projections for *Repast S* are continuous space projection, geographic information system projection (GIS), grid projections and network projections. Multiple projections can be used within one project. This can be extremely helpful when constructing an urban area. Existing grids or networks of urban areas can be used to build the city. For the SMUrFS model, we use GIS projections to simulate different agents and road network using shape files.

Watcher-protocol

The watcher-protocol is implemented by interface 'watcher' to perform the sensory activities for an agent. Watcher is used in the form of annotation (using @watch annotation) to the associated method. The function of the watcher is to wait until a specific agent performs a certain activity and sets a flag (using a Boolean parameter) to a watching agent method. The watching agent method then gets invoked and performs a certain task as per coding. Finally, the model pointer goes back to the agent who set the 'flag' and simulation continues as per scheduled events. To give an example, let's say a supplier-agent performs an auction to hire a carrier-agent. In this case, a watcher is attached to the auction event by all the carrier-agents. Thus, as soon as a supplier-agent calls for the auction, the carrier-agents start their bidding process. Once the bidding from all the carrier-agents is over the pointer goes back to the supplier-agents and they start evaluating the bid.

Scheduler-protocol

Scheduler protocol is implemented using @ ScheduledMethod annotation to the method of any agent in the model. This protocol is used to schedule events based on the starting time and interval. Thus if shopping is an activity performed by customer-agents starting the first day in the simulation and repeated every day, then it is implemented using the following syntax.

@ScheduledMethod(start = 1, interval = 1, priority = 25)

Here, the start means on the first tick. Interval means repeat the specific method after every single tick. Priority indicates when this method should be invoked if there are other methods with the same start and/or interval time.

6.3.2. GIS representation of Rotterdam city (The Netherlands)

As mentioned in the description of the context protocol, in SMUrFS model we use GIS projections to simulate different agents and road network using shapefiles. Shapefile is a popular geospatial vector data format for GIS software to represent geographical information. For SMUrFS model, we use GIS data of Rotterdam City (The Netherlands). To represent the city centre of Rotterdam, we locate the shops in areas with postcodes 3012 and 3014. Figure 6.8 shows these areas marked with a boarder.

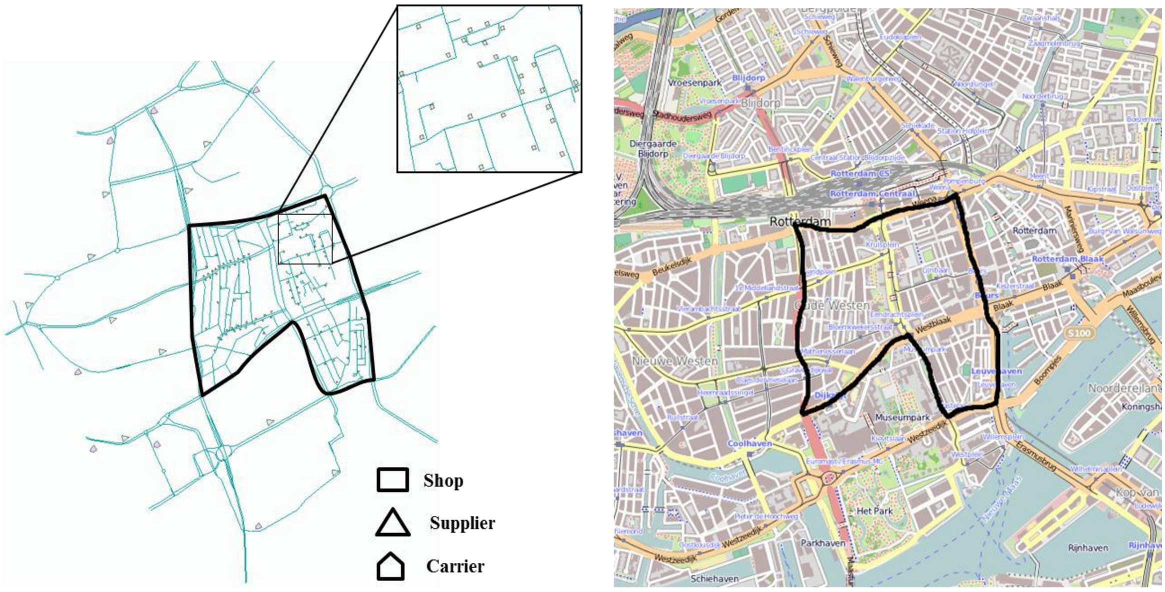


Figure 6.8 GIS representation of the Rotterdam city in the SMUrFS model

We have different shapefiles for road, shop, supplier, carrier and vehicles in this model. These shapefile contain different information depending on the associated agent type. For instance, the shop-agents' shapefile contains information about shop area, shop ID. Likewise, the shapefile for carrier agents' contains information such as running cost, fix cost, LSP ID and so on.

6.3.3. Model setup

For the SMUrFS model, we used information about the retail industry from the website of *'Hoofdbedrijfschap Detailhandel'* - *http://www.hbd.nl/*. It is an organization where employers' and workers' organizations in the retail industry collaborate. This organization provides information about retail trends for different product types.

Following three tables give data about the retail fashion industry. Table 6.2 gives details about population and number of stores for retail fashion in the five biggest cities in the Netherlands and Table 6.3 gives details about the total expenditure of different segments within retail fashion industry. Table 6.4 gives information about turnover and units per area (m^2).

Table 6.2 Population and number of shops in 5 biggest cities of Netherlands –excluding open markets and web shops (Source: www.detailhandel.info)

City	Total residents	Number of stores
Amsterdam	789.300	1.148
Rotterdam	616.000	698
The Hague	501.100	568
Utrecht	316.200	353
Eindhoven	217.300	294

Table 6.3 Expenditure as per fashion segment for 2012 – including (Source: www.detailhandel.info)

Fashion segment	Expenditure (million)	Per household	Per capita
Women's fashion	€ 4588	€ 608	€ 274
Men's fashion	€ 2497	€ 331	€ 149
baby and children	€ 1602	€ 212	€ 96
body fashion, under- and nightwear	€ 1397	€ 185	€ 83
sports and other clothing	€ 1193	€ 158	€ 71
general textile	€ 616	€ 82	€ 37
total	€ 11893	€ 1.576	€ 710

Table 6.4 Key figures about menswear (Source: Harmon et al. (2002))

Turnover per m2 (excl. VAT)	Stock per m2
2765 (Euro)	53 units

From Table 6.4, we can calculate the average cost per unit as 52.16 Euro.

Next, the yearly demand for the city of Rotterdam can be estimated using information about total per capita expenditure and unit cost as following,

(Population * per capita expenditure)/ Cost per unit

= (616000 * 710) /52 = 8747200 Units

Assuming the demand is uniform throughout the year; monthly demand is $1/12^{th}$ of yearly demand

= 8747200/12 = 728933 Units

Since, there are total 700 shops in the Rotterdam city, and we have 100 shops in the SMUrFS model, total monthly demand should be adjusted. Accordingly,

Monthly demand in the SMUrFS model = 728933/7 ≈ 100,000 units

The model setup parameters for SMUrFS are mentioned in Table 6.5

Table 6.5 Parameters for the model

Parameter	**Value**
Number of shops	100
Number of carriers	7
Number of shippers	10
Units per m^2 area	50
Price per goods-unit (Euro)	50
Average total demand per month (Units)	100000

6.3.4. Agent interaction diagram

The detailed interaction diagrams for the SMUrFS are shown in the Figure 6.9 and 6.10. The model starts with a set-up phase (Figure 6.9), where each shop-agent selects a shipper-agent. Next, shop-agents estimate their maximum stock level, safety stock level and monthly demand for the shop. Shipper-agents estimate monthly demand and conduct an auction to select the carrier-agent. During the auction, shipper-agents announce the demand and each carrier-agent sends the bid price. The shipper-agent hires a carrier-agent who bids the lowest price in the auction. Based on that price, the shipper-agent determines an ordering cost and sends this cost information to its shop-agents.

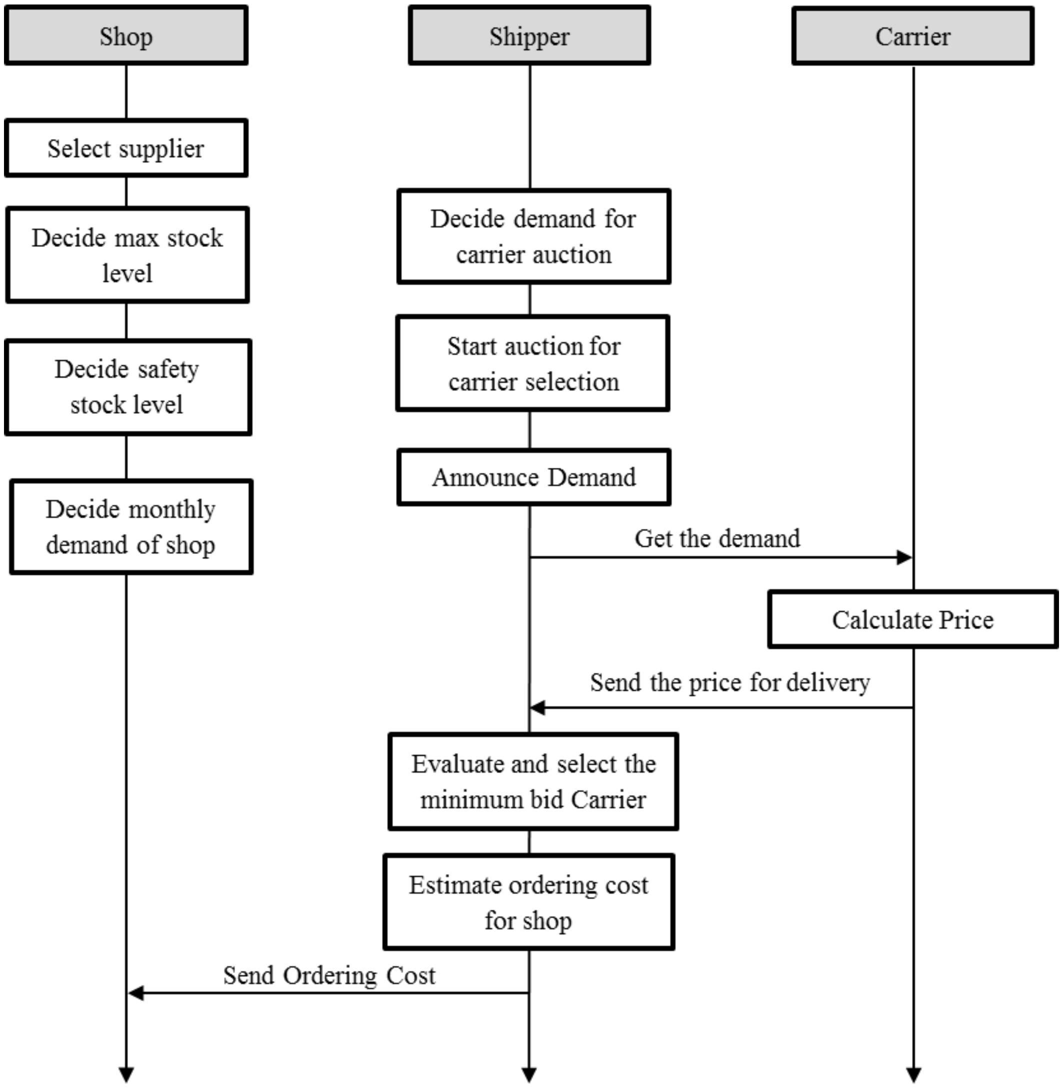


Figure 6.9 SMUrFS model stakeholder interaction diagram for the setup phase

Once the setup phase is complete, the model enters into the simulation phase and simulates the daily activities of urban goods movements. The simulation phase starts with customer-agents buying goods. Based on the assigned probability function, each customer-agent selects a shop-agent and buys goods if the stock level of the shop is enough to satisfy the demand of the customer-agent. This process is iterated for all customer-agents. At every shopping iteration, the stock level of each shop-agent is updated. At the end of the shopping activity, each shop-agent checks the stock level in the shop. If the stock level of the shop is at or below the re-ordering point, then the shop-agent places an order to the selected shipper-agent. Next, each shipper-agent collects all orders and sends them to the hired carrier-agent. Since a carrier-agent might be serving more than one shipper-agent, it collects order from all the shipper-agents. Subsequent, the carrier-agent starts making tours for goods delivery using the heuristic-based Tabu search vehicle routing algorithm. Finally, each carrier-agent assigns tours to its vehicles-agents, who then deliver goods to the shops. Once shop-agents receive the ordered goods, they update their stock level. On the next day, the simulation continues with customer-agents buying goods. The administrator-agent observes the city logistics activities in the city and collects information about the number of trucks entering the city and total truck-kms travelled to estimate their effects on the environment. The truck-agent is a passive agent and has simple behaviour of delivering goods based on the tour assigned to it.

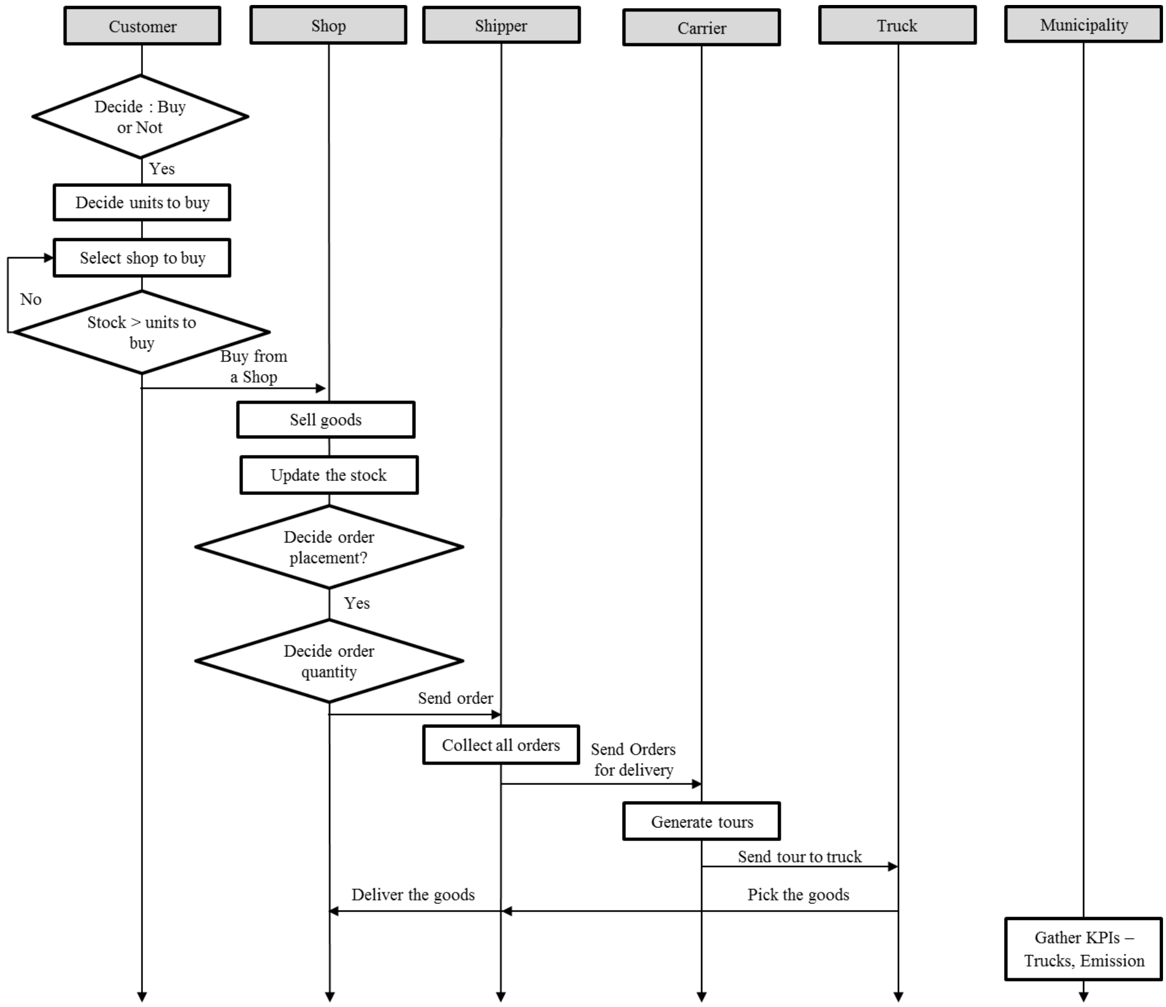


Figure 6.10 SMUrFS model stakeholder interaction diagram for the simulation phase

6.4. Reference scenario for the SMUrFS model

In the previous section, we described agents and their interactions as well as simulation phases for the SMUrFS model. This section describes the reference scenario run for the SMUrFS model and analysis of its output. The reference scenario marks the city logistics activities with respect to base situation where there exists no special policy or scheme to reduce negative externalities of the city logistics activities. Accordingly, freight related activities of shopkeepers, carriers and suppliers are not hampered by any regulations. Furthermore, in the reference scenario, municipality agent is not actively interfering but passively gathering information about different key performance indicators (KPIs).

Different types of information can be acquired during the simulation about city logistics operations. For instance, information about the ordering pattern of shopkeepers or consolidation factor for the carrier at individual and collective level can be obtained. For the policy makers (i.e. municipality) overview of important performance indicators such as total number of freight vehicles entering the city, total truck-km travelled in the city are of interest. The reference scenario gives information about the current state of the system. After implementing a policy measure, various key performance indicators (KPIs) of the reference scenario and the policy scenario can be compared to evaluate the effects of the policy on the city logistics activities. Figures 6.11 to 6.15 show graphs about different KPIs for the reference scenario in SMUrFS. The data point in these graphs shows value of a KPI averaged over six month period.

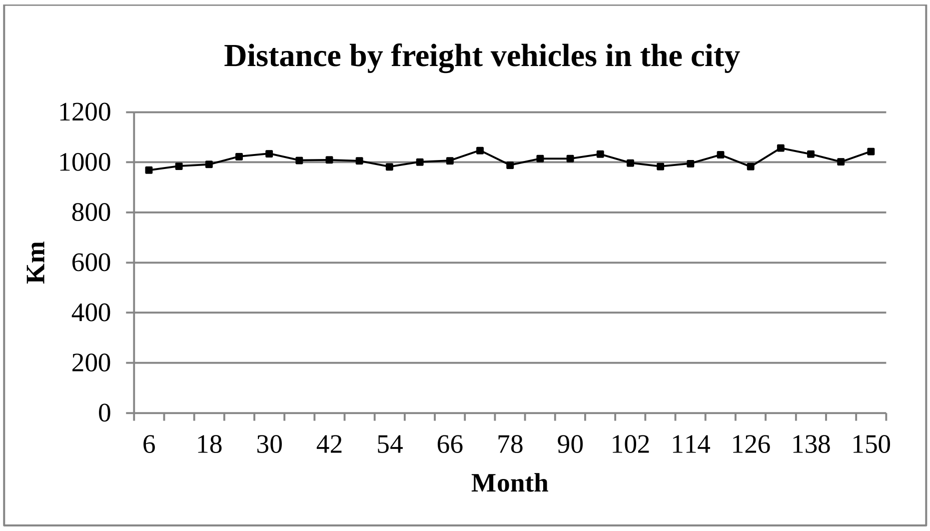


Figure 6.11 Total truck-km travelled by freight vehicles per month

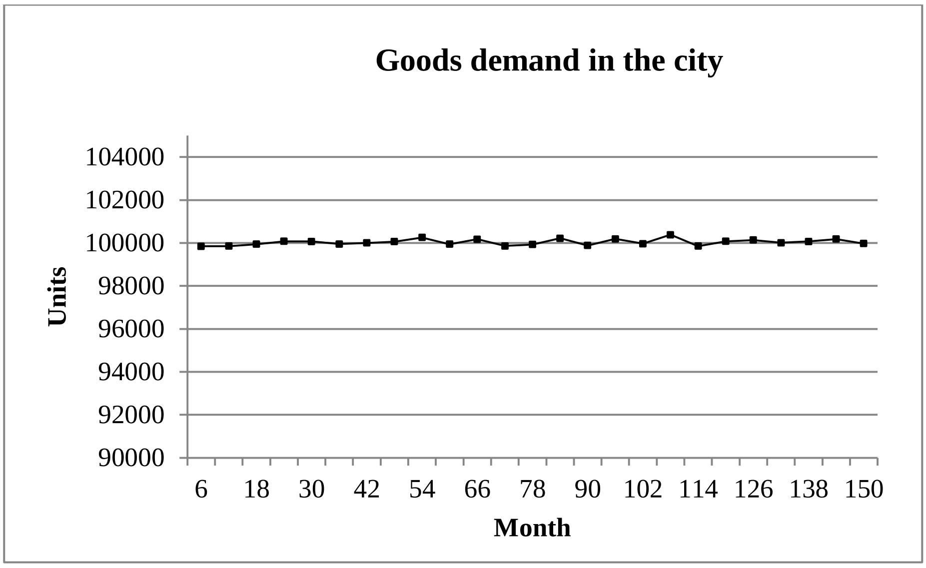


Figure 6.12 Goods demand in the city per month

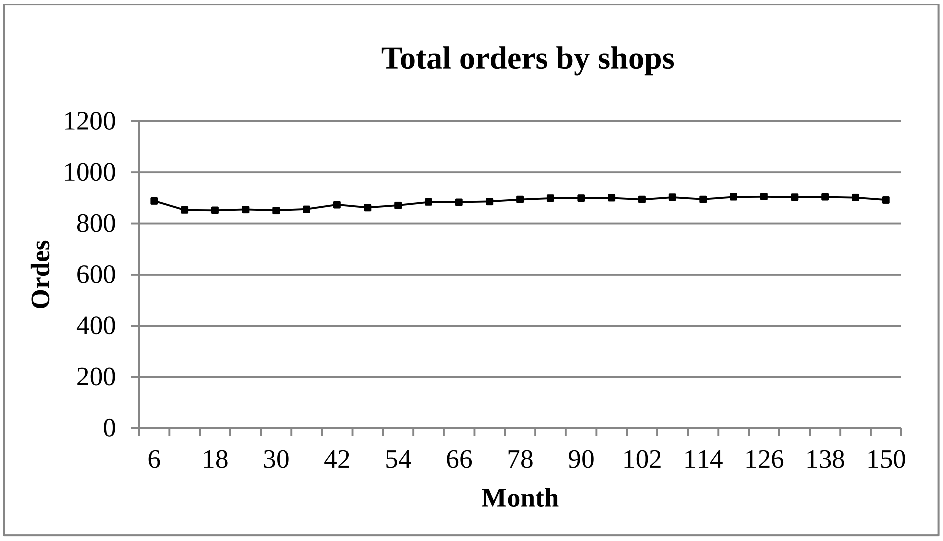


Figure 6.13 Number of orders placed by shopkeepers per month

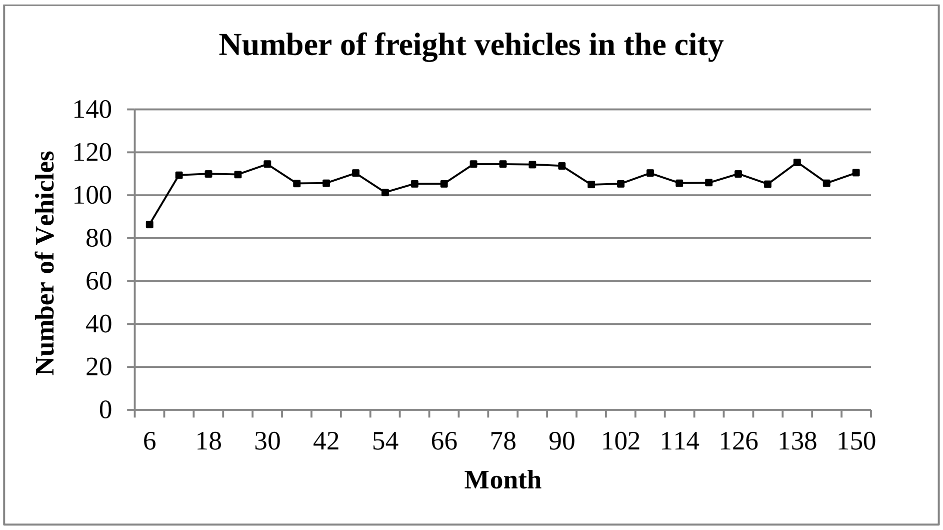


Figure 6.14 Number of freight vehicles entering the city every month

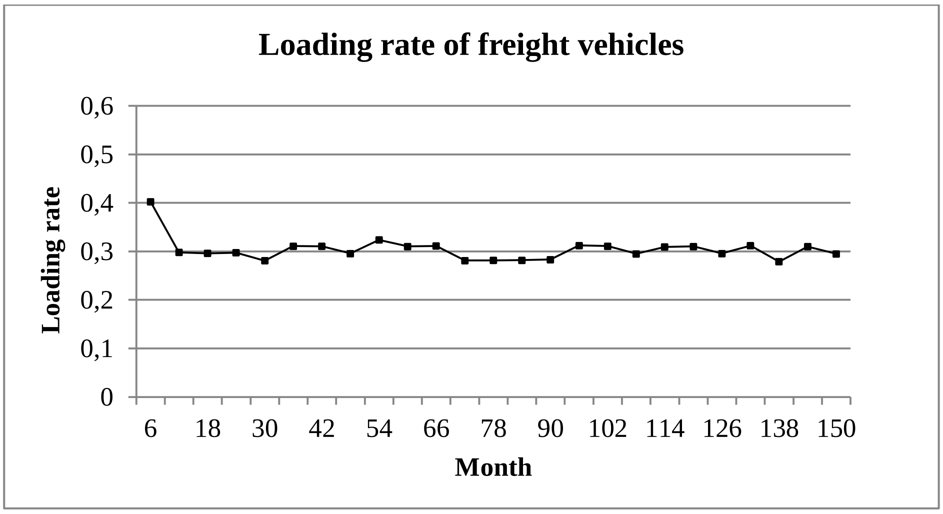


Figure 6.15 Average loading rate of freight vehicle

The individual decision making of the stakeholders creates an emergence phenomenon. As we explain in the previous sections, total demand, number shops, inhabitants of the city is same during every month. However, the ordering pattern of the shopkeepers differs every month due to change in ordering cost, demand from customers and stock availability. Different ordering patterns and goods consolidation in the freight vehicles results in a varying number of trucks entering the city every month.

In this view, we can imagine that when municipality agent is implementing a policy or a scheme, the affected stakeholders (e.g. shopkeepers, supplier, carriers) tend to change their decision making. The change in decision making leads to anew pattern of urban goods movements. Thus, using the SMUrFS model one can observe the changes in city logistics activities and respective variables of the stakeholders. With the analysis of affecting and affected variables one get insights about how the stakeholders and system might react to changes in a situation for city logistics activities. Such information can be very helpful in sketching a policy or defining a new scheme for the real life situation.

6.5. Concluding remarks

Congestion, pollution, and safety are some of the most pressing problems of urban areas. Along with the large number of passenger transport vehicles, the urban goods delivery vehicles significantly contribute to these problems. The problems related to urban goods transportation activities are primarily attributed to underlying characteristics such as heterogeneous stakeholders, their conflicting objectives and the resulting system of distributed decision making. Such autonomous decision making stakeholders do not efficiently cooperate and coordinate in their activities. The ensuing inefficient use of resources (e.g. goods delivery vehicle, time) gives rise to the city logistics problem.

To reduce the negative externalities of urban goods movement, we must first understand the decision making processes of the city logistics stakeholders under different situations. The discipline of city logistics modelling is dedicated to understanding the effects of various changes in the urban distribution system without actually changing the system. Various types of modelling systems exist for the analysis of the city logistics domain and its respective policies. Nonetheless, the agent based modelling technique is very advantageous for such analysis because it can model city logistics related entities (e.g. stakeholders, resources) and activities in a natural way. It allows one to depict the stakeholders as independent agents with different behaviours. Thus, the novelty of using the agent technology is its capability to capture the emergence and distributed decision making in varying situations. Policy analysed using this technique is more robust as it is evaluated under dynamically changing conditions of city logistics.

City logistics modellers already take an interest in the agent technology, as evident by the growing number of agent based models developed for city logistics analysis. Notably, many fields (e.g. energy, land planning) which are now fairly mature in agent based modelling started with developing ‘toy models’ for analysing their respective domain. In the same vein, agent based models in the city logistics domain are mostly ‘toy models’ where different stakeholders of the city logistics domain interact in an artificial city.

In this chapter, we present the approach of using city logistics ontology for the development of an agent based model for the city logistics domain. City logistics ontology is a knowledge model which includes city logistics entities (e.g. stakeholders, resources) and the relationships between them in a structured form. The approach presented in this chapter takes the ontology as a starting point for developing an agent based model by using ontological components as building blocks for the agent based model. Extraction of these entities and relations readily supplies the basic structure of the agent based simulation model in the form of the classes and relationships. Such flexibility can reduce the modelling time when the modeller is familiar with the ontology and extraction process. Furthermore, even just using the city logistics ontology as a structural conceptual model offers advantages over the verbal conceptual model.

The current version of the model uses GIS data from the city of Rotterdam. GIS compatibility of the model facilitates transformation of the model to real life cases. For instance, with the appropriate data (e.g. shops locations, delivery frequency), the model can be used for real-world scenarios. Furthermore, the integration of the validated city logistics ontology promises structural validity of agents and their interactions. City logistics ontology describes stakeholders in multiple levels (see Section 4.4.2). In the SMUrFS model, agents represent only primary level of stakeholder (i.e. Shipper, Carrier, Shop, Administrator). Similarly, details such as variety of goods flows, frequency of delivery for different goods types are not incorporated at this stage in the SMUrFS model. For the proof of concept model, the focus is to show integration of city logistics ontology for the ABM development. With these details included in the ABM, detail analysis of city logistics activities can be carried out. Moreover, the model is built up from very simple ground rules (i.e. change the shipment size to maximize profits) and so far, the behaviour of the model has been evaluated allowing students to play the simulation game. Students were asked to make choices based on the ground rules. The approach and outcomes of this game are reported in the next chapter.

Nonetheless, there are certain limitations to using the ontology for ABM development. First, if the modeller wants to include the information exchange or relationships other than those depicted in the ontology, she has to modify the code or modify the ontology. Secondly, extracting the Java classes is not very complicated, but modifying them for the simulation can be tricky. Sometimes the time saved by extracting classes is offset by the time spent on modifying them. This misuse of time is especially true for researchers with limited programming knowledge. In our opinion, a better way to use the ontology for ABM development is first to extract part of the ontology needed for the model. Next modify it to address the user's requirements and finally extract the model or run the model directly from the ontology. This method offers high consistency of the model and more flexibility for model extension.

References

Axelrod, R. (2006). Agent-based modeling as a bridge between disciplines. Handbook of computational economics 2: 1565-1584.

Bergkvist, M., Davidsson, P., Persson, J. and Ramstedt, L. (2005). A hybrid micro-simulator for determining the effects of governmental control policies on transport chains. Multi-Agent and Multi-Agent-Based Simulation: 236-247.

Borshchev, A. and Filippov, A. (2004). From system dynamics and discrete event to practical agent based modeling: reasons, techniques, tools. Proceedings of the 22nd international conference of the system dynamics society.

Cooper, D. J., Kagel, J. H., Lo, W. and Gu, Q. L. (1999). Gaming against managers in incentive systems: Experimental results with Chinese students and Chinese managers. American Economic Review: 781-804.

Davidsson, P., Henesey, L., Ramstedt, L., Törnquist, J. and Wernstedt, F. (2005). An analysis of agent-based approaches to transport logistics. Transportation Research Part C 13(4): 255-271.

Donnelly, R. (2007). A hybrid microsimulation model of freight flows. 5th international Conference on City Logistics, Kyoto.

Fréchette, G. R. (2011). Laboratory experiments: Professionals versus students. Available at SSRN.

Gendreau, M., Hertz, A. and Laporte, G. (1994). A tabu search heuristic for the vehicle routing problem. Management science 40(10): 1276-1290.

Gruber, T. R. (1995). Toward principles for the design of ontologies used for knowledge sharing. Int. J. Hum.-Comput. Stud. 43(5-6): 907-928.

Guyot, P. and Honiden, S. (2006). Agent-based participatory simulations: Merging multi-agent systems and role-playing games. Journal of Artificial Societies and Social Simulation 9(4).

Harder, R. (2001). OpenTS: An Open Source Java Tabu Search Framework. INFORMS Annual Meeting, Miami.

Harmon, S., Hoffman, C., Gonzalez, A. J., Knauf, R. and Barr, V. (2002). Validation of human behavior representations. Foundations for V&V in the 21st Century Workshop (Foundations' 02).

Hunt, J. D. and Stefan, K. J. (2007). Tour-based microsimulation of urban commercial movements. Transportation Research Part B: Methodological 41(9): 981-1013.

Kumar, V. and Srinivasan, S. (2010). A review of supply chain management using multi-agent system. International Journal of Computer Science(7): 5.

Le Ber, F. and Chouvet, M. P. (1999). An agent-based model for domain knowledge representation. Data & knowledge engineering 29(2): 147-161.

Liedtke, G. and Schepperle, H. (2004). Segmentation of the transportation market with regard to activity-based freight transport modelling. International Journal of Logistics Research and Applications 7(3): 199-218.

Marcucci, E., Gatta, V., Valeri, E. and Stathopoulos, A. (2013). Urban Freight Transport Modelling: An Agent-specific Approach, F. Angeli.

Mavor, A. S. and Pew, R. W. (1998). Modeling Human and Organizational Behavior:: Application to Military Simulations, National Academies Press.

Stevenson, G. and Dobson, S. (2011). Sapphire: Generating Java runtime artefacts from OWL ontologies. Advanced Information Systems Engineering Workshops, Springer.

Swaminathan, J. M., Smith, S. F. and Sadeh, N. M. (1994). Modeling the dynamics of supply chains. Proceedings of AAAI-94 SIGMAN Workshop on Intelligent Manufacturing Systems.

Tamagawa, D., Taniguchi, E. and Yamada, T. (2010). Evaluating city logistics measures using a multi-agent model. Procedia - Social and Behavioral Sciences 2(3): 6002-6012.

Taniguchi, E. and Tamagawa, D. (2005). Evaluating city logistics measures considering the behavior of several stakeholders. Journal of the Eastern Asia Society for Transportation Studies 6: 3062-3076.

Tersine, R. J. (1994). Principles of inventory and materials management.

Terzi, S. and Cavalieri, S. (2004). Simulation in the supply chain context: a survey. Computers in industry 53(1): 3-16.

7 A participatory simulation gaming framework for the validation of an agent based model: the case of city logistics

7.1. Introduction

Agent-based modelling is used for simulating the actions and interactions of autonomous entities aiming to assessing their effects on the system as a whole. It combines elements of game theory, complex systems, emergence, computational sociology, and evolutionary programming. At an abstract level, an agent based model (ABM) is a representation of the many simple agents and interactions among them. The decision making of the agents is based on the rules given to them. These rules guides them about ‘what to do’ and ‘when’.

Together with characteristics such as heterogeneity, dynamism, non-linearity, limited information sharing even a simple social system can exhibit very complex behaviour pattern. The number of interactions between entities of the system increases combinatorially with the increase in the number of entities, thus potentially allowing for many new and subtle types of behaviour to emerge which can be described as ‘aggregate complexity’. Due to its ability to model a system in a natural and flexible way, an ABM can capture such complex emergent behavioural patterns and give valuable insights about the system and its activities. Using an ABM, a modeller can model and simulate the behaviour of the system’s constituent units (i.e. agents) and their interactions, capturing system level emergence from the bottom up during the simulation.

Agent-based modelling is a promising alternative when traditional techniques reach its limitations. For instance, using classical optimization technique one can find a solution where a city logistics system can work in the most efficient way. However, when the stakeholders of the system are independent, their priority is to create optimum situation (e.g. profit, efficiency) for themselves even at the expense of system efficiency. In such situations, global optimization becomes a benchmark than a practice. An ABM can be designed for such system where each agent is optimizing its own goal. Such a model can be used as a laboratory where the system parameters of the model can be varied in such a way that system output goes in the direction of the global optimum, even though, the agents is taking decisions to optimize their well-being. Despite its capability of mapping a system in natural and flexible way, validation of an ABM remains a challenging task.

7.2. Validation in literature

The purpose of validation is to check whether the system model represents the real world at a satisfactory level. Validation is a highly discussed but often vaguely described topic in the literature. Looking back in the history, Campbell (1957) and Campbell et al. (1963) introduced the terms internal validity and external validity. Campbell and his collaborators have also invoked other types of validity regarding social science experiments, and their classification of validity types has evolved over time. Their most stable and recent list includes now four of them: statistical conclusion validity, internal validity, construct validity and external validity (Shadish et al., 2002). However, the most often invoked validation types in both, experimental economics and theory-driven experiments in the social sciences are *internal* and *external* validation. After the introduction of validity in late 50s, many other researchers introduced their versions of the validation along with criticism for other definitions and explanations for the validation. Shadish et al. (2002) give a good account of such criticism while defending their description of the validation. They also show their displeasure about the terminological confusion and at the same time find themselves responsible at some extent. Finally, authors urge to use label validation only with description that make its intended understanding clear.

Despite this confusion and criticism about validation techniques, the notions of internal validation and external validation are the most widely used in research to build confidence in the model outputs. It is without doubt that the descriptions and technique used for such validation vary with users and applications. In general, internal validity is referred as the approximate validity of inference regarding cause-effect or causal relationship. In simple terms, if one can confidently say that whatever happening in the model is due to changes made in controlled variables and other variables are not affecting the result then the model is internally valid. On the other hand, external validity is referred as the approximate validity of generalized inference. In simple terms, external validity is about checking whether the result of the research can be generalized to other situations or customers.

According to Steyerberg et al. (2001), internal validation can be done using boot-strapping, cross-validation or data splitting techniques. These techniques mainly concerned with evaluating the model using the same data used for the model development. In simple terms, out of total data available for model development, part of the data is used for model development and remaining data is used for assessing the outcome of the model. On the other hand for simulation studies, often code verification is considered as internal validation. For simulation studies, validation techniques mentioned by Sargent (2005) are considered quite frequently. The study lists multiple validation techniques and explains how each technique can be used to validate different parts and function of the model. Table 7.1 gives an overview about these techniques.

Table 7. 1 Validation techniques for simulation studies (Source: (Sargent, 2005)

Animation	Turing tests
Comparison to other models	Multistage validation
Degenerate tests	Operational graphics
Event validity	Sensitivity analysis
Extreme condition tests	Predictive validation
Face validity	Traces
Historical data validation	Historical methods (Rationalism, Empiricism, Positive economics)

Besides, the study discusses other important concepts such as conceptual model validation, data validity, computerized model verification and operational validity. The study concludes that validation is critical to any model but there is no specific test that can be easily applied for a model, and validation of every simulation model presents a new and unique challenge for the development team.

Little research effort has been spent on the definition of specific methods and techniques for ABM validation. Often, statistical validation techniques applied to other simulation paradigms are deemed equally suitable for an ABM without much questioning - e.g. (LeBaron, 2001; Rand et al., 2003; Xiang et al., 2005; Happe et al., 2006). One notable effort supporting conventional empirical validation techniques comes from Windrum et al. (2007). They claim "empirical validation techniques used for the econometric model can be used for validation of ABM provided commonly accepted, minimal protocol for the analysis of ABM models developed and agreed upon". However, Moss (2008) refutes this claim arguing that the proposed approaches are fairly conventional and follows econometrician approach that includes building a model using prior data and running regression on the available data. Moss reasons that social theories do not always reflect observation and experience and thus numerical data is not always the natural way to describe social phenomena.

There are mainly two obstacles in validating an ABM with traditional techniques. First, unavailability of data is a known issue with any modelling technique during model development as well as validation, and ABMs are no exception. ABMs are often developed to analyse future scenarios such as new policy, scheme or any change in the system. Since the scenario is about the future, there is no data that can be compared to the model output for the validation. For instance, it is hard to forecast how the introduction of congestion changes will affect the goods delivery practice and in turn goods ordering patterns from the shopkeepers.

Second and more appropriate reason for unsuitability of traditional techniques is the integral structure of the ABM. According to its design philosophy, ABMs are characterize by autonomous behaviour of the agents. The 'independent' agents create a decentralized decision making system where the global behaviour (i.e. system outcome) emerges from interactions between these agents. When multiple agents with different goals and rules interact in (close to) infinite ways, they create a complex emergent system that is difficult to track. An equally frustrating fact caused by the complexity is that, in the absence of clear-cut a priori expectations about the results, the unexpected output raises confusion about the legitimacy of the result (Galán et al., 2009).

An ABM is a complex adaptive system where path dependency effect plays a critical part in driving system behaviour. Such path dependent interactions give rise to unexpected patterns and consequences. Due to the path dependency of decision making, a completely different sequence of decision making could result in the same model output. Furthermore, the model outcome might be similar to the observed output, however, the events and/or its sequences which lead to the model outcome may have followed a completely different decision making path than expected. In more general terms, the model output is the result of internal decision making and may differ with alteration in the decision path. On the contrary, with the set of rules embedded in agents, their behaviour is modelled to take a ‘certain action’ in a ‘certain situation’. It suggests that the internal decision making behaviour of agents is truly responsible for the model output and thus it cannot be ignored while validating ABMs.

Extending his view, Moss advocates a companion modelling approach for development of ABMs where agent models and role playing games are linked in a cyclic process to receive and deliver feedbacks to and from the real world and stakeholders. The approach can be used to validate the representation of an ABM by matching the ABM process patterns through role playing games. An example of using a role paying game for validation of an ABM for spatial planning is demonstrated by Ligtenberg et al. (2010). The example shows a qualitative comparison between spatial patterns generated by a group of role players and by an agent based model.

7.3. Validation of agent based models

Ontology is the first step for developing an ABM. It includes basic architecture of the agents, their attributes and relations in the form of the semantic information embedded in the ontological classes and relations between them (van Dam and Lukszo, 2006; Livet et al., 2010). The domain-specific ontological objects serve as building blocks for an agent based model. Therefore, the validation of an ABM starts with the validation of the ontology (see Figure 7.1). At this stage, validation evaluates whether the ABM represents the real world in terms of structural elements and their relationships. *Chapter 5* describes city logistics ontology validation. Readers interested in additional reading about ontology validation are referred to (Banks, 1998; Obrst et al., 2007).

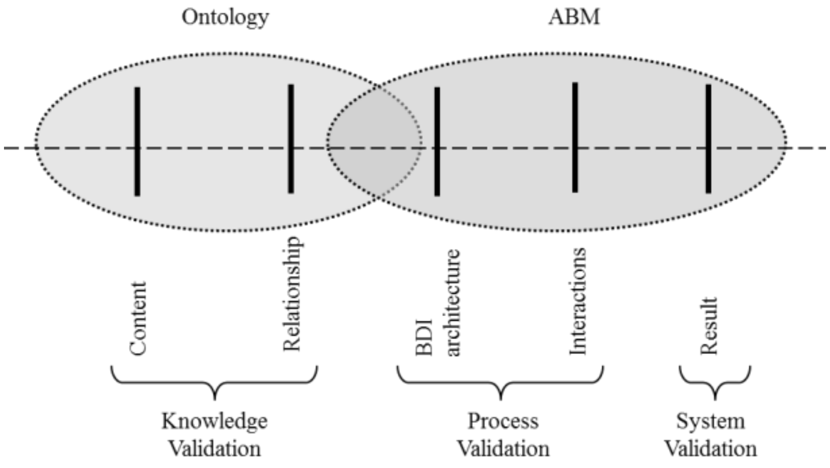


Figure 7.1 Components of agent based model validation

Ontology defines agents in the ‘blank state’ where only basic characteristics of agents are included. In the ontology, different agents are connected with each other through multiple relationships. However, at this stage the agents are not yet capable of taking actions or carry out interactions with other agents or the system. Modeller (e.g. researcher) interested in exploring specific decision making processes and phenomena must incorporate such behaviour to create fully functional agents. Based on interaction protocols embedded, the agents become 'capable' of deciding about their actions and interactions with model environment and other agents. At this stage, an ABM can be represented by the functional processes carried by agents performing different activities in the model. In an ABM, agents are modelled to behave independently – similar to their real counterpart (i.e. stakeholders). Such independent decision making of the individual agent leads to the emergence of the system presented as a macro output of the model. Accordingly, the final output of the model is the result of the 'certain actions' taken by agents under 'certain conditions'. Thus, validating an ABM at this stage is very important since it evaluates the accuracy of behavioural representation of the real world system in the ABM.

The third stage of the validation is by validating output of the model. It follows traditional procedure where the performance indicators of models are validated with hypothesis (in case of synthetic data) or real-world measurements of those indicators (in case of real data). As argued above, the absence of relevant data is a serious issue for system output validation (Kleijen, 1999). Furthermore, even though the system outcome might be similar to the observed output, the events and/or their sequence may not have followed a logical process and could still be completely different than the real processes. In this situation, evaluating correct representation of the decision making processes that lead to the system outcome is a promising way of validating ABMs

7.3.1. Participatory simulation game framework for process validation in ABM

According to the classical research article by Rao and Georgeff (1995), the decision making mechanism of an agent follows the Belief- Desire-Intention architecture. A belief of an agent is defined as the information it perceive about the state of the environment of the model. A belief can have a form of a variable, a dataset or some type of data structure. In essence, belief represents the perception of the agent towards the current state of the system. Next, the desire of the agent is represented as a motivational state that the agent wants to reach or accomplish. Desires are, in fact, priorities for objectives of the agent under different situations. Lastly, the intention of the agent is described as the final act the agent takes, based on the beliefs and desires at the particular stage of the system. As the action of the player is a final outcome that can be observed, in the rest of the chapter word 'action' will be used instead of 'intention'. Notably, the Belief- Desire-Action (BDA) has similar structure to the utility in the discrete choice analysis where agent would choose the alternative (e.g. action) that maximize its utility based on the assigned specific weights (e.g. belief) to the decision parameters. Accordingly, to validate the process of an agent, we need information about belief, desire and action of a representative stakeholder.

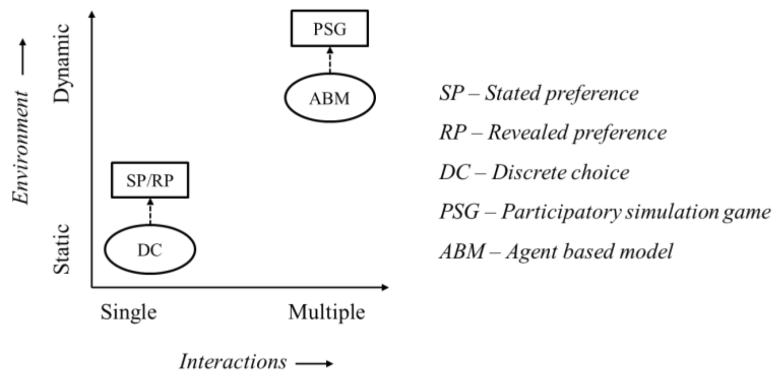


Figure 7.2 Positioning of a participatory simulation game for validation of an ABM

The method of discrete choice analysis is a very mature field for exploring the behaviour choices, where it is assumed that the individual behaviour is not affected by other stakeholders of the system. However, an ABM has a dynamic setting where multiple agents are interacting with each other for decision making and the choice of one agent affects (and is affected by) the decision of other agents (see Figure 7.2). In this situation collecting data from an individual stakeholder using a method such as stated preference does not capture the interdependency of these agents' behaviour. Therefore, we need a technique that can capture the dynamics of agent behaviour in a simple but effective manner.

Participatory simulation game (PSG) is an effective alternative for collecting information about interlaced behaviour of the stakeholder in a dynamic setting. According to Colella (2000), "participatory simulation takes the simulation off of the computer screen and brings it into the experiential world of the player". In PSG, we put the stakeholder in the setting of the ABM and thus the player's decision making is now interlaced with decision choices of other agents of the ABM. By bridging an agent based simulation model with the human players, we can create an environment in which players are taking decisions (i.e. action) based how they perceive (i.e. belief) the system state and their objective (i.e. desire).

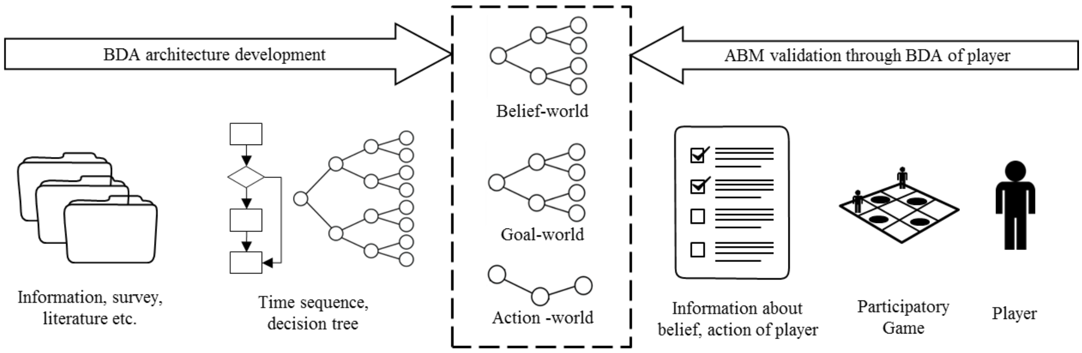


Figure 7.3 Framework for the validation of an ABM using a participatory simulation game

Consequently, we propose a participatory simulation game approach for the process validation of an agent based model. Figure 7.3 depicts the schema for this approach. The left side represents the typical process for developing agent behaviour in the ABM. The right side shows the process for collecting decision making attributes from a player using a PSG. By design, participatory simulations focus on the behaviours and interactions of the participants which allow comparing the behaviour of the players in the game with that of the agents in the model. This makes the approach more appropriate for validation purposes since the players are taking decisions in exactly the same environment as that of agents. In this way, we check how closely the model behaviour represents the real world behaviour. Such evaluation also gives an indication about the applicability of the model outcome in the real world situation. In the following section, a proof of concept game developed for the process validation of city logistics agent based model is described.

7.4. Proof of concept – validation of the city logistics agent based model

Building on the framework described in the previous section, a simple participatory simulation game for the SMUrFS is developed. The game aims to explore the decision making processes of the shopkeeper-agent and collect information about its underlying beliefs and the actions taken in specific situations.

7.4.1. Decision making of the shop agent in SMUrFS

The shopkeepers have a strong influence on urban transportation flows as they decide when to order, how much to order and when they want to have the order delivered. In the SMUrFS model, the shop-agent represents shopkeepers and takes following decisions:

- select a shipper for goods replenishment
- selects the shop size, profit margin, safety stock and maximum stock level
- selects goods re-ordering point and replenishing order quantity

The decision about selecting a shipper is straight forward and is taken based on minimum distance between the shop and the shipper's location. The information about the shop size is supplied to the shop-agents based on the normal distribution. In the proof of concept validation game, we are interested in collecting following information about shopkeeper's behaviour: 1) Profit margin selection 2) Re-ordering point (ROP) and 3) Ordering quantity (OQ).

In SMUrFS, in the beginning of the simulation, shop-agent estimates monthly demand for the shop as a function of the shop area using the given total demand for the city. During simulation, the monthly demand is calculated using a simple moving average formula using the demand of last three months. To estimate when next order should to place, the shop agent uses following formula:

*Re-order point = (Average Daily Demand * Lead Time in Days) + Safety Stock*

Since the lead time is one day, and the assumption about safety stock is constant, the belief of the shop-agent about the average demand reflects in the form of ROP. The shop-agent believes that an ROP is the best stock level for goods ordering. In other words, a shop-agent believes that ordering before this point results in excess stock leading to extra inventory costs while ordering after this point results in less stock availability leading to fewer customers.

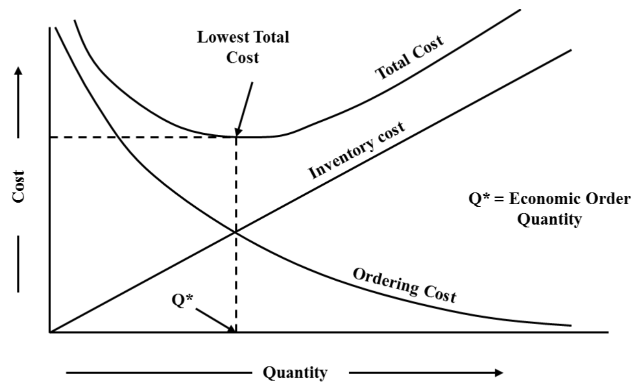


Figure 7.4 Economic order quantity

Once the ROP is decided, the shop-agent has to select the OQ for placing an order for goods. To calculate an OQ, the shop-agent juggles mainly between the inventory cost and the ordering cost. These costs work in opposite direction and, as shown in Figure 7.4, there exist an OQ where the total cost is the lowest. This point is an economic order quantity (EOQ) and is calculated using following formula.

$$Q = \sqrt{\frac{2O_cD}{I}}$$

where Q= Order Quantity, O_c = Ordering costs per order, D = *D*emand, I =Inventory costs

The shop-agent in the SMUrFS is programmed to use the EOQ formula to decide order quantity. In this case study, we are interested in comparing ROP and EOQ attributes of player and shop-agent.

7.5. Participatory simulation game setting

The SMUrFS model is created using an ABM platform RepastS (North et al., 2005) which does not allow participatory simulation. Another ABM platform, NetLogo (Tisue and Wilensky, 2004) has the HubNet technology. This technology allows a human player to take control of a part of the system and get involved in the decision making process. Therefore, a participatory simulation game was designed using the NetLog platform for validation of the shop-agent in the SMUrFS model. In this game, the player was asked to take control of one of the shops in the simulation. A number of modifications and simplifications were implemented in the game to make the game easier to understand. Care was taken so that these modifications would not affect the decision making processes of the shop-agent.

The game is simplified to consider three agents: customer-agents, shop-agents and shipper -agents. The carrier and shipper agents of the SMUrFS model were merged into a single type of a shipper-agent. In the game, the shipper-agent collects orders from shops and delivers goods. Because of this simplification, the auction process for selection of the carrier is not included in the game. Similarly, the TABU search algorithm used for vehicle routine in the SMUrFS model is replaced by a simple algorithm in the game.

For the validation game, the shop player (be it an agent or a human player) with the highest profit is considered the winner of the game. As comparing profits for the winner selection becomes needlessly complicated with different shop areas, all the shops are allotted the same 100 m^2 area. In this situation, all the shop-agents start their decision making with the same initial conditions that makes the comparison between the behaviour of the agents and that of the player easier. In summary, only those elements which affect the decision making processes of the players are kept in the game. Efforts are made to make the game simple and interesting so the players take choices that describe their behaviour at best.

Table 7. 2 Information provided to players at the beginning of the game

Information Parameter	Detail
Total monthly demand	100.000 units
Total population of the city	10.000 customers
Customers shop every	Once a week
Capacity of 1 m2	50 units
Average area of the shop	100 m2
Unit Price	50 money-units
Minimum profit margin	5 %
Maximum profit margin	35 %
Inventory costs	30 % of unit price/year
Truck Capacity	1000 units

Total 16 teams participated in the game session. During the game session, total 16 games were played. In every game one team took control of one of the 50 shop-agents. The shop-player was given information (see Table 7.2) in the form of a hand-out. Furthermore, the player was informed that a shop with the highest profit at the end of the game is considered the winner of the game.

The game was played for a period of 3 simulated months or 90 days. In 90 days, players try out different strategies and find the best strategy for goods ordering. The following management information (see Table 7.3) was available on the game interface to the players, during the game.

Table 7.3 Parameters available to the player during participatory simulation game

Parameter
Total Ordering cost
Total purchase cost
Total inventory cost
Total revenue
Total net profit
Last ordered quantity
Current stock level

Each player also filled-in a questionnaire during the game. If placed an order, the player wrote down the reasons behind the decision. The players were asked to mentioned variables they considered while choosing the re-order point and order quantity. Information from the questionnaire is used to get insights about the player's actions and beliefs. At the end of the game session, a group discussion was conducted where students discussed their strategies and gained insights about the BDA structure of other players.

7.5.1. Decision making in the game

During the course of the game, the player takes several decisions revealing the decision making parameters and behavioural attributes associated with the goods ordering process.

(1) Shipper-selection

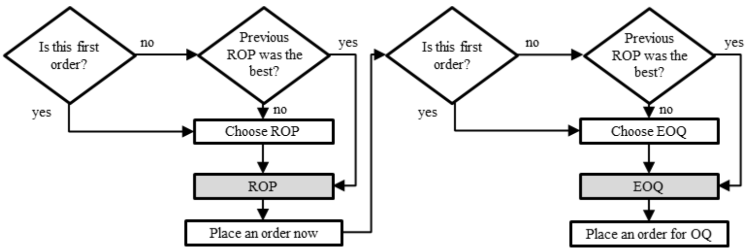
The player selects the shipper in the beginning of the game. The shippers are located in the periphery of the city. Players are given information about cost per hour, order preparation cost (%), profit margin (%) and distance from shipper. This information is not sufficient to know how the ordering cost is decided by the shippers. As a modeller it was known to us that the ordering cost of each shipper does not vary from other shippers significantly. Thus, selecting a different shipper does not make a big difference in the profits made. Furthermore, the ordering cost changes every month so a shipper with lowest ordering cost in the beginning might have higher ordering cost in the next months. Thus, the outcome of the decision itself is relatively insignificant. However, by engaging the players in the process of decision making we want to encourage the players to think about a strategy before starting the game. This settling also gives them an opportunity to start a discussion prepares to take decisions using limited information.

(2) Selecting the profit margin

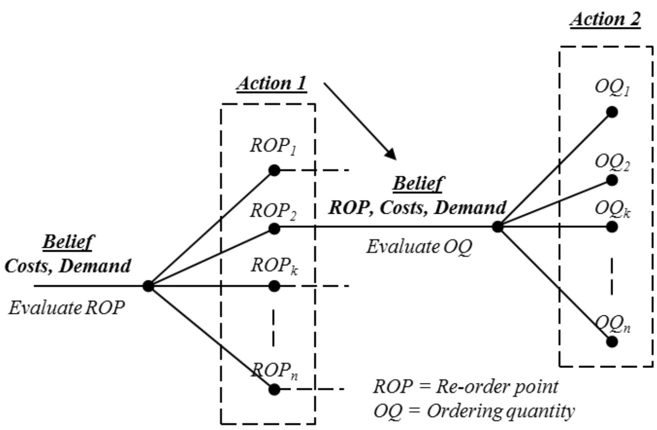
In the SMUrFS model, the customers decide their utility based on the price charged for the product, the shop area and goods availability (i.e. stock level) in the shop. Selecting a very high-profit margin allows the shop to make more profit per unit sale but also leads to fewer customers selecting the shop and vice versa. The player is given a minimum and maximum value of the profit margin. Clearly, the player cannot know in advance the precise effects of a particular profit margin. Therefore, the player must select the profit margin based on the perception about other shops' profit margin. The profit margin distribution graphs of the players and shop-agents are compared.

(3) Decision about an ordering strategy

An ordering strategy is very important for analysing behaviour of the players, and it consists of two decisions, 1) a decision about when to place an order (i.e. ROP) and (2) a decision about how much quantity to order (i.e. OQ). During the game, the shop player takes these decisions. There are multiple possibilities for an ROP and an OQ for placing an order. Figure 7.5 (a) depicts a flow chart for taking decision about an ROP and an EOQ. The decision tree in Figure 7.5 (b) gives more elaborate information about parameters affecting the decision making about an ROP and an OQ, indicating a belief and an action of the shopkeeper for goods ordering process.



(a)



(b)

Figure 7.5 (a) Decision flow-chart for ordering the process (b) Decision tree for ordering the process

Parameters such as a demand trend, approximation of the future demand and selection of the safety stock are closely associated with selection of an ROP. The action of deciding an ROP serves as a belief for the next decision about an OQ. Other factors affecting the decision about an OQ are costs and demand from customers. Based on the decision about an ROP, the player has multiple options for selecting an OQ for placing the order. A certain payoff can be associated with each OQ option. Finally, a decision about an OQ is taken assuming that the selected OQ will lead to the desired payoff (i.e. goal – highest profit, in this case). The choice of the ordering strategy has a considerable impact on the game outcome as ordering goods in a non-optimal way lowers the profits.

7.5.2. Students as validation referents

In any simulation model, a situation where the players are affecting the model outcome requires to make sure that human behaviour is adequately presented in the model. In the SMUrFS model, we want to validate decision making behaviour of shopkeepers. For this purpose, we asked undergraduate students taking supply chain and logistics courses to become validation referents and assume the role of the shopkeeper in the validation game. Critics of human behaviour validation will surely question this arrangement asking – How closely undergraduate students can represent the behaviour of shopkeepers?

To argue in favour of this arrangement, we would like to refer to a detailed review about behaviour validation by Harmon et al. (2002). The review gives very good account of shortcomings of human behaviour validation techniques and settings. According to the review, often validators believe that a good validation referent for validating certain human behaviour is a stakeholder (i.e. person) doing the same job. However, this does not translate into the best outcome. The reason being, real stakeholders, used as validation referents, often, expect the simulated behaviour to perform exactly like their behaviour rather than an abstraction. A real stakeholder often overlooks the fact that a model is an abstraction of the reality and thus the model behaviour should also represent the abstraction of real behaviour. The authors cite results of survey National Research Council study (Mavor and Pew, 1998) to support their opinion.

Department of Defence and the military services in USA have developed a *Recommended Practices Guide (RPG) for Verification, Validation and Accreditation (VV&A) procedures*[21]. The work is based on their research experiments and scientific references. According to this guide "Selection of the validation referent is usually done on the basis of direction, convenience, economics, a decision to use proxy information for the validation referent, extent of coverage of the intended use domain, … or some combination of these". This suggests that factors such as complexity of the task, availability of experts, economic consideration are important for the selection of a validation referent.

Secondly, in the experimental economics, the issue of 'subject surrogacy' (a situation where students or low-level professionals are considered for research in place of real subjects/professionals) is widely discussed. It is an on-going debate; the general tone of the argument is that a surrogate (e.g. students, low-level professionals) can replace professionals for a structured task (e.g. routine tasks) in decision making. However, more complex situations are necessary for professionals to show different behaviour (Abdolmohammadi and Wright, 1987; Cooper et al., 1999; Potters and Van Winden, 2000; Hopfensitz and Wranik, 2009; Fréchette, 2011). Apart from this, there are multiple instances found in different fields of research where knowledge of students is successfully used for validation purposes (Barreteau et al., 2001; Holguín-Veras et al., 2004; Guyot and Honiden, 2006; Ligtenberg et al., 2010) .

[21] Validation and Accreditation (VV&A) Recommended Practices Guide." Office of the Director, Defense Research and Engineering, Defense Modeling and Simulation Office.

Based on the above arguments, we agree that students cannot precisely represent behaviour of real stakeholders. This is true especially when the behaviour to be validated represents complex decision making in the model. However, it is also evident from the arguments that when simple behaviour is to be validated, a person possessing sufficient knowledge about decision making attributes can satisfactorily serve as a validation referent. We also agree that real stakeholders expect to see the model's behaviour to be similar to their own business's setting. Such expectation hampers the validating generalization of behaviour presented in the model. Concluding, undergraduate students validating behaviour of a shopkeeper is acceptable in this proof of concept game depicting simple behaviour of shopkeepers.

7.6. Results and discussion

The players start their decision making by selecting a supplier for goods replenishment. With the available information about the suppliers, the players could not clearly comprehend which supplier is the best to select from the cost point of view. The available information about suppliers covered hourly cost, order preparation percentage, and profit margin of the supplier. During the discussion session, the players mentioned that since the range of costs provided was not very wide their decision for selecting a supplier was based on the distance from the shop.

The next decision of the players is about selecting the profit margin. For this experiment, the profit margin cannot be changed during the game. Therefore, the players choose a profit margin carefully at the beginning of the game. The graph of distribution of the profit margin selected by the players and agents can be seen in Figure 7.6. Here, the difference in the frequency is due the fact that there are 100 shop-agents in the SMUrFS model whereas total 16 players played the game. Nonetheless, the shape of the histogram and range of profit margin selection is of interest here. We can see that players selected a profit margin as low as 9% with the idea to attract more customers and sell more. Thus, the range of the profit margin selected by the players is from 9 to 30. For the agent, this range is from 15 to 30. The insight into profit selection might be clearer had the players been given an option to change their profit margin during the game. With that option, players might have varied their profit margin to find their respective optimal point. Also, the profit margin selection of larger number of players might give more clear insights.

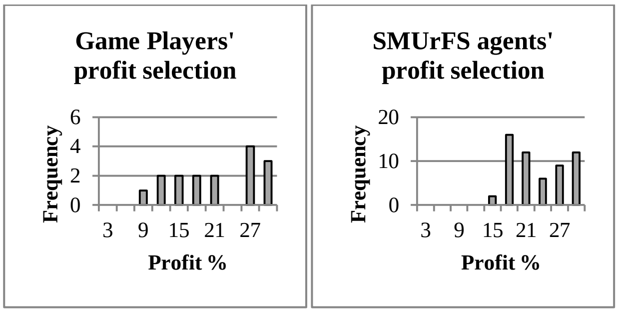


Figure 7.6 Comparison of profit margin selection between players and agent

Next, the players take decisions about goods ordering process. Based on their belief generated using information mainly about various costs, demand trends, the shop-players selected a specific stock level point where the order is placed for goods. This action is compared with the decision about an ROP selected by the agents. Later, when the stock reaches the decided level, the players place an order for a certain amount of goods. This decision about the order quantity is compared with action of order quantity ordered by agents in the model.

7.6.1. Reorder point (ROP)

Shop-players take the decision about 'what is the best (optimal) stock level to place an order'. Figure 7.7 shows the graph of ordering points selected by the teams as per their belief about the best stock level for ordering goods during 90-day simulation period. The x-axis shows the day when the order was placed whereas the y-axis shows an ROP. In the figure, the first graph shows the ROP of an average SMUrFS agent; the second graph belongs to the game shop-agent and the remaining graphs show the ROP of the shop-player teams.

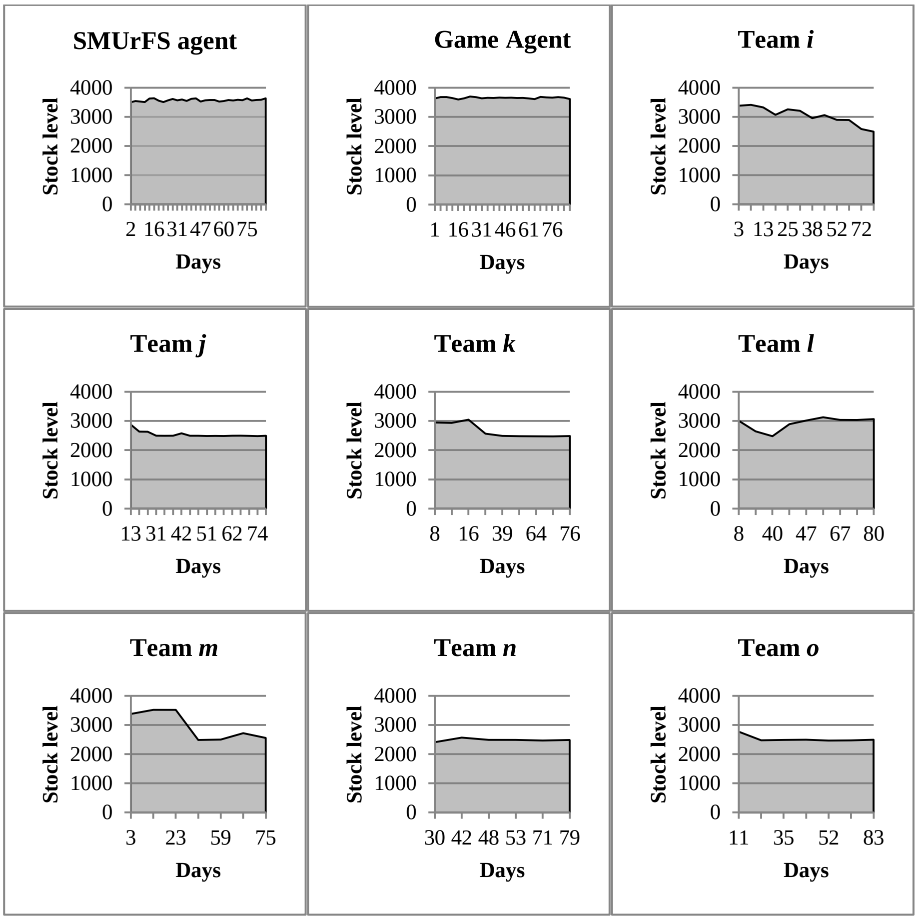


Figure 7.7 Comparison of re-ordering point selection between players and agents

It is apparent from the graphs of the players that the ROP is not constant for the entire 90 day period. The graphs fluctuate in the beginning and in most cases it reaches a steady level in the end. On the other hand, the ROP of the agent (in the model as well as in the game) is constant from the beginning to the end. The fluctuation in the graphs of the players occurs because the players select an ROP during the initial period based on the limited information available; however, the 'believed' optimal stock point often turns out to be sub-optimal due to lack of information. For example, information about clear customer demand trend and profit with respect to stock availability is available only after some simulation-days. Based on this information, the players re-evaluate their belief and select new ROP if the previous ROP did not give expected results. If the previously selected ROP gave expected results then the players continue ordering at the point. Thus, for the players the belief evolves over time and in most cases reaches a stable ROP.

Contrarily, the agent in the model follows a strategy of a fixed ROP. At the beginning of the simulation game (i.e. setup phase), the agent decides an ROP for its shop based on the equation as described in *Chapter 6*. The agent has a belief that the calculated ROP is optimal. Therefore, the agent does not change the ROP and places an order every time the stock level goes below the determined ROP. This approach is evident in the ROP graph of the agent in Figure 7.7. In case of the players, they observe the demand and the profit trend to decide their ROP. Furthermore, they learn to identify the best point to place an order through the process of repetitive decision making and the subsequent profit outcome.

Overall, the decision about an ROP of players differs from that of the agent mainly in two aspects. First, the pattern of an ROP decided by the players is not steady. In most cases, it varies at the beginning of the game just to converge to a steady point towards the end of the game. The initial 30-40 days are a learning period for the players during which they are trying to find their strategy for optimal ordering behaviour. Shop-agents do not have such a learning curve, or trial and error period. Since the demand pattern is static in the model, the agents' learning is replaced with the final knowledge about the required minimum stock level. The belief of the agent is established without a learning phase whereas the ROP of players emerges from learning about demand and profit patterns. Second, the (finally converged) ROP of the players differs from that of shop-agents. However, the fact that players try (and succeed in) establishing a rather stable stock level indicates that the belief of agents about fixed re-order point is in line with the belief of the players. While shop-agents have minimum stock levels of 70 to 85% of maximum capacity, players observed the profit variance with respect to stock level. Obviously, the players' behaviour is more realistic compared to the agents' behaviour.

In conclusion, the agents evaluate their strategy only in the beginning of the simulation but the players evaluate their strategy constantly – which is a realistic behaviour of decision makers. Because a static demand from customers is assumed, the one-time evaluation strategy of the agent in the current model is acceptable. However, in case of more dynamic demand related evaluations, the behaviour of the agent needs to be changed by implementing a learning mechanism for the ordering pattern.

7.6.2. Ordering quantity (OQ)

Based on the ROP, the players decide their action about an OQ. Figure 7.8 shows an illustrative set of choices for the ordering quantity throughout the period of 90 simulation days by SMUrFS shop-agent, game shop-agent and shop-player teams in that sequence.

As expected, the effect of ordering a large quantity (e.g. 1000) immediately becomes visible on their profit. The effect is significant as their profit reduced by the number of units purchased times 50, since one unit costs 50 money-units. Realizing a big reduction in profit, the players started reducing their OQ gradually. Trying to balance among ordering cost, inventory cost and ordering quantity, most teams converge to ordering quantity of 300 to 500 units. Most players were confident about their final OQ and stated during the group discussion and in the questionnaire that they would continue ordering as per that strategy if they play the game again. Nonetheless, some players were still in the trial and error phase at the end of the 90 day playing period.

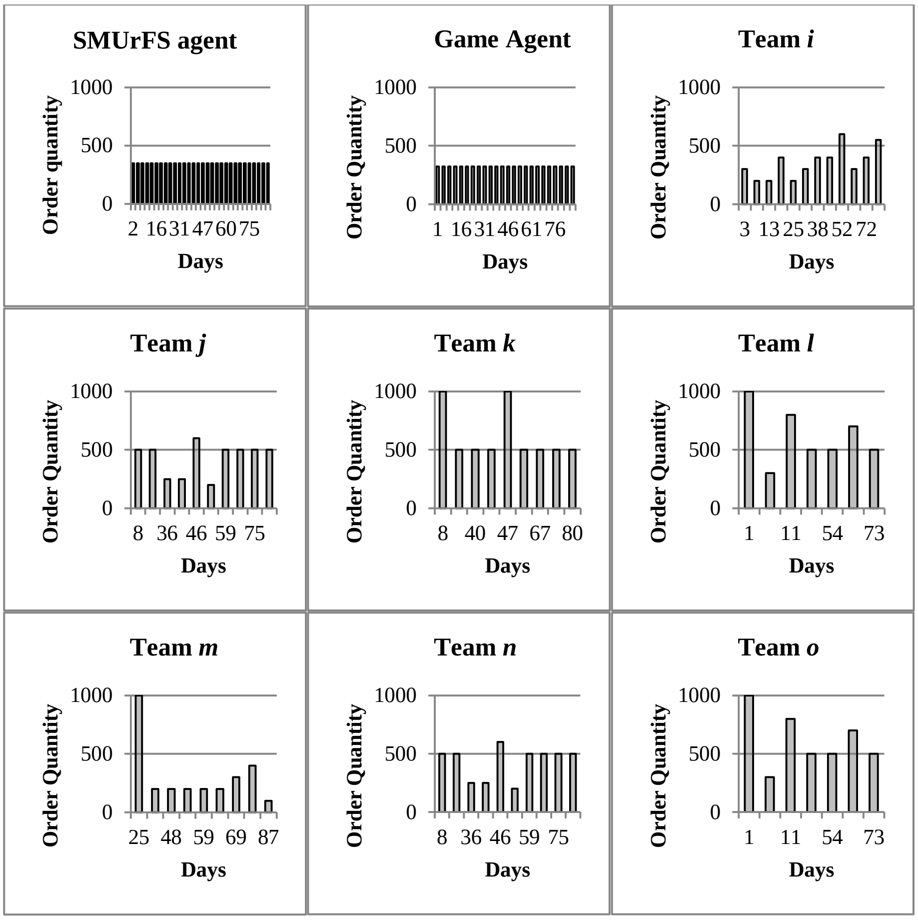


Figure 7.8 Comparison of ordering quantity selection between players and agents

On the agent side, the modelled agent follows a simple formula and does not change its action over the period. The agents are supplied with the economic order quantity (EOQ) formula that optimizes the OQ at the given demand, ordering cost and inventory cost. Under the assumption of static demand, the agents select their ordering quantity at the beginning of the simulation and place the order for that OQ every time stock level reaches the ROP.

Comparing the OQ selected by the players to the OQ of the modelled agents, it is apparent that players follow a trial and error method to find their preferred strategy. In the model, agents already start with a fix strategy. After the trial and error period, the players considered that they had found an optimum OQ and use it for following orders. In about half the cases, the OQ selected by the players was between 300 and 500 units. This number is quite close to the OQ calculated using the EOQ formula. This result is positive evidence that players were indeed optimizing their OQ, which is quite promising as most players said they were not familiar with the EOQ formula.

The players are unaware of game strategies and, therefore, take time to understand the system and try different strategies for selecting an ROP and an OQ before converging to a single point. On the other hand, agents use formulas to calculate optimal ROP and OQ. In the final states, both qualitatively and quantitatively, the results of belief and action show similarity in the decision making process of players and agents. This proof of concept experiment proves that decision making mechanism of the agents can be evaluated using participatory simulation game approach. Real shopkeepers would add additional value to the experiment, setting the bar higher for the ABM and allowing a true external validation of the model.

7.7. Conclusions, recommendations and future research

Validation is a big challenge for most simulation-based modelling platforms and especially for ABMs. Characteristics such as path dependency, emergence and multiple interactions, as well as the absence of micro-level data, make the traditional empirical validation of agent based models significantly difficult. Furthermore, the complexity of social processes does not guarantee that each simulation run follows the same sequence, leading to conflicts in the final output and making the concept of validation different than in a well-controlled experiment. These difficulties indicate that a different approach is needed to validate an ABM.

We argue that by aligning agents' decision making mechanisms with that of players playing a role of stakeholder, an ABM can be validated for the behaviour presented in the model. Based on this reasoning, we proposed a validation framework based on a participatory simulation game for validating an ABM. Using this framework, the human player is asked to assume a role of the agent in the game. Next, information is collected about the decision making behaviour of the human player and compared with agent's behaviour to validate the agent type for its intended decision making processes. A proof-of-concept participatory game was developed for the city logistics model SMUrFS to validate its shop-agent. The game is developed using an ABM platform NetLogo and HubNet technology. A game session was planned where the game was played by 16 teams (each team consisting two players) of undergraduate students, and decision attributes of the players were recorded for validation. Comparison of these attributes with decisions of agents reveals that shop-agents follow static behaviour with little learning. On the other hand, the players are constantly evaluating the situation and accordingly updating their decision. The final output of the game also indicates that the attributes of players' converge after initial learning period to match with attributes of the agent showing consistency with the agent's behaviour.

Undoubtedly, it would be interesting to see the outcome of the game with real stakeholders playing the role of the shop-agent. Therefore, for further testing of the participatory simulation game, some sporadic game playing experiments with logistics professional were conducted. Analysis of the results obtained from these extra tests also indicates the similar trends found in the experiments done by the students. It was apparent that the professionals also converge to the ROP and OQ as students did albeit after a longer trial and error period. An interesting fact observed during these experiments was that the professionals had a stronger preference for certain choices and were more likely to stay with their choice. For instance, it was found that a player with an inclination towards ordering higher quantities continues to order larger orders even if that is not the optimum decision. This is contrary to most other results where players focus mainly on the profit while decision making. It is too early to conclude about such specific behaviour and its implication on the decision making of the stakeholders. Nonetheless, this observation opens up another behavioural research agenda for validation of agent interactions.

The main goal of this chapter is to present and demonstrate a new approach for validation of the behavioural process of an ABM. The initial proof suggests that the participatory game provides a promising approach for process validation of ABMs. The approach is flexible and can be adapted to use for validating behaviour at different levels of detail. Evidently, an important benefit of this approach is that it allows to collect decision making information under the same assumptions that of the model. This setting makes process validation more relevant for an ABM under test.

Recommendations

Based on our experience with game development, experiments and results analysis, we have the following suggestions:

- The BDA (i.e. Belief, Desire and Action) architecture of the agent must be clear before conducting experiments. Tools like data flow analysis, interaction diagrams or sequence diagrams may help to capture essential BDA information about the agent to be validated.
- Finding the balance between scientific accuracy and player immersion is very important. If a part of the real model is not needed or will only have a minimal impact on the player's decision making process, it is not useful to implement this part in much detail. For example, the complexity of the vehicle routing algorithm may be irrelevant for the decision making process of the shop-players.
- Thinking from a gaming perspective, instead of a modelling perspective. Even after watching the movie presentation on how to play the game and doing trial runs with game moderators some players still found the interface puzzling to make decisions and suggested to make the interface more intuitive. Therefore, keeping the game simple and interface intuitive is another important aspect of the game development.

Future research

The proof-of-concept game presented here for the city logistics model SMUrFS is only a small step towards improved validation of ABMs. It opens the door for further explorations of validation approaches for social simulation processes. There are several options for further research. Firstly, a more interactive version where the roles of multiple agents are being played by players who are competing against not only agents, but also other players, is a possibility. Such an extension would give an opportunity to experiment with process validation under situations such as cooperation, negotiation and competition. Secondly, this research can be taken further by applying this validation technique to other ABMs. Multiple case studies are needed to write a clearer overview of the validation technique, challenges and limitations of using participatory simulation games and strengthen its position in validation literature. Thirdly, creating a connection between the participatory gaming validation framework and gaming models for teaching purposes could provide interesting results. From the education point of view, the game can be used as an interactive tool to understand the decision making processes and complexity of city logistics activities. It can be used as a tool to educate stakeholders and researchers interested in the city logistics domain.

References

Abdolmohammadi, M. and Wright, A. (1987). An examination of the effects of experience and task complexity on audit judgments. Accounting Review: 1-13.

Banks, J. (1998). Handbook of simulation, Wiley Online Library.

Barreteau, O., Bousquet, F. and Attonaty, J.-M. (2001). Role-playing games for opening the black box of multi-agent systems: method and lessons of its application to Senegal River Valley irrigated systems. Journal of artificial societies and social simulation 4(2): 5.

Campbell, D. T. (1957). Factors relevant to the validity of experiments in social settings. Psychological bulletin 54(4): 297.

Campbell, D. T., Stanley, J. C. and Gage, N. L. (1963). Experimental and quasi-experimental designs for research, Houghton Mifflin Boston.

Cooper, D. J., Kagel, J. H., Lo, W. and Gu, Q. L. (1999). Gaming against managers in incentive systems: Experimental results with Chinese students and Chinese managers. American Economic Review: 781-804.

Fréchette, G. R. (2011). Laboratory experiments: Professionals versus students. Available at SSRN.

Galán, J. M., Izquierdo, L. R., Izquierdo, S. S., Santos, J. I., Del Olmo, R., López-Paredes, A. and Edmonds, B. (2009). Errors and artefacts in agent-based modelling. Journal of Artificial Societies and Social Simulation 12(1): 1.

Guyot, P. and Honiden, S. (2006). Agent-based participatory simulations: Merging multi-agent systems and role-playing games. Journal of Artificial Societies and Social Simulation 9(4).

Happe, K., Kellermann, K. and Balmann, A. (2006). Agent-based analysis of agricultural policies: an illustration of the agricultural policy simulator AgriPoliS, its adaptation and behavior. Ecology and Society 11(1): 49.

Harmon, S., Hoffman, C., Gonzalez, A. J., Knauf, R. and Barr, V. (2002). Validation of human behavior representations. Foundations for V&V in the 21st Century Workshop (Foundations' 02).

Holguín-Veras, J., Thorson, E. and Ozbay, K. (2004). Preliminary results of experimental economics application to urban goods modeling research. Transportation Research Record: Journal of the Transportation Research Board 1873(1): 9-16.

Hopfensitz, A. and Wranik, T. (2009). How to adapt to changing markets: experience and personality in a repeated investment game. TSE Working Paper 9.

Kleijen, J. (1999). Validation of models: statistical techniques and data availability. Simulation Conference Proceedings, 1999 Winter, IEEE.

Lebaron, B. (2001). A builder’s guide to agent-based financial markets. Quantitative Finance 1(2): 254-261.

Ligtenberg, A., Van Lammeren, R. J., Bregt, A. K. and Beulens, A. J. (2010). Validation of an agent-based model for spatial planning: A role-playing approach. Computers, Environment and Urban Systems 34(5): 424-434.

Livet, P., Muller, J.-P., Phan, D. and Sanders, L. (2010). Ontology, a mediator for agent-based modeling in social science. Journal of Artificial Societies and Social Simulation 13(1): 3.

Mavor, A. S. and Pew, R. W. (1998). Modeling Human and Organizational Behavior:: Application to Military Simulations, National Academies Press.

Moss, S. (2008). Alternative approaches to the empirical validation of agent-based models. Journal of Artificial Societies and Social Simulation 11(1): 5.

North, M. J., Howe, T. R., Collier, N. T. and Vos, J. R. (2005). The repast simphony development environment. Proceedings of the Agent 2005 Conference on Generative Social Processes, Models, and Mechanisms, sn.

Obrst, L., Ceusters, W., Mani, I., Ray, S. and Smith, B. (2007). The evaluation of ontologies. Semantic Web: 139-158.

Potters, J. and Van Winden, F. (2000). Professionals and students in a lobbying experiment: Professional rules of conduct and subject surrogacy. Journal of Economic Behavior & Organization 43(4): 499-522.

Rand, W., Brown, D. G., Page, S. E., Riolo, R., Fernandez, L. E. and Zellner, M. (2003). Statistical validation of spatial patterns in agent-based models. Proceedings of agent based simulation.

Rao, A. S. and Georgeff, M. P. (1995). BDI agents: From theory to practice. Proceedings of the first international conference on multi-agent systems (ICMAS-95), San Francisco.

Sargent, R. G. (2005). Verification and validation of simulation models. Proceedings of the 37th conference on Winter simulation, Winter Simulation Conference.

Shadish, W. R., Cook, T. D. and Campbell, D. T. (2002). Experimental and quasi-experimental designs for generalized causal inference, Wadsworth Cengage learning.

Steyerberg, E. W., Harrell Jr, F. E., Borsboom, G. J., Eijkemans, M., Vergouwe, Y. and Habbema, J. D. F. (2001). Internal validation of predictive models: efficiency of some procedures for logistic regression analysis. Journal of clinical epidemiology 54(8): 774-781.

Tisue, S. and Wilensky, U. (2004). NetLogo: A simple environment for modeling complexity. International Conference on Complex Systems.

Van Dam, K. H. and Lukszo, Z. (2006). Modelling energy and transport infrastructures as a multi-agent system using a generic ontology. Systems, Man and Cybernetics, 2006. SMC'06. IEEE International Conference on, IEEE.

Windrum, P., Fagiolo, G. and Moneta, A. (2007). Empirical validation of agent-based models: Alternatives and prospects. Journal of Artificial Societies and Social Simulation 10(2): 8.

Xiang, X., Kennedy, R., Madey, G. and Cabaniss, S. (2005). Verification and validation of agent-based scientific simulation models. Proceedings of the 2005 Agent-Directed Simulation Symposium.

8 Multi-stakeholder perspective analysis: A delivery cap and price scenario

8.1. Introduction and motivation

From the economic point of view, a new policy or initiative often involves extra costs to the stakeholders. Improper distribution of the extra cost could lead to unsatisfied stakeholders (those who are negatively affected by such policy) and eventually to the failure of such initiatives. For instance, most urban consolidation centre (UCC) operations started with a huge subsidy from the government could not last long due to high building, maintenance and operational costs. In a study done for New York City, Holguín-Veras (2008) explains that the balanced cost distribution between the city logistics stakeholders is a necessary condition for the success of a city logistics policy. Such situations point to the fact that the economic aspect of cost distribution also requires analyses from the viewpoint of multiple stakeholders. Their reactions to the extra cost give an indication as to whether such a concept has potential for solving city logistics related problems.

The agent based model SMUrFS that was explained in *Chapter 6* is based on the multi-perspective city logistics ontology. In this chapter, we explore multi-perspective decision making in the city logistics domain using the SMUrFS model. For this, we developed a scenario that aims to understand how decision making by different stakeholders translates into truck movements in the city. With the use of a scenario, we also try to find a solution to reduce truck movements in the city areas. In section 8.2 of this chapter, we describe the scenario setup and decision making of the stakeholders. Next we provide results of the scenario followed by its analysis. In section 8.3, conclusions are given along with a discussion on the insights gained from the scenario analysis.

8.2. Delivery cap and price scenario

The concept of delivery cap and price scenario is inspired from the carbon credit system of the Kyoto protocol[22]. In the Kyoto protocol, the effect of carbon is considered at the global scale, and as per the treaty each country that is part of this protocol is responsible for reducing the carbon level. The Kyoto Protocol introduced a medium called carbon credit to achieve the goal of CO_2 reduction. Each county receives a certain carbon credit, and each carbon credit permits emissions of one ton of CO_2. If a country has emissions of CO_2 that is more than its allowance, it incurs an extra cost. Conversely, a country able to stay under its allowance can trade its credit with another country.

The delivery cap and price scenario in this chapter focuses on the city logistics issues at a local level. In this view, it is important to mention the assumptions, scope and objective of the delivery cap and price scenario. The goal in this scenario is to reduce the number of truck-km travelled by the carriers' vehicle (e.g. diesel, gas powered trucks). Distance travelled by these trucks is directly associated with congestion, pollution and safety related issues in the urban areas. The goods delivery vehicles travel in the city as per the frequency of goods ordered by the shops. The scenario introduces a cap on the number of goods deliveries received by the shops. The following section explains the scenario in detail.

8.2.1. Scenario setup

An urban consolidation centre (UCC) is a city logistics concept that is intended to consolidate goods for delivery in the urban areas. A UCC essentially separates the distribution activities inside and outside the city by transhipping at the city border. Large goods delivery vehicles deliver goods to a UCC. The goods from different vehicles are consolidated in smaller trucks – often in an environment friendly way (e.g. using electric trucks) to transport to the shops. This way the urban areas can be saved from pollution, traffic congestion and unsafe road conditions resulting from the use of large goods delivery trucks (Van Duin et al., 2010).

Shopkeepers are free to choose between goods delivery through a UCC or direct delivered by the carrier. For shopkeepers, using the service of a UCC incurs extra handling of goods that may add up to extra delivery time and cost. Furthermore, it is also difficult to clearly point out the responsible party (the UCC or the carrier) in case of an error in goods delivery. If a shopkeeper is using a UCC, then the carrier does not need to deliver goods to a shop through congested city areas. The carrier saves time and costs by delivering goods to a UCC. However, the carrier does not give any discount to the shop whose goods are delivered via a UCC. Thus, a shopkeeper does not have any financial incentive for choosing a UCC over direct delivery by the carrier. Due to these reasons, although using a UCC is often a free service, shopkeepers do not opt for this service.

City logistics problems (e.g. pollution, congestion, safety, maintenance) caused due to freight vehicle movements have costs (e.g. accidents, poor air quality, less accessibility) associated with them. The cap and price scenario explores a new business case to internalize the external costs by introducing a cap on the number of free goods delivery to a shop. Accordingly, a shop that is the recipient of a freight delivery has to pay extra money if it wants to use the city road network for more goods deliveries than the prescribed limit. Within this setting, the municipality is aiming to reduce the distance travelled by the carrier's freight vehicles and increase the use of a UCC for goods delivery in the city. It is assumed that UCC vehicles are

[22] United Nations framework convention on climate change. *Kyoto Protocol, Kyoto*.

smaller in size and run on clean energy and, thus, do not create a nuisance in terms of pollution and congestion.

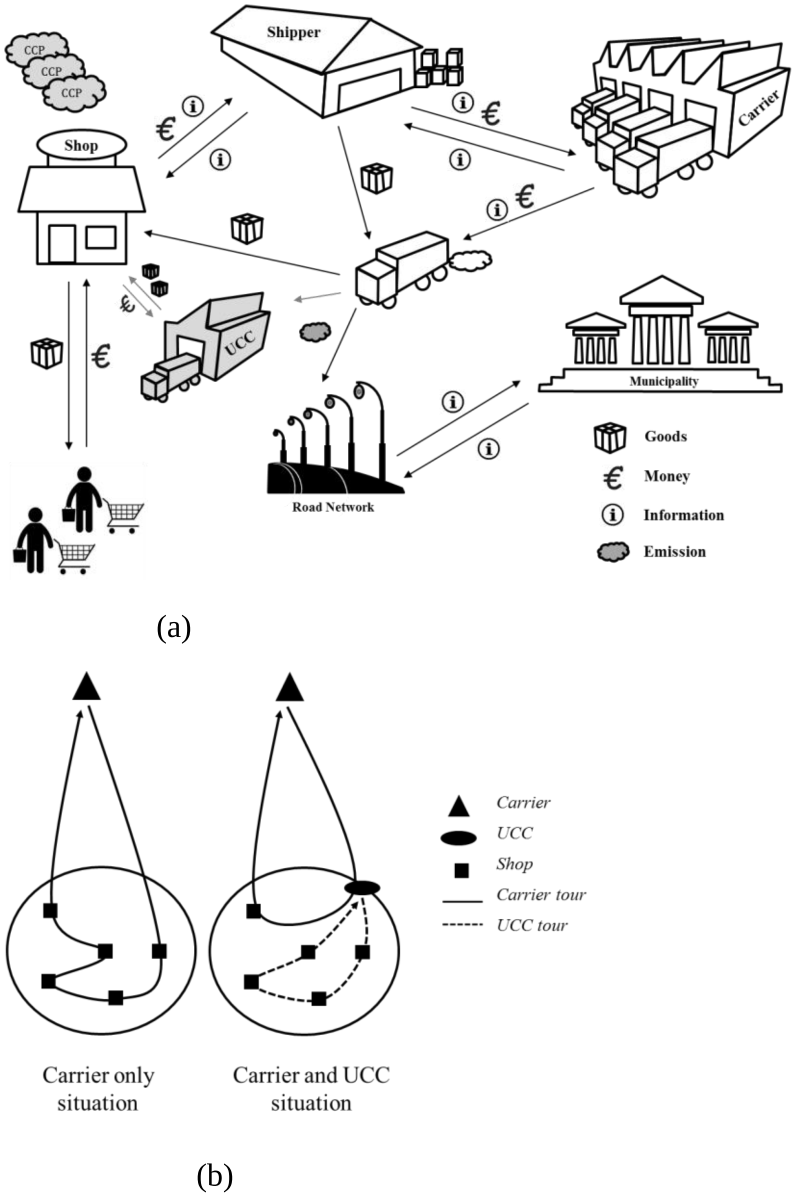


Figure 8.1 Delivery cap and price scenario setup in SMUrFS

Figure 8.1 shows the setup for cap and price scenario with a newly introduced UCC agent in the SMUrFS model. When UCC did not exist the shops used to get goods deliveries directly at their location. Now the shops can choose to get a delivery either at the UCC or the shop location. The shop informs the carrier about its choice when it places an order. As shown in figure 8.1.b, the carrier accordingly delivers goods to the shop location or to the UCC. Orders delivered at the UCC are consolidated, and goods are delivered to the shop by a UCC vehicle. The dotted line depicts an example of a UCC tour. The scenario extends the decision making interactions of the SMUrFS model. Accordingly, along with the decision making by SMUrFS agents explained in *Chapter 6*, the cap and price scenario involves additional decision making by shop-agents, the municipality-agent, and the UCC-agent. Apart from the introduction of the UCC-agent, the number of each type of agents remains the same as in the original

SMUrFS model. In the following text, the decision making process during the cap and price scenario is described.

(1) Decision making by Municipality agent

The municipality wants to reduce the total distance travelled by the carriers' freight trucks in the urban areas. In order to achieve this goal, the municipality has two levers. The municipality implements a cap on the number of free deliveries to each shop by allotting a limited number of delivery points (D_p) for every month. One delivery point must be used by a shop to place an order for goods delivered to a shop location. Thus, with this cap, a shop can receive only a limited numbers of free deliveries at the shop premise. If a shop wants to place an order above the allocated number of delivery points, it has to choose between getting the delivery through the UCC and buying an extra D_p from the municipality. Now the municipality can use the price of delivery point (P_{D_p}) as a second lever where an increase in price can force the shops to use the UCC. If only few shops are using the UCC, it does not have the economy of scale and thus the price of using the UCC might be higher. To make the UCC affordable the municipality offers a subsidy to the UCC during this period. Later, when the UCC is used by more shops, the municipality starts reducing the subsidy provided to the UCC. Figure 8.2 shows the decision making schema of the municipality.

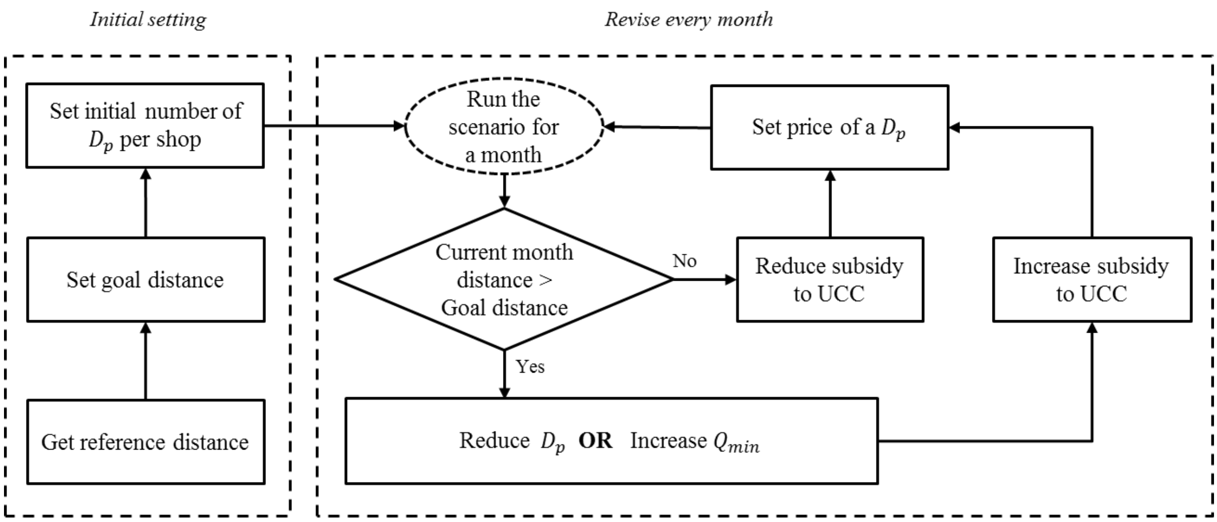


Figure 8.2 Decision making schema of the municipality

As shown in Figure 8.2, certain decisions are taken only once in the beginning of the scenario, whereas other decisions are taken every month after the UCC starts its operation. For the first 12 months of the scenario, there is no cap on the number of free deliveries to the shops. This period is considered as a reference situation. The distance travelled during this period is averaged to get the reference distance. Next, the municipality sets a goal to reduce the monthly distance travelled by the carriers' freight vehicles by a certain percentage from the reference distance.

At the beginning of the 13th month, the UCC operation starts. At that time, the municipality introduces a delivery cap by allocating an initial number of D_p to each shop. The number of D_p awarded to each shop varies and is based on the goods demand of the shop. It is assumed that the area of the shop (A_S) can be used to represent the goods demand. The number of D_p awarded to each shop is calculates using the following formula.

$$D_p = \frac{A_S}{F_{D_p}} \qquad ...(8.1)$$

Here, F_{D_p} is a freight trip generation factor. It is assumed that for every 20 m^2 of shop area one goods delivery trip per month is made. Therefore, the initial value of D_p per shop is calculated taking F_{D_p} equal to 20. Note that the number of D_p obtained using the above formula is rounded to its nearest integer. Every month, the municipality evaluates the distance travelled by the carriers' vehicles. If the distance travelled during a month is more than the goal distance then the number of D_p provided to the shops is reduced in the subsequent month. The reduced number of D_p is calculated by increasing the value of F_{D_p} by 1 in the formula from equation 8.1.

Next, the price of delivery point P_{D_p} is calculated using the following formula,

$$P_{D_p} = U_{price/unit} * Q_{min} \qquad ...(8.2)$$

Here, $U_{price/unit}$ is the price of using the UCC for delivering a single unit and is decided by the UCC-agent. Q_{min} is a minimum shipment size such that shops placing an order below the value of Q_{min} are worse off by buying extra D_p and, thus, shall use UCC service for goods delivery. Let's understand how Q_{min} influences the decision making of a shop. In table 8.1 three shops A, B and C are mentioned with their order quantity for the next delivery.

Table 8.1 Example for delivery option selection

$U_{price/unit}$ = 8 Euro-cent					
Shop	Order quantity	P_{D_p} (Euro) when Q_{min}= 100	P_{D_p} (Euro) when Q_{min}= 150	P_{D_p} (Euro) when Q_{min}= 200	UCC use cost (Euro)
A	100	8	12	16	8
B	150	8	12	16	12
C	200	8	12	16	16

For this example, the $U_{price/unit}$ is assumed to be 8 Euro-cent. The total cost of using UCC is calculated by multiplying the UCC price per unit by the number of units ordered (i.e. order quantity) by the shop. The order quantity for shops A, B and C is shown in the second column. P_{D_p} for Q_{min} equal to 100, 150 and 200 is calculated in the third, fourth and fifth column respectively. Now, if the municipality considers Q_{min} equal to 100 then the P_{D_p} becomes 8 Euro. In this case shop A is indifferent between using the UCC and buying extra D_p since the costs for both options are the same. However, shops B and C are better off buying a D_p. Similarly, when the municipality considers Q_{min} equals to 150, shop A is better off using the UCC and shop C is better off buying a D_p whereas shop B is indifferent between these two options. In the same manner the case of 200 as Q_{min}can be explained.

The initial value of Q_{min} is set to 80. The municipality uses these two levers (i.e. D_p and Q_{min}) on an alternating month basis. Accordingly, if the truck distance is not reduced as per the goal at the end of the month *n-1* then at the beginning of month *n* the municipality reduces only the number of D_p per shop and does not change the value of Q_{min}. At the end of the month *n*, the municipality evaluates the effect of reducing D_p in terms of a distance reduction. If the goal is not reached then in the beginning of month *n+1* it increases Q_{min} keeping D_p unchanged and so on. Value of Q_{min} is increased by 1 everytime it is changed. The subsidy provided to the UCC increased by 2% every time a change in D_p or Q_{min} occurs. When the goal distance is reached, the municipality starts reducing the subsidy by 2% until the subsidy provided to the UCC becomes zero.

(2) Price setting by UCC agent

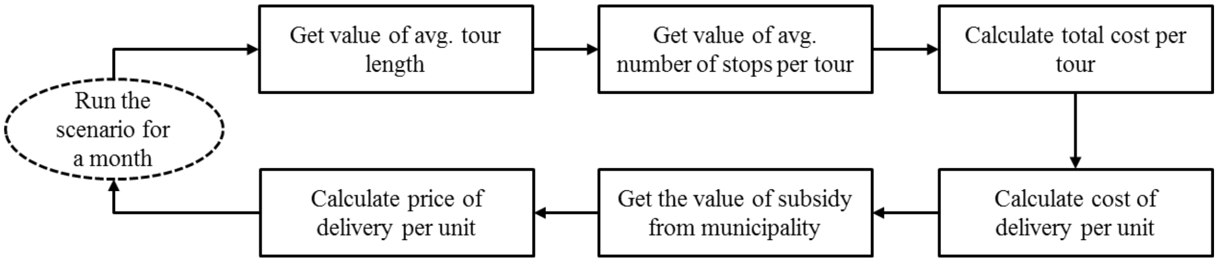


Figure 8.3 Price setting process of the UCC

The UCC-agent decides the price for UCC service. Figure 8.3 shows the price-setting mechanism of the UCC-agent. The UCC delivers goods to shops using electric trucks. UCC incurs costs in terms of fuel (i.e. electricity) and the driver's wage. The UCC calculates the total cost by summing the running costs and fixed costs of the operation. The running cost of the operation is divided into two types of costs 1) the costs associated with driving and 2) the costs associated with (un)loading goods at the receiver's location.

UCC decides running cost using the following formula,

$$R_c = R_{c\alpha}T_l + R_{c\beta}S_n \quad ...(8.4)$$

Where R_c is the total running cost, T_l is an average tour length, S_n is the average number of stops and $R_{c\alpha}$ and $R_{c\beta}$ are constant factors. Hourly salary of the driver, an average speed of the truck, fuel cost and fuel efficiency is included in the calculation of $R_{c\alpha}$. Salary of the driver and average service time per stop is included in the calculation of $R_{c\beta}$. The total cost per tour ($U_{cost/tour}$) is calculated as the sum of running costs and fixed costs (F_c).

$$U_{cost/tour} = R_c + F_c \quad ...(8.5)$$

For this scenario following values are considered. Using this information, cost per km turns out to be 2 Euro for a tour of 7 km and number of stops equal to 5.

$R_{c\alpha}$ (€)	$R_{c\beta}$(€)	F_c(€)
0.5	2	0.7

The UCC price is provided to the shops in terms of the price per unit. The cost of delivering a single unit ($U_{cost/unit}$) by UCC is calculated by dividing total tour cost by an average loading rate (LR_{avg}) and the UCC vehicle capacity (U_{veh_cap}). The capacity of the carrier's vehicle in

SMUrFS is 3000 units. The UCC vehicles is smaller in size, and its capacity is assumed as half that of the carrier's vehicle – i.e. 1500 units.

$$U_{cost/unit} = \frac{U_{cost/tour}}{LR_{avg} * U_{veh\_cap}} \quad ...(8.6)$$

The main goal of the UCC is to provide clean alternative delivery services and to survive without making a loss. Thus, the UCC does not add any profit margin while deciding the price. The municipality provides the subsidy to make UCC usage affordable to shops. In that case, the UCC adjusts its price based on the subsidy offered. The final price of using the UCC ($U_{price/unit}$) is decided by reducing the $U_{cost/unit}$ as per subsidy S provided by the municipality,

$$U_{price/unit} = U_{cost/unit} * (1 - S) \quad ...(8.7)$$

The initial values for tour length, number of stops and loading rate is provided. Later the UCC derives these values based on simple moving average from the values of the last three months.

(3) Decision making by Shop-agent

Figure 8.4 shows decision making by a shop in this scenario.

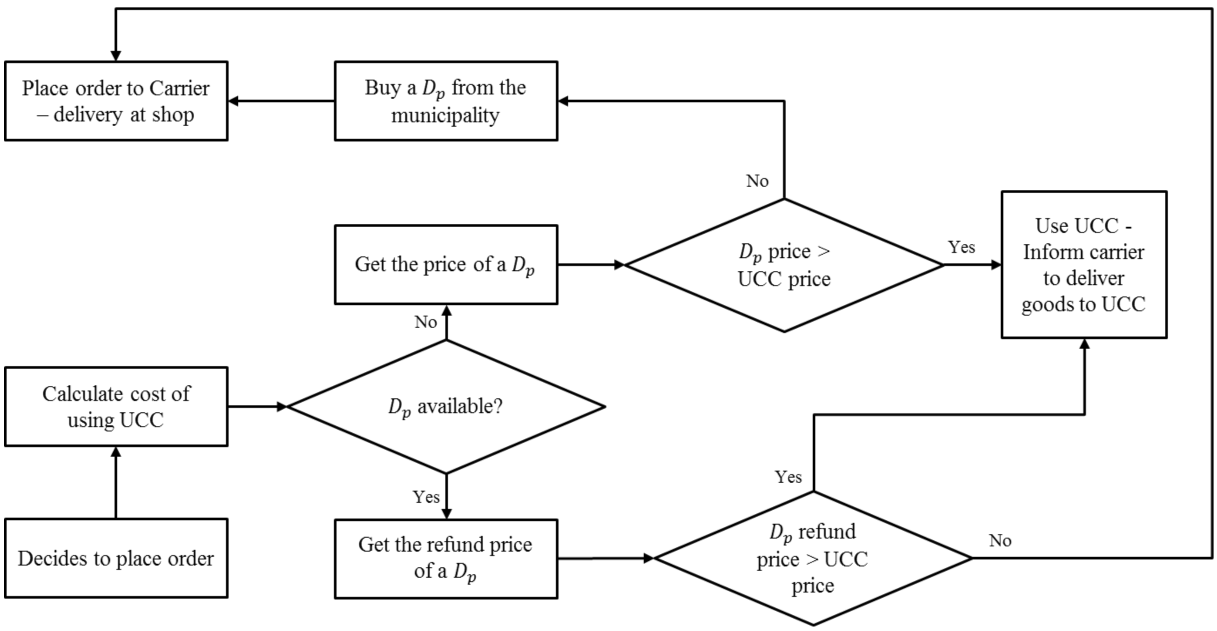


Figure 8.4 Decision making schema of a shop

When a shop decides to place an order it must use a D_p to get delivery at its location. If there is no D_p left then the shop must decide whether to use the UCC or buy D_p. If the order by the shop contains Q_s number of units, then the price of using UCC is calculated using the following formula:

$$U_{price} = U_{price/unit} * Q_s \quad ...(8.8)$$

Next, it inquires with the municipality about price of P_{D_p}. The shop compares these two costs and selects the cheaper option. If UCC is cheaper then the shop informs the carrier to deliver goods to the UCC and pays U_{price} to the UCC. Otherwise, the shop buys a D_p paying P_{D_p} to the municipality and places an order with the carrier. In case the shop has one or more D_p then it compares between prices of refunding a D_p and using the UCC and selects the cheaper option.

It is apparent from the decision making by each of the types of agents that the decisions made by the municipality, the shops and the UCC are interdependent and influence each other. Each agent tries to find the optimal value for its decision based on the decisions taken by other agents. For this scenario, the municipality sets a goal to reduce the monthly distance travelled by the carriers' freight vehicles by 30 percent from the reference distance.

The following outputs of the model are used to analyse the effect of the cap and price scenario on the city logistics activities:

- Distance travelled by freight vehicles in the city
- Number of vehicles entering the city for goods delivery
- Loading rate of freight delivery vehicles entering the city
- Average cost incurred to a shop
- Cost incurred by the municipality

8.2.2. Simulation results and analysis

The results presented in this section illustrate the impact of the cap and price scenario on the goods transportation activities in the city. Figures 8.5 to 8.9 show graphs comparing various KPIs (Key Performance Indicator) for the reference and the cap and price scenario. Since the simulation ran for 150 months, representing data for 150 months makes the graphs very congested. For this reason, the data point in these graphs shows the value of KPI averaged over the six month period.

Table 8.2 Comparison of KPIs between cap and price and reference scenario

Output	Cap and price Scenario	Reference Scenario
Distance travelled by Carrier vehicles (Km)	626	1026
Distance travelled by UCC vehicles (Km)	363	-
Loading rate of UCC vehicles	64%	-
Loading rate of Carrier vehicles	30%	30%
Average extra cost to a shop (Euro)	-17	-
Net extra cost to the Municipality (Euro)	498	-
Number of Carrier vehicles entering the city	109	111
Number of UCC vehicles entering the city	48	-

Table 8.2 gives a comparison of KPIs between the cap and price and the reference scenarios. The output values in the table are the average values for the last 12 months when the simulation reached a steady state. The comparison of KPIs presented in Table 8.2 indicates that the distance travelled by the carrier vehicles reduces by more than 30% in the cap and price scenario compared to the distance travelled in the reference scenario. Accordingly, the carriers' vehicle-km reduces to 626 in the cap and price scenario compared to 1026 in the reference scenario. With the introduction of the UCC, UCC vehicles are delivering goods to the shops in the city areas. The distance travelled by UCC vehicles is 363 km. The UCC vehicles are smaller in the size and uses cleaner energy (e.g. electricity). In this view, although the total vehicle-km reduction is not significantly less, the city is getting benefits due to less distance travelled by diesel operated large vehicles. Due to the introduction of UCC and the cap and price system, a shop is incurring an average cost of 17 euro. On the other hand, the municipality is generating net revenue of 498 Euro by selling delivery points to the shops. In the rest of this section, these results are discussed in detail by analysing outputs from the model.

(1) Distance travelled by freight vehicles

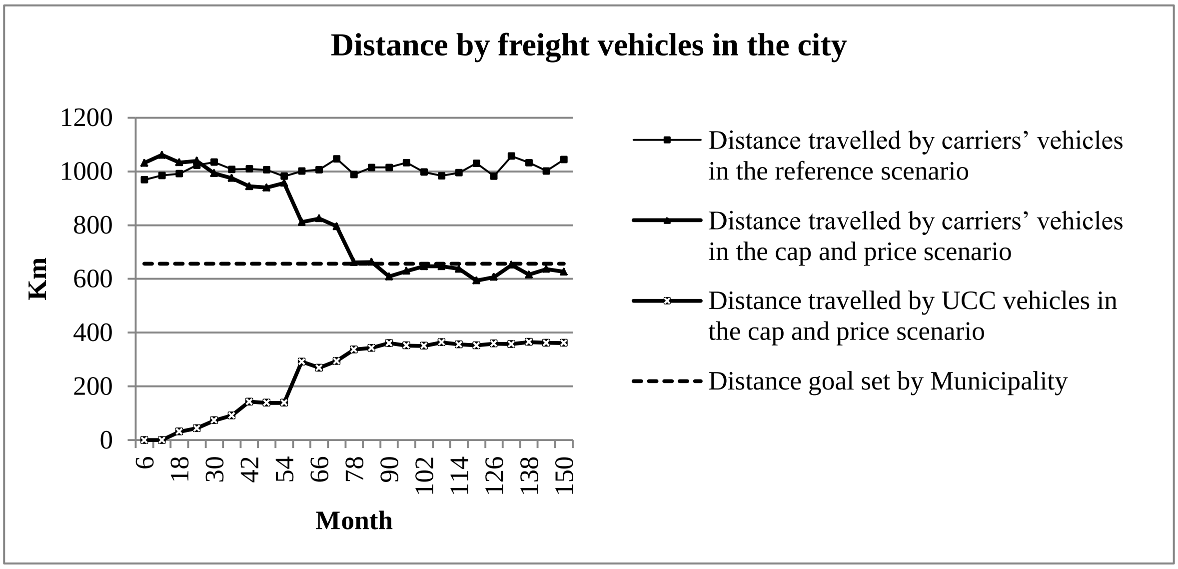


Figure 8.5 Distance travelled by freight vehicles in the city

Figure 8.5 shows the distance travelled by goods delivery vehicles during the cap and price and the reference scenarios. The dashed line represents the goal distance set by the municipality. It is apparent from the graph that when UCC operation and the delivery cap is introduced from the 13th month the distance travelled by the UCC vehicles is almost zero. This situation implies that the D_p available to the shops are enough for the number of goods delivery orders they place. Furthermore, the cost of using UCC is not low enough and the cost of buying D_p is not high enough to prompt a switch from carrier delivery to UCC delivery. Municipality realizes this as it cannot see a sufficient decrease in distance travelled by the carrier vehicles. In response, the municipality re-evaluates its strategy and reduces the number of D_p allocated to the shops or increases $P_{D_p}$to influence the decisions of the shops. The municipality also offers a subsidy to make UCC services affordable.

This strategy puts the shopkeepers ordering lower quantity in a situation where they are better off using the UCC instead of buying extra D_p. If only economic conditions are considered then some shops are better off by using UCC even if they have sufficient D_p available because the D_p refund price is higher than the price of using the UCC for delivery. The shift in selection of delivery option reduces the distance travelled in the city by the carrier vehicles. The municipality follows this decision strategy until the goal to reduce the distance travelled by the carrier vehicles is achieved.

(2) Number of freight vehicles entering the city

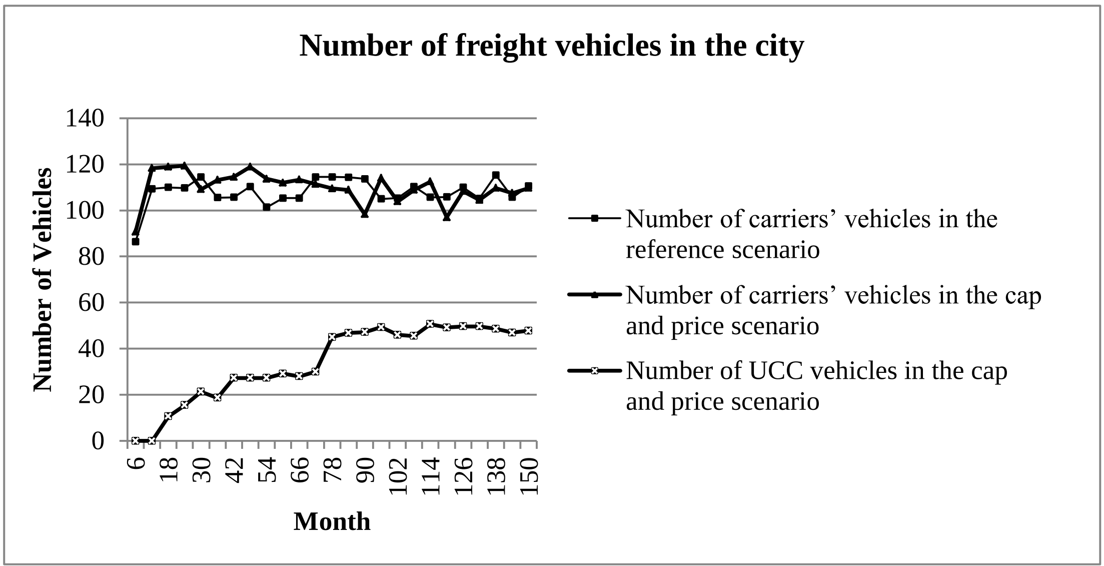


Figure 8.6 Number of vehicles entered in the city for goods delivery

The graphs in figure 8.6 show the number of vehicles entering the city for goods delivery. Figure 8.5 shows that the distance travelled by the carrier vehicles reduces during the cap and price scenario. However, the number of carrier vehicles entering the city does not reduce significantly. The reason behind this outcome is that the carriers' vehicles deliver goods to the UCC for some of the shops but still enter the city to deliver goods to other shops in the tour (refer Figure 8.1-b). Due to this setting the distance travelled in the city reduces but the number of vehicles entering the city does not change significantly. When more shops start using the UCC service, more tours are needed to deliver goods to the shops from the UCC, and this is visible as the number of UCC vehicles entering the city is increasing.

(3) Loading rate of freight vehicles

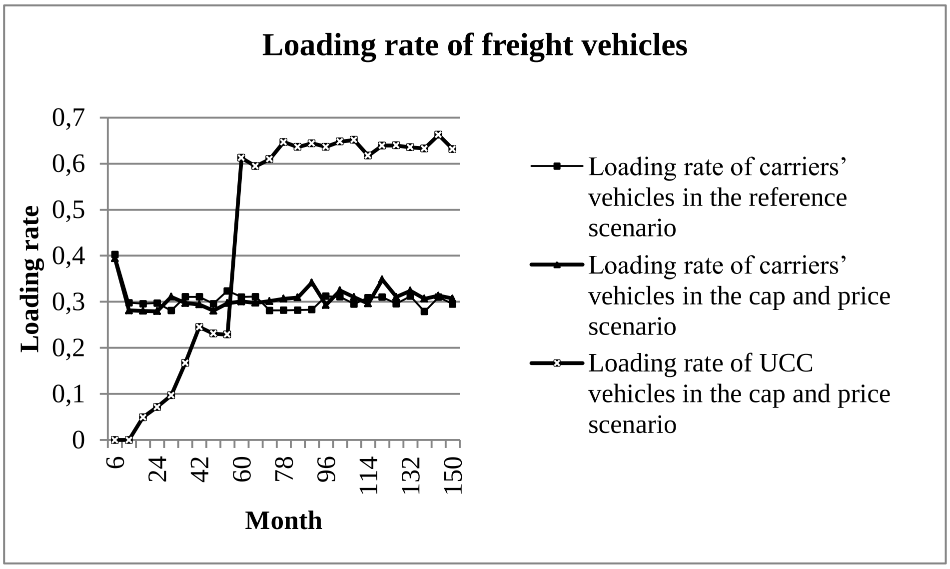


Figure 8.7 Loading rate of freight delivery vehicles entering the city

Information about the loading rate of the carrier and UCC vehicles is represented in Figure 8.7. As visible in the figure, the loading rate of carrier vehicles is almost the same in both scenarios. Many shops are ordering goods through the UCC during the cap and price scenario. However, carrier vehicles still need to enter the city to deliver the goods to the shops that opted for delivery at the shop location. In this situation, the loading rate does not change in the cap and price scenario. Notably, the distance travelled by the carrier vehicles reduced as they deliver goods to fewer shop locations. In the setup of the SMUrFS model, there are 100 shops and seven carriers. The low loading factors of the carriers also occurs because goods delivery to 100 shops is distributed among seven carriers. On the other hand, when shops start using the UCC service, UCC vehicles can easily consolidate goods to achieve a high loading rate. The figure shows that somewhere around the 60th month, the loading rate of UCC vehicles jumps to around 60%. The reason for this could be the high number of shops switching to the UCC for goods delivery around that period. It is also interesting to see that the loading rate of the UCC vehicles is not increasing beyond 65%, even though, the number of shops using UCC is increasing. This result implies that the average goods order quantity of the shops does not allow higher consolidation of goods.

(4) Cost occurred to the shops and the municipality

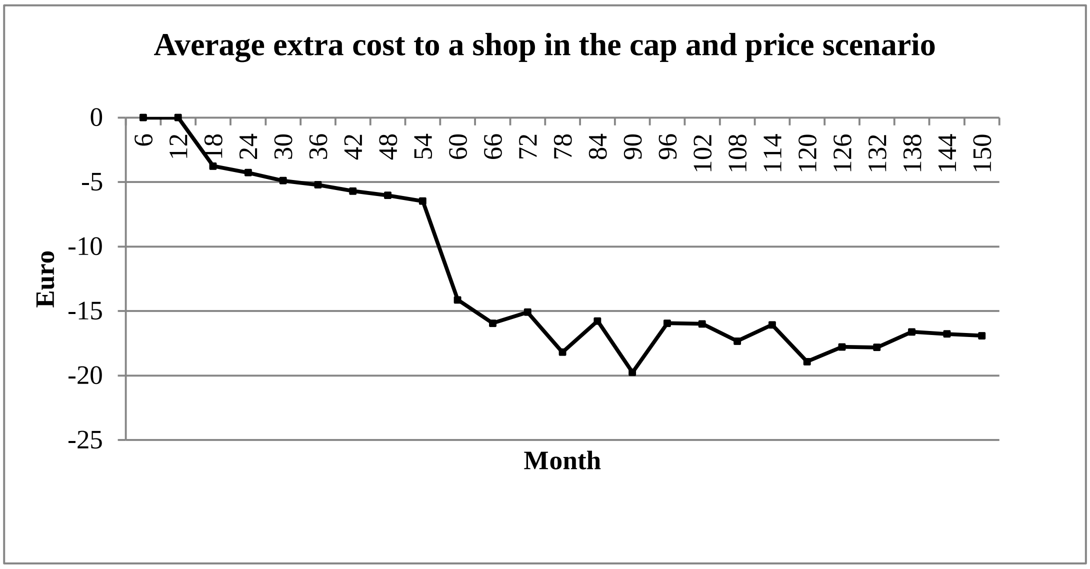


Figure 8.8 Average cost incurred to a shop

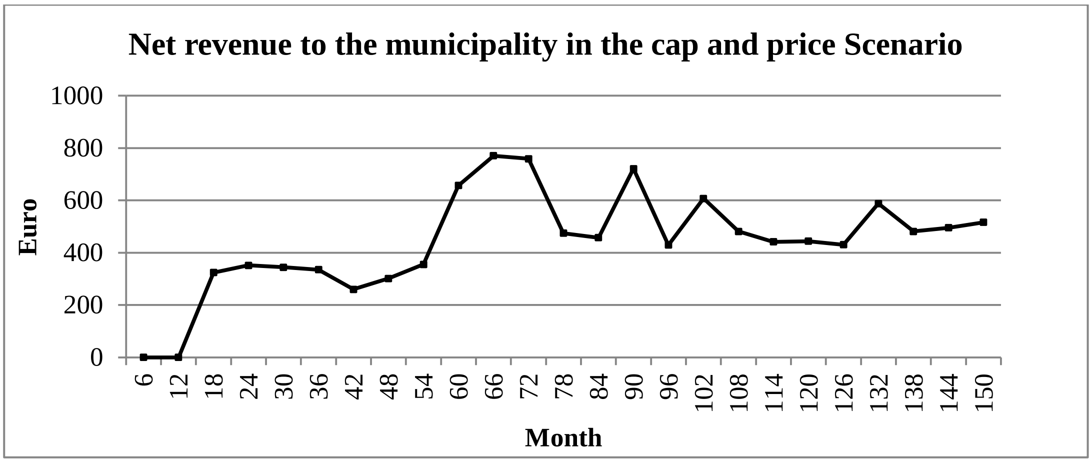


Figure 8.9 Net revenue of the municipality

The cap and price scenario setting incurs extra costs in the delivery operations, and some stakeholders must bear theses extra costs. The extra cost can occur to the shops when shops use UCC services and/or buy extra D_p. Although the UCC and the municipality are different physical entities, we assume the finances are handled by the municipality. Thus, the extra cost can occur to the municipality if the UCC does not generate enough revenue to recover its operating costs.

The shops have different freight generation patterns and thus the extra cost varies from shop to shop based on its use of the UCC and purchase of D_p. Figure 8.8 represents the average cost to a shop in the cap and price scenario. The graph indicates that the extra cost varies during the simulation and reaches to a steady level of 17 Euro per month during the last 12 months. This is a combined cost for using the UCC and buying D_p. Similarly, Figure 8.9 shows that extra income to the municipality reaches at a steady level of 500 Euro during the last 12 months. The net revenue generated by the municipality includes revenue from the sale of D_p, the cost associated with a refund of D_p and subsidizing the UCC operation.

The graphs of municipality revenue and average extra cost for a shop do not mirror each other, because the rate of change of using the UCC and buying D_p varies during the simulation. Accordingly, some shops buy D_p during the early months and switch to the UCC service when D_p starts getting more costly. On the other hand, some shops always stick to the UCC service or buying D_p due to their ordering patterns. The revenue of the municipality increases when more shops are buying D_p. Initially when the UCC operation starts, the price of buying D_p is low due to lower Q_{min}. In that situation, shops opt for buying D_p instead of using UCC. With increase in Q_{min} the price of D_p increases and shops start using the UCC. This is evident from a reduction in revenue to the municipality during months 66 and 102 in Figure 8.9. After this period the revenue is almost steady implying that for some shops it is always cheaper to buy D_p than using the UCC.

In assessing the results for the individual stakeholder, the municipality is achieving its goal of reducing the carriers' vehicle-km and associated congestion, pollution and safety related problems. The municipality also generates some revenue from the sale of delivery points. The cap on free delivery is imposed on the shops and thus they incur extra cost for using the UCC or buying delivery points. The UCC is supported by the municipality and, thus, does not incur any extra cost. The situation of the carriers is not explored here in detail, but it can be foreseen that carriers would benefit from the cap and price mechanism. Due to this mechanism, shops using UCC service still pay the full ordering price to the carrier even if the goods are delivered at the UCC. Thus, the carrier vehicle is driving shorter distances and saves money on the operational costs.

At the system level, the extra cost for each of 100 shops is 17 Euro, and the income to the municipality is around 500 Euro. This calculation gives 1200 net extra cost to the system for the cap and price scenario. This calculation implies that the cost of reducing 400 carriers' truck-km is around 1200 (i.e. 3 Euro to reduce a km). This cost is mainly associated with use of the UCC. Evidently, introduction of the UCC includes extra handling of goods in the goods delivery operation. It requires resources (e.g. driver, trucks) which incur costs. In the cap and price scenario, the extra cost of the system is suffered by shops. It is important to note that the assumptions about this stylized city, in particular its dimensions, number of shops and carriers, strongly affect the cost outcome of the scenario. For instance, a bigger city size would show a greater reduction in truck-km for less system cost. Therefore, care should be taken while generalizing the outcome of the solution for the city logistics domain.

8.3. Conclusions and future research

Understanding cumulative and serialized effects of the decision making by multiple stakeholders is the key to finding effective measures for city logistics related problems. The cap and price scenario evaluated in this chapter illustrates this point and emphasizes that such understanding cannot be achieved without involving multi-stakeholder perspectives. The cap and price scenario involves interdependent decision making by shopkeepers, the UCC and the municipality. The decisions taken by each of these stakeholders affect other stakeholders and serve as input for their consequential decision making. In this scenario, a mechanism is created to motivate the stakeholders to take decisions so that the total distance travelled by the carrier vehicles in the city reduces as per the goal.

The outcome of the cost of the system raises certain questions. How to know whether the cost incurred in solving city logistics problems is reasonable? For instance, the net system cost of 1200 Euro for reducing 400 vehicle-km of diesel driven vehicles translates to 3 Euro per km in the cap and price scenario. This can be considered as a high cost for a city logistics solution. However, city logistics activities have monetary effects (e.g. infrastructure maintenance) as well as social implications (e.g. air quality in the city). Thus, city logistics initiatives should be assessed from the economic as well as social perspective. Subsequently, calculating the correct cost of city logistics problems is another real challenge. Success in this direction can be helpful in measuring the effectiveness of the city logistics solutions.

The scenario presented in this chapter creates a situation where multiple stakeholders from a city logistics domain are interacting with each other, in order to perform their activities in an optimal way. The scenario serves as a template for exploring other multi-stakeholder perspectives such as including congestion charges for carriers and transferring the extra costs of the municipality to other stakeholders. Furthermore, the decision making processes of the stakeholders can include more sophisticated algorithms and other checks. The scenario can be also expanded to include other and more complicated decision making by the stakeholders. For instance, the municipality could also have a goal to reduce the number of vehicles entering the city, along with a distance goal.

The city logistics agent based model SMUrFS is used to develop this scenario. The scenario clearly shows how the outcomes of the system are affected by decision making of multiple stakeholders. The cap and price mechanism gives insights as to how different stakeholders adjust their activities and decision making processes as per their individual objectives. The state of the system that emerged due to the distributed decision making cannot be captured if only explored from a single stakeholder's point of view. The adjustments of different decision making parameters and decision making interactions of stakeholders give useful insights into working in the city logistics domain. In summary, the scenario shows the usefulness of the SMUrFS model for modelling multi-perspective problems in the city logistics domain.

References

Holguín-Veras, J. (2008). Necessary conditions for off-hour deliveries and the effectiveness of urban freight road pricing and alternative financial policies in competitive markets. Transportation Research Part A: Policy and Practice 42(2): 392-413.

Van Duin, J., Quak, H. and Muñuzuri, J. (2010). New challenges for urban consolidation centres: A case study in The Hague. Procedia-Social and Behavioral Sciences 2(3): 6177-6188.

9 Conclusions, future research and recommendations

9.1. Summary and conclusions

The sub-optimal planning of city logistics activities leads to inefficient use of resources and in turn creates problems such as pollution, poor accessibility, and unsafe urban areas. This is exacerbated by interdependency of city logistics activities, decision making with limited information and stakeholders' preference for personal objectives over system efficiency. Finding synergy between stakeholders to create an efficient city logistics system is a real challenge. Therefore, taking a holistic view to capture the perspectives of city logistics stakeholders is an essential step towards understanding the real reasons for these - often inefficient - truck movements and towards solving city logistics problems.

In this view, the city logistics modelling platform must be able to capture complex interactions among the stakeholders based on their multiple perspectives. With the capabilities of representing a system in a natural and flexible way, agent based modelling (ABM) is a promising alternative for the city logistics domain. The main objective of this thesis as stated in Chapter 1 is as follows:

"To explore the usefulness of the agent based modelling technique and develop a framework for the successful implementation of this technique for the city logistics domain."

This Ph.D. research focused on defining the methodological relations between characteristics of the city logistics domain and ABM, and designing the stages for the successful implementation of modelling technology. As a result, a comprehensive framework for using agent technology for the city logistics domain was developed. The framework provides a practical guide for the development of a well-articulated and viable agent based model for the city logistics domain. The framework includes various elements: a multi-perspective semantic

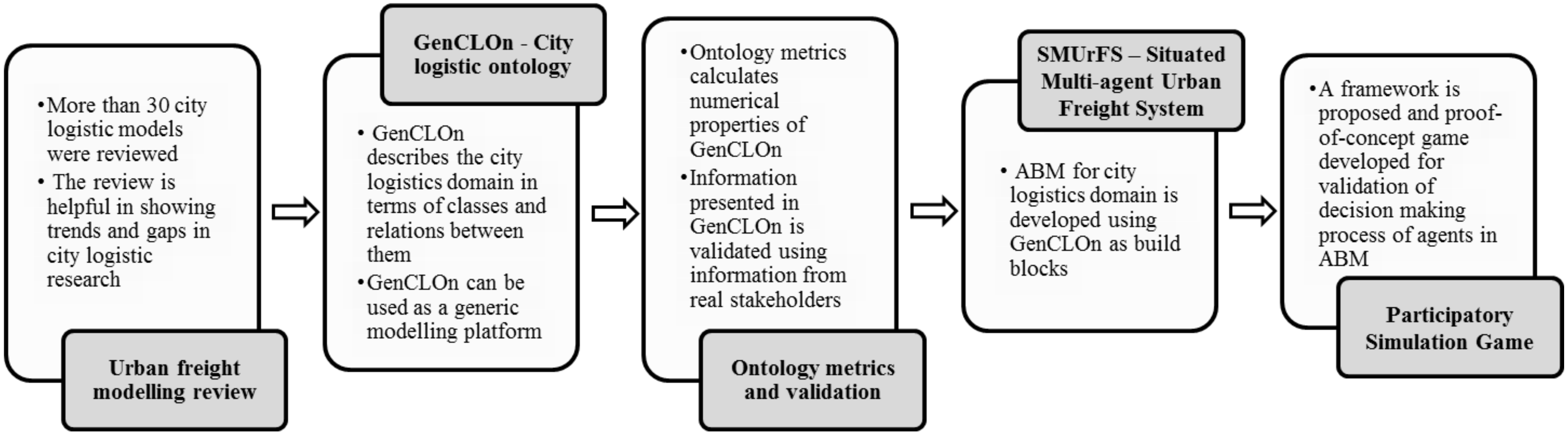


Figure 9.1 Framework for agent based model development for the city logistics domain

data model (i.e. ontology) and its validation, development of an agent based model using the ontology, and a validation approach.

The general conclusion can be drawn that the framework proposed in this thesis describes a comprehensive and promising approach for multi-stakeholder analysis of city logistics solutions. Figure 9.1 shows the proposed framework for ABM development and gives detail about each component.

In the following sections, we discuss the conclusions and the insights we obtained by answering the research questions presented in *Chapter 1*.

Research question 1: What are the relevance and gaps in city logistics modelling research and how can these gaps be filled?

Models are tools to analyse a domain in a methodical way. Different types of models have been developed for the city logistics domain at different detail levels. To get the overview of the role of modelling in the city logistics domain, a systematic review of city logistics models was completed in *Chapter 2*. This review reflects the first component of the Figure 9.1. The models were studied with respect to four important modelling factors: 1) Stakeholder represented in the model, 2) activity descriptor, 3) objective of the model, and 4) solution approach implemented to achieve the objective.

The review of the city logistics models reveals that the vast majority of the modelling efforts describe the system from an administrator's point of view, to evaluate governmental measures. Most literature on city logistics modelling considers how an administrator can create efficient city logistics transportation without considering leading roles from other active stakeholders (e.g. through collaboration). Next, since most negative effects related to city logistics transportation are visible in transportation, most models consider trip generation and traffic flow as the primary (often only) descriptors. This approach suffers from a 'missing link' as the generation of the city logistics traffic is largely dependent on other system descriptors from earlier stages of decision processes (e.g. modal transfer, vehicle loading). Therefore, in order to understand the root cause of city logistics related traffic, other descriptors must be considered. The majority of the reviewed models aim at improving the efficiency of activities and reducing environmental effects. Only few of the reviewed models focus on other important objectives such as economy and infrastructure. Thus, it can be concluded that city logistics models need a broader emphasis on multiple segments of the system. Three broad categories of solution approaches are reported in the city logistics modelling literature, namely policy, planning and technology. From the review we conclude that often policy measures are implemented without considering the holistic view of the domain activities.

Heterogeneity and autonomy in decision making are two important characteristics of city logistics stakeholders. The analysis of the review results indicates that current models do not cover effects of decision making by multiple stakeholders. The solutions presented in the majority of the models are from a single stakeholder perspective. However, the resulting inefficiencies of the city logistics system are to a large extent the outcomes of the distributed decision making by all relevant stakeholder groups. City logistics has multiple stakeholders, and they interact to carry their respective activities. Therefore, a solution developed from a single stakeholder's perspective does not consider actions from other stakeholders. Such a solution may not be able to solve the problems at hand.

In this regards, capturing interactions between heterogeneous stakeholders of the system is the key to understanding the causes of the inefficiencies in the city logistics domain. Consequently, the model developed to study city logistics related solutions must incorporate multiple perspectives of the stakeholders and their interactions. With this background about current city logistics models and its limitations, the research opportunity lies in modelling different actors independently (e.g. firm, store, logistics service provider, truck) and capturing their interactions to understand the emerging city logistics system. In broader terms, interrelations between stakeholders and their activities by representing their business decisions must be explored. Such analysis is capable of assessing the effects of a variety of technology trends, business trends, and policy scenarios.

On a positive note, the review also indicates that city logistics modelling approaches have evolved from solely focusing on administrative solutions to include impacts of social and behavioural interactions of other stakeholders. Evidently, the latest research is considering multiple perspectives of stakeholders to analyse the domain in contrast to putting all constraints in a single equation and find the optimum solution without considering dynamics of interactions in decision making. By modelling decentralized decision making of city logistics activities, strategic, tactical and operational decisions can be incorporated into the model. ABM is an approach where distributed decision making of the multiple stakeholders can be included by modelling each entity as an autonomous agent. This technique allows modelling the city logistics stakeholders of the domain as different agents to capture the emerging system and analyse the effects of their decision making on the city logistics domain.

Research question 2: What kind of system model can capture the perspectives of multiple stakeholders of the city logistics domain?

In traditional modelling approach, a modeller captures a user's view of the real world and mentally maps these concepts to instances developed in the model. Such informal or ad-hoc mapping causes inaccuracies as well as inconsistencies between the users' concepts and the model developed by the modeller. Instead, a formal model capturing domain information in a semantic form is better alternative. Such a semantic model, called an ontology, captures domain knowledge in the form of objects, concepts and relationships that exist among them. The information embedded in the ontology is linked with other related information. Such a semantic setting gives a detailed overview of a specific concept and helps in exploring the domain knowledge in a systematic way.

Driven by this motivation, a formal ontology for the city logistics domain - GenCLOn - is developed in *Chapter 4* and shows as the second component in Figure 9.1. The city logistics ontology comprehensively specifies the city logistics domain in terms of the concepts involved along with their relations. Extensive information and knowledge has been collected from the relevant literature as the theoretical foundation of the ontology. After a series of information processing actions including sorting, refining and summarizing, the domain of city logistics was classified into general classes. Section 4.4.2 describes classes such as 'Stakeholder' (e.g. supplier, carrier), 'Objective' (e.g. profit), 'KPI' (e.g. tour length, emission), 'Resource' (e.g. truck, shop, warehouse), 'Measure' (e.g. toll tax, UCC), 'R&D' (e.g. dynamic routing)'. Together with the large number of sub-classes attached afterwards, they represent the city logistics domain with a hierarchical structure that abstracts the real world. Information about multiple types of city logistics stakeholders is incorporated in the GenCLOn by connecting the 'Stakeholder' class to other classes. Next, these classes and its sub-classes are attached to other classes by an appropriate 'object property' and 'data property'. The relationships axioms are described in section 4.5. The relationships held among these classes provide the perspectives of different stakeholders about city logistics activities. Finally, section 4.6 describes different uses of the ontology such as a semantic conceptual model, use for analysis and reasoning and use as a base for developing a model.

Research question 3: How to evaluate the scope and accuracy of the information database of the city logistics domain?

This research question is answered in *Chapter 5* and shown as the third component in Figure 9.1. The ontology for the city logistics domain is the formal conceptual model describing domain information in terms of concepts and relationship among them. There is reluctance to using ontologies among practitioners and researchers. Systematic evaluation and validation of an ontology can generate required confidence for its usage. Ontology metrics are prepared in section 5.3 to evaluate the scope of city logistics ontology. The metrics evaluate the ontology in a quantitative way by calculating numerical properties such as depth (i.e. details of concepts), breadth (i.e. number of concepts), attributes, and relationships. The metrics indicate that GenCLOn contains a wide variety of concepts from the city logistics domain, and that it is a shallow ontology. The shallowness indicates that the GenCLOn classes are connected with each other through the most fundamental and necessary relationships to represent the city logistics domain at an abstract level.

Next, section 5.4 describes the validation of the city logistics ontology by assessing the correctness of the information presented in the ontology. The accuracy of the city logistics ontology is checked against the reference data from the real-world stories of the city logistics domain. Data collected from interviews with 12 real-world stakeholders as well as more than 30 city logistics models and various other scientific sources is used to validate GenCLOn. In a novel approach, the data is streamlined to generate cognitive maps representing the generic perception of city logistics stakeholders. The map has an ontology-like structure consisting of concepts and relationship. The representation of the concepts and their relationships are validated using details from these cognitive maps. Two important checks are done for city logistics ontology validation. Section 5.4.2 describes 'system component validation', which tests whether all-domain people understand and utilize the concepts in the same manner. 'Knowledge representation validation', presented in section 5.4.3, checks the structural integrity of the ontology and ensures that entity-relationships are correctly constructed. Furthermore, the GenCLOn is also validated against one agent based model and two real-life case studies on city logistics in section 5.5. Here, the validation is done by finding overlaps between the concepts, attributes and relationship presented in the model and the terms and relationships appearing in the ontology. The validation results conclude that GenCLOn is a valid ontology and includes all important generic stakeholders, activities and relationship between different concepts of the city logistics domain. Additionally, validation done using information from different stakeholders' also suggests that GenCLOn expresses the multi-stakeholder perspective in representing the city logistics domain.

Research question 4: What is a good approach for agent based model design for including multiple perspectives of city logistics stakeholders?

In recent years, agent based modelling (ABM) has been practiced as an alternative technique to model a domain because of its strong capability for capturing the dynamic behaviour of individual stakeholders and their interconnections. The usefulness of ABM is visibly accepted among city logistics researchers, as evident from the increasing number of agent based models found in the city logistics modelling literature. The effort to develop an ABM is nontrivial when multiple stakeholders must be included. An ABM is developed based on a domain specific knowledge base abstracted into agents and their relationships. Often such knowledge bases are conceptual and constructed by the modellers using sources like literature, surveys and project reports. Such individually constructed knowledge bases are subjective and, often, are built with little sharing or reuse – almost everyone starts from a blank slate. In this situation use of an ontology for the development of an agent based model can be really rewarding in terms of time spent by the research community and precision of shared concepts.

Furthermore, to model the city logistics domain using the agent based simulation technique successfully, communication between heterogeneous stakeholder-agents of the domain must be implemented accurately. For accurate communication, the agents of the model should have common knowledge of different terminologies and the types of decisions they are making. From a semantic point of view, these agents should have a common view of the system and coordination in their activities. This reasoning suggests that a multi-stakeholder city logistics ontology – GenCLOn - should be used as a base to develop an ABM for city logistics. It can work as a common platform for communication and information exchange between agents. The fourth component of the framework in Figure 9.1 is associated with this research question.

This approach is explained in section 6.2 and takes an ontology as a starting point for developing an agent based model by using concepts and relationships presented in the city logistics ontology as building blocks of the model. Extraction of the ontology entities and relations readily supplies the basic structure of the ABM in the form of the classes and relationships. Importantly, the use of components of a validated ontology promises the structural integrity of the model and can also reduce the modelling time.

The proof of concept model SMUrFS developed from the city logistics ontology is described in section 6.3. For the SMUrFS model, agents such as customer-agent, shop-agent, shipper-agent, carrier-agent and administrator-agent are created using city logistics ontology GenCLOn. Based on the information obtained from the ontology the model incorporates interactions between city logistics stakeholders. The attributes and interactions of these agents are described in section 6.2.1. The interactions implemented based on the information from the ontology are expanded whenever needed. For instance, the vehicle routing done by the carrier-agents is included in the decision making processes of the carrier-agent. Section 6.4 shows the shows the simulation of the city logistics domain for a hypothetical city.

Research question 5: How to validate an agent based model for the city logistics domain?

ABM is a promising way of modelling the city logistics domain due to its capability of mapping a system in a natural and flexible way. Checking the validity of an ABM is the next important task. Section 7.3 discussed validation of an agent based model at different levels. The agent presentation in the model and their connections with other agents are important checks. Therefore, the source of conceptual information used for agent presentation and connection must be valid. If the validated ontology is used for extracting agents, attributes and their connection with other agents, then ABM promises the structural integrity of the model. As described in *Chapter 5*, the city logistics ontology is validated using information from city logistics stakeholders and literature. The model developed from such a validated ontology represents correct attributes and relationships in the agents.

Next, characteristics such as path dependency, emergence and multiple interactions as well as the absence of micro-level data make the traditional empirical validation of ABM significantly difficult. The complexity of social processes modelled in the ABM does not guarantee that each simulation run follows the same sequence, leading to conflict in the final output and making the concept of validation different than in a well-controlled experiment. Therefore, validation of an ABM needs an innovative approach. Agents in an ABM are autonomous and independent decision makers and, therefore, the system outcome is the result of interactions between the agents. Consequently, it is further argued that an ABM can be validated by aligning agents' underlying process mechanisms with that of stakeholders' decision making processes.

Based on this line of reasoning, *Chapter 7* describes a participatory simulation gaming framework for the validation of an agent based model. The last component of the framework, as shown, is Figure 9.1 is about validation of an ABM. Using the proposed validation framework, a proof-of-concept participatory simulation game for the city logistics model SMUrFS is developed and described in section 7.4. The game focuses on validating the decision making process of a shop-agent by comparing it with the decision making process of a player who is playing a role of shop-agent in the game. Section 7.5 describes the setting of the game and decision making during the game. The game was played with the university students, and the results of the game are presented in section 7.6. By aligning the players' belief about ordering point and action about ordering quantity, the similarity between the decision making process of SMUrFS' shop-agent and that of players is identified. The results of the experiment conclude that a participatory gaming approach is a promising step towards the validation of agent based models, and it provides a base for process validation for an ABM.

9.2. Future research

The framework developed during this Ph.D. research represents a step towards standardizing and facilitating the use of agent based modelling for the city logistics domain. Further research from this point onwards can be done by improving the current model and extending its current capabilities.

9.2.1. Model improvements

(1) City logistics ontology

As the city logistics domain is expanding, newer concepts are being introduced and some older concepts are becoming obsolete. City logistics ontology should be enriched to keep up with this continuously changing domain. Next, the content covered by the city logistics ontology can be further refined as well as enriched. The ontological restrictions on classes and properties have been deliberately simplified to facilitate reasoning and debugging. The ontology can be improved by clearly specifying these restrictions. For instance, object properties can be further defined as 'functional', 'symmetric', 'transitive' and their domains and ranges can be strictly constrained. These operations can definitely make the ontology more precise. However, the decision should be taken deliberately since it also imposes high hardware requirements as well as more exposure to inconsistency caused by strict ontological commitments among objects. It is also possible to directly import an external ontology to improve a part of the city logistics ontology. For example, if an ontology dedicated to road is accessible, we can just download it and import it into the city logistics ontology. Thus, we can replace the current class ‘Road’ by new class ‘Road’ as long as the new one is more detailed than the current class.

(2) Agent-based model

The agent based model SMUrFS is developed using the city logistics ontology and includes the top-level stakeholders (e.g. carrier, retailer, supplier). The SMUrFS model can be improved by describing the stakeholders in more detail. For instance, a supplier could be a producer, a wholesaler or a trader. Similarly, a carrier can be represented as a 3PL. With the instance creation in the ontology this detailed level presentation can be easily achieved. Next, the behaviour and the stakeholders can be expanded by including more decision making parameters and more detailed learning capabilities of the agents. Currently, the vehicle routing in the model is done based on distance minimization. In real life, decisions about routing also include other factors such as time of travelling, congestion, and priority of delivery. The routing algorithm can be improved by including similar factors. Demand estimation for the shops in the current model is done based on shop size. This can be improved by incorporating other relevant factors (e.g. number of employees). In the current model, selection of a supplier by the shops is done based on the distance between the shop and a supplier location. The supplier selection process can be improved by including more criteria in the decision making process. Only a single type of goods is considered in the current model. The model can be expanded to include different product types or product groups to include a variety of supply chains.

(3) Validation game

The proof-of-concept game for validation of an ABM is developed using NetLogo software. Therefore, the interface of the game is simple and less interactive. The interface of the game can be improved to make it more appealing and interesting. For instance, the visualization of the city represented in the game can be improved with better animation. The current game has a competition element in terms of profit. However, the reward mechanism – similar to the mechanisms present in the commercial games - can be introduced in the game that provides extra benefits, incentives or extra power to the player. The gaming experiment was performed with a number of students, who do not have experience with a real domain and with experts in the field of logistics, who did not represent all stakeholders. Therefore, playing the game with real stakeholders can give a new set of results to validate agent behaviours.

9.2.2. Model Extension

(1) City logistics ontology

The city logistics ontology is still at a generic level due to the extensiveness of the domain it tries to represent as well as the relatively low importance of instance creating at the current phase. As a result, many classes just end up with sub-classes rather than specific instances that are addressed with concrete data. Since all the attributes that an instance should possess have already been stipulated in the class the instance belongs to, the ontology itself can act as the template for instance building. Accordingly, the work left revolves around only collecting and assigning data to the corresponding slots. Furthermore, detailed logistics concepts (e.g. supplier contract, transportation contract) are not included as the purpose of GenCLOn is to represent daily activities of urban goods movements. Nevertheless, it should be noted that these concepts are very important as they decide on the pattern of urban goods movements. Further effort is demanded to specify these factors in detail.

(2) Agent-based model

City logistics has many different concepts, processes, and consequential effects. City logistics ontology describes stakeholders in multiple levels (see Section 4.4.2). In the SMUrFS model, agents represent only primary level of stakeholder (i.e. Shipper, Carrier, Shop, Administrator). Similarly, details such as variety of goods flows, frequency of delivery for different goods types are not incorporated at this stage in the SMUrFS model. For the proof of concept model, the focus is to show integration of city logistics ontology for the ABM development. With these details included in the ABM, detail analysis of city logistics activities can be carried out. In this regards, the model can be extended in many ways. Currently, the model includes city logistics activities represented by goods delivery to the shops. However, city logistics activities also include trips by service vans, garbage collector trucks, construction material trucks and other types of large truck movements. Thus, one way the model can be extended is by including other types of truck movements. Goods delivery vehicles share the road network with other vehicles (e.g. cars, bus) and pedestrians. Incorporating effects of non-commercial vehicles in the model is another way to extend the model. Online shopping is a new way of buying goods. A possibility of browsing a variety of products at your convenience and ordering it with a mouse click has given a new dimension to shopping. This phenomenon is significantly affecting goods delivery timing, frequency and order size. Therefore, an interesting extension of the model could be done by including online shopping and its effects.

Another aspect where the model can be extended is by expanding the richness of stakeholder behaviours. Decisions taken by the city logistics stakeholders are not optimal because often these decisions are taken due to emotional preference, long term practice, reluctance to change and other similar reasons. Behaviour of stakeholders in the current model can be extended by adding such reasoning into the decision making model. Discrete choice modelling is a mature research field for behavioural research. By combining it with the agent based modelling, the preference of the agent can be represented more accurately. Furthermore, the main goal behind the interactions between city logistics stakeholders is delivering or receiving the goods. However, these interactions are not straightforward but include other communications such as the information request, delivery preference, negotiation for price and more. Incorporating interactions for negotiation, cooperation and coordination between stakeholders can make the model more realistic.

(3) Validation game

The proof-of-concept game for the city logistics model SMUrFS is only a small step towards improved validation of ABMs. It opens the door for further explorations of validation approaches for social simulation processes. There are several options for further research. Firstly, a more interactive version of the game can be developed where the roles of multiple agents can be played by players. In addition, the players are competing against not only agents but also other players. Such an extension would give an opportunity to experiment with process validation under situations such as cooperation, negotiation and competition. Secondly, the concept of validating behaviour of agents can be applied to other models by developing similar games. Application of the participatory game concept to other models can strengthen its position and allow preparing a clearer overview of the validation technique, challenges and limitations of using participatory simulation games. Thirdly, creating a connection between the participatory gaming validation framework and gaming models for teaching purposes could be an interesting extension.

9.3. Recommendations for using the framework

The framework developed during this Ph.D. research takes the basic components – domain entities and their relationships - of the city logistics domain as the starting point for developing a complex decision analysis tool – an agent based model. The users of this framework can be a variety of people attached to and interested in the city logistics domain, including administrators, researchers and private or NGO stakeholders. The framework can be used for practical and theoretical research, as well as a knowledge document. Information gathered in the systematic review of city logistics models can be used to get an overview of a variety of studies done to understand the city logistics domain and related problems. The review can also serve as a mirror depicting trends and gaps in city logistics research, providing hints toward future research possibilities.

The city logistics ontology can be used for several objectives. In its simplest form, it can be used as a knowledge document to get information about the domain including entities, their attributes and relationships between them. If the ontology is used for model development or to carve a research agenda, care should be taken to modify the content of the ontology. In the ontology, some important factors such as public transport, individual shopping trips and service-oriented traffic are weakened considerably due to its generic nature. Accordingly, concepts not related to the objective of the model can be dropped or presented as information rather than the object. Similarly, key concepts should be expanded to a sufficient level. For instance, only their ultimate influences on freight traffic are shallowly represented in the ontology via data properties as instant 'traffic load of roads' and 'demand rate of goods'. If the ontology is used to develop a model to analyse the effect of individual shopping trips on the city logistics activity, then detailed information about individual shopping must be updated in the ontology. Moreover, due the limitation of the current ontology editors, some dynamic and stochastic relations among objects can hardly be represented. Accordingly, relations defined by default can deviate more or less from the real world. For example, the relations between stakeholders and objectives are quite uncertain and have to be asserted in a deterministic way in the ontology nowadays. Thus, relationships between different concepts should be adjusted if necessary.

The agent based model SMUrFS, developed in *Chapter 6*, depicts a generic situation of the city logistics domain. The use of such an approach allows using the model as a tool for preliminary analysis of different scenarios as shown in *Chapter 8*. The simple and basic stakeholder behaviours and interactions presented in the model can be regarded as a useful feature of the model. The simple structure of the model can be used to understand how multiple stakeholders with basic behaviours can create a complex decision making city logistics system. Analysis of outcomes for different policies, rules or measures using the model can provide important insights for research direction for further analysis. Insights received from the primary study can be used to carry out a more thorough analysis of one or more activities, by developing a complex model for a specific part of the system. Straightforward use of the model for getting a recommendation about the real city logistics solutions is not possible at this stage. In order to do that the model must be adjusted and improved with appropriate data and calibration. The current version of the model uses GIS information for the location of stakeholders and road network. The GIS compatibility is helpful in transformation of the model to real life cases.

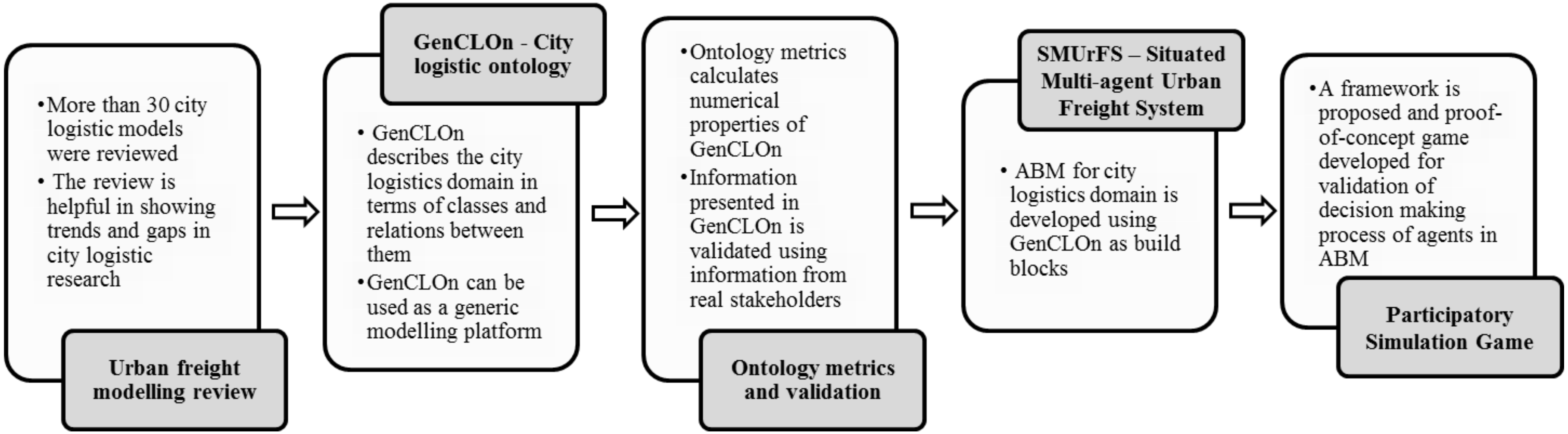
The participatory simulation game can be played with city logistics stakeholders to collect information about their decision making parameters for different city logistics activities. Although the game is developed with the goal of validating agent behaviours, it can also be used to collect information about behaviours for a model expansion. Accordingly, the game can be modified to capture details of decision making behaviours of the stakeholders. Data gathered from the game session can be used to develop new behaviour or improve existing behaviour of agents in the model. From the education point of view, the game can be used as an interactive tool to understand the decision making processes and complexity of city logistics activities. It can be used as a tool to educate stakeholders and researchers interested in the city logistics domain.

This thesis describes a comprehensive framework for multi-stakeholder analysis of city logistics solutions using an ontology driven approach combined with agent based modelling, and provides a proof-of-concept for each stage. The framework describes different stages which are comprehensive in nature and can be treated as a guide for the systematic development of an agent based model for the city logistics domain. Conclusively, the framework shows that a rigorous course can be taken to successfully implement agent technology in models for the city logistics domain.

Summary

World urban population is 4 billion today and is expected to reach 5 billion by 2030. In the search for a better life, employment and development, more and more people are migrating from rural areas to urban areas. This trend is the primary reason for the expansion of existing urban areas and the development of new cities. With economic, technological and societal development, cities are witnessing a proportional increase in the number of commercial vehicles. The volume of goods delivery vehicles is estimated to be 10-20% of passenger traffic. Although fewer in number, these vehicles are bigger in size. Therefore, the contribution of congestion of freight delivery vehicles is higher than that of ordinary cars. Freight delivery vehicles contribute to 20-30% of vehicle-kilometres but, depending upon the type of pollutant, produce 16-50% of the emissions of air pollutants. Due to their size and frequency of trips, whether on the road or parked for loading/unloading, goods delivery vehicles raise road safety related issues. Noise generated by trucks is even a greater nuisance, especially when operating in a quiet neighbourhood or during night time. With the expected increase in urbanization, all these problems generated due to urban goods movements compel us to think about how we should plan our cities in order to reduce these negative externalities without sacrificing need for goods of city inhabitants.

The problems arising from urban goods delivery activities are often associated with organizational synergy problems between city logistics stakeholders. The idea of collaboration and cooperation does not always come naturally to organizations, especially between companies offering the same or similar products or services. A step further towards this problem reveals that the city logistics domain consists of many different types of stakeholders. These stakeholders perform urban goods movement related activities in isolation. Thus, each activity might be efficient from an individual stakeholder viewpoint but the entire process of goods movement is characterised by inefficient use of retail space, truck capacity and other resources. Often these stakeholders are unaware that collaboration can alleviate the social, environmental problems as well as be profitable to the business. Such a



Framework for agent-based model development for the city logistics domain

lack of synergy is partly attributed to a lack of information exchange between city logistics stakeholders.

Interdependent city logistics activities, decision making with limited information and stakeholders' preference for personal objectives over system efficiency create a sub-optimal city logistics domain. As these heterogeneous city logistics stakeholders have different perspectives towards the system, finding synergy between their working styles to create an efficient city logistics system is a real challenge. Therefore, capturing the holistic view of perspectives of city logistics stakeholders is an essential step towards understanding the real reasons for solving city logistics problems. In this view, a city logistics modelling platform must be able to capture complex interactions among stakeholders and their multiple perspectives. With its capabilities of mapping a system in a natural and flexible way, an agent-based modelling (ABM) technique is a promising alternative for modelling the city logistics domain. In order to use ABM for the city logistics domain, it is necessary to study various aspects of the city logistics domain relevant for developing an agent based model. Accordingly, the objective of this PhD research is:

"To explore the usefulness of the agent-based modelling technique and develop a framework for the successful implementation of this technique for the city logistics domain."

This Ph.D. research focuses on defining the methodological relations between characteristics of the city logistics domain and ABM, and designing the stages for successful implementation of the modelling technology. The result is a comprehensive framework for using agent technology for the city logistics domain. The framework integrates all the important aspects of modelling and, thus, provides a practical guide for model development. The framework includes various elements – a multi-perspective semantic data model (i.e. ontology) and its validation, the development of an agent base model using this ontology, and a validation approach for the agent-based model. The figure shows the proposed framework for agent-based model development for the city logistics domain and provides details for each component.

Review of state of the art

Models are tools to analyse a domain in a methodical way. Different types of models are developed for the city logistics domain at different detail levels. To get the overview of the role of modelling in the city logistics domain, a systematic review of city logistics models is carried out in *Chapter 2*. The analysis of the review results indicates that current models do not, or poorly, cover effects of decision-making by multiple stakeholders. The resulting inefficiencies of the city logistics system are to a large extent the outcomes of the distributed decision making by multiple stakeholders. However, the solutions presented in the majority of the models are from a single stakeholder perspective. City logistics has multiple stakeholders, and they interact to carry out their individual activities. A solution developed from a single stakeholder's perspective usually does not consider actions from other stakeholders. Therefore, such a solution may not be able to solve the city logistics problems.

In this regards, capturing interactions between heterogeneous stakeholders of the system is the key to understanding the causes of the inefficiencies in the city logistics domain. Consequently, the model developed to study city logistics related solutions must incorporate multiple perspectives of the stakeholders and their interactions. With this background about current city logistics models and its limitations, the research opportunity lies in modelling different actors independently (e.g. firms, stores, logistics service providers, trucks) and capturing their interactions to understand the emerging behaviour of the city logistics system. In broad terms, interrelations between stakeholders and their activities must be explored by representing their business decisions. Such an analysis is capable of assessing the effects of a variety of technology trends, business trends and policy scenarios.

By modelling decentralized decision making of city logistics activities, strategic and tactical decisions at a logistics level and operational decisions at a distribution level can be incorporated into the model. The agent based modelling technique is an approach where distributed decision making of the multiple stakeholders can be included by modelling each entity as an autonomous agent and capture the effect of emerging behaviour on the city logistics domain.

A generic city logistics ontology

In order to model the actors of city logistics domain correctly, we need information about the types of stakeholders, activities, resources and their interrelations. Thus, the first step is to build a conceptual map that represents the city logistics domain by depicting the concepts and relationships in a comprehensive way. In the traditional modelling approach, a modeller captures a user's view of the real world and mentally maps these concepts to instances developed in the model. Such an informal or ad-hoc mapping causes inaccuracies as well as inconsistencies in the users' concepts and the model developed by the modeller. Instead, a formal model capturing domain information in a semantic form is a better alternative. Such a semantic model is called an ontology and captures domain knowledge in the form of objects, concepts and relationships that exist among them. The information embedded in the ontology is linked with other related information. Such a semantic setting gives a detailed overview of a specific concept and helps in exploring the domain knowledge in a systematic way.

Driven by this motivation, a formal ontology for the city logistics domain - GenCLOn - is developed in *Chapter 4*. The city logistics ontology comprehensively specifies the city logistics domain in terms of the classes and relationships between them. It contains classes such as 'Stakeholder' (e.g. supplier, carrier), 'Objective' (e.g. profit), 'KPI' (e.g. tour length, emission), 'Resource' (e.g. truck, shop, warehouse), 'Measure' (e.g. toll tax, UCC), 'R&D' (e.g. dynamic routing)'. Together with the large number of sub-classes attached these classes represent the city logistics domain with a hierarchical structure that abstracts the real world. Information about multiple types of city logistics stakeholders is incorporated in the GenCLOn by connecting the 'Stakeholder' class to other classes. Next, these classes and its sub-classes are attached to other classes by an appropriate 'object property' and 'data property'. The relationships held amongst these classes represent the perspectives of different stakeholders about city logistics activities.

Ontology metrics and validation

An ontology can be very useful knowledge base; however, there is still reluctance to using ontologies among practitioners and researchers. The reluctance is mainly due to doubts about the accuracy of the knowledge representation within the ontology. A systematic evaluation and validation of an ontology can generate the required confidence for its usage. Ontology metrics are prepared in *Chapter 5* to evaluate the scope of the city logistics ontology. The metrics indicate that GenCLOn contains a wide variety of concepts from the city logistics domain, and that it is a shallow ontology. This shallowness indicates that the GenCLOn classes are connected with each other through the most fundamental and necessary relationships to represent the city logistics domain at an abstract level.

Furthermore, the validation of the city logistics ontology is done by comparing it against the reference data from the real-world stories of the city logistics domain. Data collected from interviews with 12 real-world stakeholders as well as more than 30 city logistics models and various other scientific sources is used to validate GenCLOn. In a novel approach, the data is streamlined to generate a cognitive map representing the generic perception of city logistics stakeholders. The map has an ontology-like structure consisting of concepts and relationship. The representation of the concepts and their relationships are validated using details from these cognitive maps. The validation process concludes that GenCLOn is a valid ontology and includes all important generic stakeholders, activities and relationship between different concepts of the city logistics domain. Additionally, validation done using information from different stakeholders' also suggests that GenCLOn expresses the multi-stakeholder perspective in the city logistics domain.

An agent based model for the city logistics domain

ABM is a very useful technique for modelling the city logistics domain. However, the effort to develop an ABM is nontrivial when multiple stakeholders must be included. An ABM is developed based on a domain specific knowledge base, abstracted into agents and their relationships. In this situation use of an ontology for the development of an agent-based model can be rewarding in terms of time and precision. Furthermore, to model the city logistics domain using the agent based simulation technique successfully, communication between heterogeneous stakeholder-agents of the domain must be implemented accurately. For accurate communication, the agents of the model should have common knowledge of different terminologies and the types of decisions they are making. From a semantic point of view, these agents should have a common view of the system and coordination in their activities. This reasoning suggests that the multi-stakeholder city logistics ontology GenCLOn should be used as a base to develop an ABM for city logistics. It can work as a common platform for communication and information exchange between agents.

Chapter 6 describes the approach that takes an ontology as a starting point for developing an agent-based model. The concepts and relationships presented in the city logistics ontology are used as building blocks of the model. The ontology entities and relations readily supply the basic structure of the ABM in the form of the classes and relationship. Importantly, the use of components of a validated ontology secures the structural integrity of the model and can also reduce the modelling time. The proof of concept model SMUrFS is developed from the city logistics ontology. For the SMUrFS model, agents such as customer-agent, shop-agent, shipper-agent, carrier-agent and administrator-agent are created using city logistics ontology GenCLOn.

The SMUrFS model is applied and tested in *Chapter 8* using a scenario where multiple stakeholders from the city logistics domain are interacting with each other to perform their activities in an optimal way. The analysis of the scenario shows that the state of the system that emerges from distributed decision making cannot be captured if explored only from a single stakeholder's point of view. The scenario shows the importance of including multi-perspective decision making in policy design and illustrates the usefulness of agent based model for incorporating multi-perspective city logistics domain.

Validation of an agent-based model using a participatory simulation game

ABM is a promising way of modelling the city logistics domain due to its capability of representing a system in a natural and flexible way. Checking the validity of an ABM is the next important task. Little research effort has been spent on the definition of specific methods and techniques for ABM validation. Often, statistical validation techniques applied to event based simulation models are deemed equally suitable for an ABM without much questioning. However, characteristics such as path dependency, emergence and multiple interactions as well as the absence of micro-level data make the traditional empirical validation of ABM significantly more difficult. The complexity of social processes modelled in the ABM does not guarantee that each simulation run follows the same sequence, leading to variations in the final output and making the concept of validation different than in a well-controlled experiment. Therefore, validation of an ABM needs an alternative approach, which is rooted in process validation next to statistical validation.

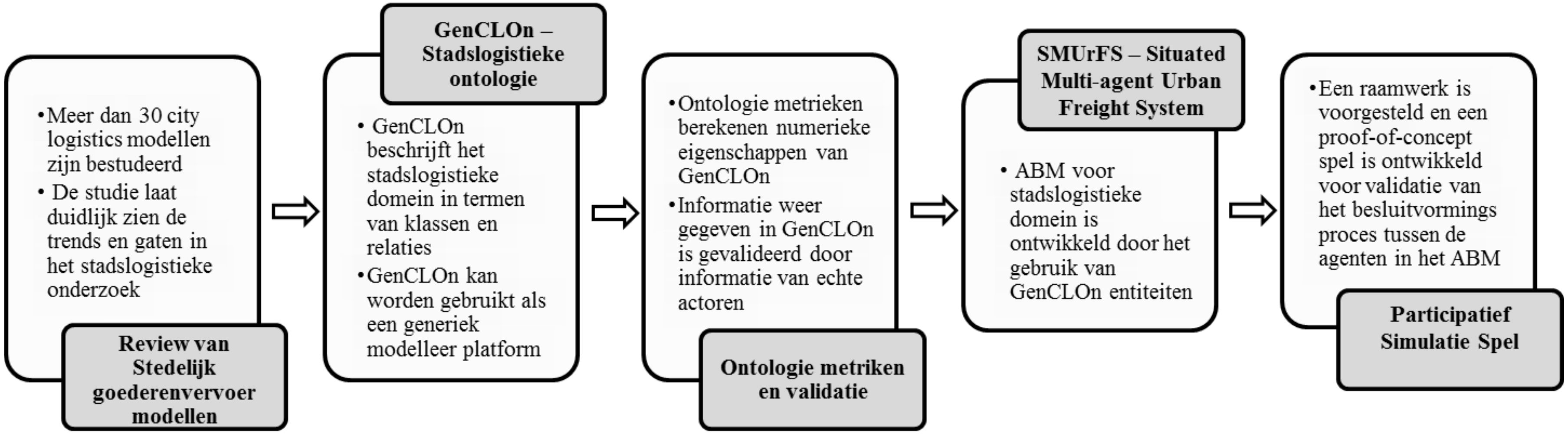
Agents in an ABM are autonomous and independent decision makers and, therefore, the system outcome is the result of interactions between the agents. Consequently, we argue that an ABM can be validated by aligning agents' underlying process mechanisms with that of stakeholders' decision-making processes. Based on this line of reasoning, *Chapter 7* describes a participatory simulation gaming framework for the validation of an agent-based model. Using the proposed validation framework, a proof-of-concept participatory simulation game for the city logistics model SMUrFS is developed. The game focuses on validating the decision making process of a shop-agent by comparing it with the decision-making process of a player who is playing a role of shop-agent in the game. The game was played with the university students and with experts from the industry and research communities. By aligning the players' belief about ordering point and ordering quantity, similarities between the decision-making process of SMUrFS' shop-agents and that of the real players can be determined. The results of the experiment indicate that a participatory gaming approach is a promising step towards the validation of agent-based models, and that it provides a base for process validation for an ABM.

Agent-based modelling can be useful for many unrequited policy analysis problems in the city logistics domain. However, the time and precision required for developing such a system is a challenging task. Overcoming these challenges requires painstaking efforts but assures in-depth understanding about urban freight transportation process for successful city logistics policy analysis. This thesis describes a comprehensive framework for multi-stakeholder analysis of city logistics solutions using an ontology driven approach combined with agent based modelling, and provides a proof-of-concept for each stage. The framework describes different stages which are comprehensive in nature and can be treated as a guide for the systematic development of an agent based model for the city logistics domain. Conclusively, the framework shows that a rigorous course can be taken to successfully implement agent technology in models for the city logistics domain

Samenvatting

Op dit moment leeft 4 miljard van de bevolking in stedelijk gebied en naar verwachting zal dit aantal stijgen naar 5 miljard in 2030. In de zoektocht naar een beter leven, werkgelegenheid en betere kansen voor ontwikkeling, migreren meer en meer mensen van het platteland naar stedelijke gebieden. Deze trend vormt de voornaamste reden voor de uitbreiding van bestaande stedelijke gebieden en de ontwikkeling van nieuwe steden. Als gevolg van economische, technologische en maatschappelijke ontwikkelingen ervaren steden een evenredige toename van het aantal bedrijfsvoertuigen. Het aandeel goederenleveringen in steden wordt geschat op 10-20% van het totaal aantal voertuigbewegingen in de stad, in kilometers gemeten 20-30%. Afhankelijk van het soort verontreiniging, produceren vrachtauto's echter ongeveer 16-50% van de totale uitstoot van luchtverontreinigende stoffen. Door de grootte van de voertuigen, de frequentie van het aantal stadsritten, het parkeren op de weg of op speciaal gecreëerde laad- en losplaatsen hebben zij ook een invloed op de verkeersveiligheid. Het geluid van de voertuigen vormt vaker nog een grotere overlast voor de directe leefomgeving. Met de toekomstige verwachte groei van de verstedelijking en de genoemde problemen worden wij gedwongen na te denken hoe wij de negatieve externe effecten van het goederenvervoer kunnen reduceren, zonder aan de dagelijkse behoefte aan goederen van de inwoners voorbij te gaan.

Als we dit probleem van dichterbij bekijken, blijkt dat de stad op logistiek gebied bestaat uit veel verschillende belanghebbenden. Zo kan het zijn dat vanuit een mono-actor bedrijfsperspectief het logistieke proces als efficiënt wordt gezien terwijl vanuit een integraal systeemperspectief het goederenvervoer gekenmerkt wordt door een inefficiënt gebruik van winkelruimte en vrachtwagencapaciteit . Bedrijven voeren het stedelijke goedervervoer vaak uit in isolement, onbewust dat met samenwerking sociale en ecologische problemen verlicht kunnen worden, terwijl ook de winstgevendheid voor een individueel bedrijf verbeterd kan worden. Het idee van de samenwerking ontstaat niet altijd vanzelf en zeker niet tussen bedrijven die dezelfde of soortgelijke producten of diensten hebben. Dit gebrek aan synergie is deels toe te schrijven aan een gebrekkige informatie-uitwisseling tussen logistieke actoren in de stad, zowel bij het ontwerp, de planning als de uitvoering van logistieke processen.



Raamwerk voor ontwikkeling van ABM

Dit proefschrift concentreert zich op een strategisch informatiesysteem voor het ontwerp van logistieke concepten en beleid vanuit meerdere actoren. Voor een slim ontwerp van logistieke concepten is een holistische benadering nodig waarin de doelen en percepties van alle belanghebbenden bij het stedelijke goederenvervoer worden meegenomen. Vanuit deze benadering moet een stadlogistiek modelleerplatform in staat zijn om complexe interacties vast te leggen tussen de belanghebbenden en hun vele perspectieven. Een *agent based model* (ABM)-techniek biedt de mogelijkheden voor het beschrijven van een systeem op een natuurlijke en flexibele manier, waarbij actorengedrag gemodelleerd kan worden via de agenten. Het doel van dit promotieonderzoek is als volgt:

"Het verkennen van het nut van de ABM techniek en het ontwikkelen van een methodologisch kader voor succesvolle implementatie ervan in het stedelijke logistieke domein."

Dit promotieonderzoek richt zich op het definiëren van de methodologische relaties tussen de karakteristieke elementen van het stads logistieke domein en ABM, en ontwerpen van een stappenplan om te komen tot een succesvolle implementatie ervan. Het resultaat is een methodologisch raamwerk voor de ontwikkeling en het gebruik van ABM. De afbeelding toont het voorgestelde raamwerk voor de ontwikkeling.

Review van state of the art

Modellen zijn hulpmiddelen om een domein op een systematische manier te analyseren. Verschillende typen van modellen worden ontwikkeld op het gebied van de stedelijke logistiek, op verschillende detailniveaus. In *Hoofdstuk 2* wordt een overzicht gegeven van de verschillende studies en worden modellen beoordeeld naar de volledigheid waarmee stedelijke logistiek wordt beschouwd. Het kennen van interacties tussen stakeholders van het systeem is een belangrijke sleutel tot het begrijpen van oorzaken van inefficiënties in stedelijke distributie. De analyse toont aan dat de huidige modellen niet, of slechts beperkt de effecten van besluitvorming door meerdere actoren meenemen. Stadsdistributie kent meerdere stakeholders, en ze hebben interacties met andere actoren om hun individuele activiteiten te kunnen uitvoeren. In de meeste modellen zijn de gevonden oplossingen vanuit het perspectief van één enkele actor weergegeven. Als een oplossing geen rekening houdt met de acties van andere belanghebbenden, kan deze echter vaak niet of maar beperkt bijdragen tot de oplossing van problemen.

Raamwerk voor modelontwikkeling

Voor het te ontwikkelen model betekent dit dat oplossingen vanuit meerdere actorperspectieven bestudeerd moeten kunnen worden. De uitdaging in ons onderzoek ligt daarom in het modelleren van de verschillende actoren afzonderlijk (bijvoorbeeld bedrijven, winkels, logistiek dienstverleners, vrachtwagens) en in samenhang, via de dynamische relaties tussen individuele zakelijke beslissingen. Het ABM betreft een modelleertechniek waarin gedistribueerde besluitvorming van de verschillende stakeholders kan worden opgenomen, door het modelleren van alle autonome agenten en het opgetelde effect van hun gedrag op de stedelijke logistiek. Dit leidt in Hoofdstuk 3 tot het raamwerk voor modelontwikkeling. Dit raamwerk integreert de belangrijke aspecten van het modelleren en voorziet daarmee in een praktische gids voor modelontwikkeling. Het bestaat uit verschillende elementen: een semantisch datamodel (ontologie) vanuit een multi-actor perspectief, methoden voor validatie van de ontologie, de ontwikkeling van een ABM-basismodel met behulp van deze ontologie, en een validatie aanpak voor het ABM als geheel.

Een essentieel en vernieuwend onderdeel van onze aanpak is dat we een ontologie als basis nemen voor het ABM. Om het gedrag van de actoren juist te kunnen modelleren is eenduidige informatie nodig over de soorten belanghebbenden, hun activiteiten, hun middelen en hun onderlinge relaties. Als eerste stap is het belangrijk dat een conceptueel model gemaakt wordt waarin helder alle concepten en hun relaties zijn afgebeeld. In een traditionele modelleeraanpak maakt de onderzoeker een conceptueel model van de werkelijkheid vanuit het belangrijkste perspectief in het model (meestal die van de modelgebruiker). Een dergelijke informele of ad-hoc afbeelding veroorzaakt onjuistheden alsmede inconsistenties tussen modellen wanneer deze vanuit verschillende gebruikers of verschillende onderzoekers worden ontwikkeld. Een beter alternatief hiervoor is het ontwikkelen van een formeel model waarin ten eerste domeininformatie is vastgelegd in een semantische vorm en, daarnaast, deze informatie eenvoudig overgedragen en gedeeld kan worden. Een dergelijk semantisch model noemt men een ontologie en vangt domeinkennis in de vorm van objecten, concepten en hun onderlinge relaties. Een ontologie wordt opgeslagen in een semantische database en helpt bij het verkennen van de domeinkennis op een systematische manier. In de praktijk van logistieke modellen is tot nu toe geen gebruik gemaakt van ontologieën. Juist voor toepassing in een multi-actor omgeving is dit volgens ons onontbeerlijk.

GenCLOn - een ontologie voor stedelijke logistiek

Vanuit de bovenstaande motivatie wordt in *Hoofdstuk 4* een formele ontologie voor het stads logistieke domein - GenCLOn - ontwikkeld. De ontologie voor stedelijke logistiek specificeert uitvoerig het domein in termen van de klassen en onderlinge relaties. Klassen betreffen concepten zoals 'Stakeholder’ (bv Leverancier, Vervoerder), 'Doelstelling' (bijvoorbeeld, Winst), 'KPI' (bijvoorbeeld Trip lengte, Emissie), 'Bron' (bijvoorbeeld vrachtwagen, winkel, magazijn), 'Maatregel' (bijvoorbeeld Tol belasting, Stadsdistributiecentrum) en Onderzoek' (bijvoorbeeld Dynamische routering) '. Samen met een groot aantal subklassen representeren deze het domein in een hiërarchische structuur, als abstractie van de werkelijkheid. Informatie over meerdere actoren in het domein is verwerkt in GenCLOn door de 'stakeholder' class aan te sluiten op andere klassen. De relaties gevonden tussen deze klassen vertegenwoordigen zo de onderling gerelateerde perspectieven van de verschillende belanghebbenden van de stads logistieke activiteiten.

Beoordeling van een ontologie vanuit een multi-actor perspectief

In de praktijk zijn onderzoekers en wetenschappers vaak terughoudend in het gebruik van ontologieën. De terughoudendheid is vooral te wijten aan twijfels over de juistheid van de kennisrepresentatie. De systematische evaluatie en objectieve validatie van een ontologie kan het vertrouwen in een ontologie versterken. In *Hoofdstuk 5* worden maten voor de validatie van een ontologie opgesteld om de omvang en rijkheid van de ontologie te bepalen. Deze tonen aan dat GenCLOn de meest relevante concepten van de stad logistiek domein bevat, en dat deze een relatief ondiepe, ofwel generieke, ontologie is. Verder is de validatie van de stads logistieke ontologie uitgevoerd door het vergelijken van de referentiegegevens met praktijkverhalen en interviews. In totaal zijn gegevens verzameld uit interviews met 12 actoren uit het logistieke veld, van 30 verschillende modellen in het domein en diverse andere wetenschappelijke bronnen. Voor de validatie is een nieuwe aanpak bedacht waarbij de gegevens omgezet worden in een cognitieve kaart die de perceptie van de stakeholders samenvat. Deze kaart kent eveneens een ontologie-achtige structuur, bestaande uit concepten en relaties. De mate, waarin de concepten en hun relaties in de ontologie vertegenwoordigd zijn, kan dan eenvoudig worden getoetst met behulp van deze kaart. Wij concluderen dat GenCLOn een valide ontologie is en dat het de belangrijke generieke stakeholders, hun perspectieven en activiteiten, en de relaties tussen de verschillende concepten in het domein omvat.

Een ABM voor het stedelijk logistieke domein

Wij ontwikkelen vervolgens een ABM op basis van de domein specifieke ontologie GenCLOn, geabstraheerd tot agenten en hun relaties, zodat deze kan werken als een gemeenschappelijk platform voor communicatie en informatie-uitwisseling tussen agenten. *Hoofdstuk 6* beschrijft deze aanpak. De concepten en relaties in de ontologie leveren de basisstructuur van het ABM en waarborgen zo de structurele integriteit van het model. De validatie van het conceptuele model voor het agent gebaseerde model ligt immers al besloten in de gebruikte ontologie GenCLOn. Ook kan via speciale software voor het opbouwen van een ABM vanuit een ontologie de modelleringstijd verkort worden. Verder is in het ontwikkelde ABM (SMUrFS genaamd) gebruik gemaakt van de agentdefinities uit GenCLOn zoals klant-agent, winkel-agent, verlader-agent, vervoerder-agent en beleid-agent.

Validatie van ABM met behulp van een participatief simulatiespel en toepassing

Er is nog weinig onderzoek gedaan naar de definitie van specifieke methoden en technieken voor ABM validatie. Vaak worden statistische validatie technieken toegepast en gebruikt zoals bij discrete simulatiemodellen, zonder al te veel vragen te stellen over geschiktheid van deze technieken voor het valideren van een ABM. Echter, typische aspecten zoals pad-afhankelijkheid van uitkomsten, emergent gedrag in het model en de afwezigheid van micro-level data maken de validatie van ABM aanzienlijk moeilijker. Daarom heeft validatie van een ABM behoefte aan een alternatieve benadering, die meer geworteld is in zogenaamde procesvalidatie, naast statistische validatie. Agenten in een ABM zijn autonoom en onafhankelijke beslissers; de systeemuitkomst is het gevolg van interacties tussen de agenten. Daarom zijn wij van mening dat de basis voor ABM validatie ligt in de onderliggende beslismechanismen van individuele stakeholders, binnen de context van het systeem. Op basis van deze redenering beschrijft *Hoofdstuk 7* een participatief simulatiespel voor de validatie van een ABM. Met behulp van het voorgestelde validatieraamwerk wordt een proof-of-concept ontwikkeld voor een participatief simulatiespel, ten behoeve van het SMUrFs-model. Het spel richt zich op het valideren van de keuzes van de winkelier-agenten in het model, door deze te vergelijken met de keuzes van een mens, die de rol van winkelier-agent speelt in het spel. Het spel is gespeeld met de universitaire studenten en met deskundigen uit de industrie en de onderzoekswereld. Door de spelobservaties zien we een convergentie ontstaan van de overtuigingen tussen de spelers over bestelpunten en – hoeveelheden en overeenkomsten tussen de besluitvorming van winkelier-agenten en die van de echte spelers. De resultaten van het experiment geven aan dat een participatieve spelaanpak een veelbelovende stap is in het valideren agent gebaseerde modellen, en dat deze een basisstap vormt voor procesvalidatie van een ABM.

Het SMUrFS model is toegepast in *Hoofdstuk 8* in een beleidsscenario waarbij meerdere actoren interactief met elkaar reageren op gemeentelijk beleid, om emissies in de stad te reduceren. Het scenario toont het belang aan van het opnemen van het multi-actorperspectief en illustreert het nut van ABM in deze beleidscontext.

Tot slot

Een *agent based model* kan nuttig zijn voor de analyse van vele onbeantwoorde beleidsvragen over stedelijke logistiek, vanuit het perspectief van meerdere stakeholders. De ontwikkeling van een dergelijk model is een uitdagende taak. Dit proefschrift ontwikkelt een raamwerk voor een ontologie-gebaseerd ABM voor stedelijke logistiek. De stappen van het raamwerk worden beschreven, de aanpak wordt gevalideerd en middels een ‘proof-of-concept’ gedemonstreerd. Het proefschrift kan hiermee dienen als een gids voor de systematische ontwikkeling van een ABM voor het domein van de stedelijke logistiek.

સારાંશ

એક અંદાજ મુજબ વિશ્વની શહેરી વસ્તી અત્યારે ૪ અજબ છે જે ૨૦૩૦ સુધીમાં ૫ અબજ થઇ જશે. વધુ સુખ સગવડભર્યા જીવન, સારા રોજગાર તથા વિકાસને ધ્યાનમાં લઇ, વધુ ને વધુ લોકો ગ્રામ્ય વિસ્તાર થી શહેરી વિસ્તાર તરફ લોકો પ્રયાણ કરી રહ્યા છે. આજ કારણસર આજે વધુ ને વધુ નવા શહેરો તથા શહેરી વિસ્તારનું વિસ્તરણ થઇ રહ્યુ છે. આર્થિક, સામાજિક અને ઔધોગીક વિકાસને લીધે શહેરોમાં કોમર્શિયલ (વ્યાપારી) વાહનોનું પ્રમાણ પણ વધી રહ્યુ છે. યાતાયાતમાં યાત્રી વાહનોનાં પ્રમાણમાં ૧૦% થી ૨૦% વાહનો માલ-સામાન પરીવહનનાં વાહનો હોય છે, તેવો એક સર્વે છે. જો કે સંખ્યામાં ઓછા હોવા છતા તેમનુ કદ વિશાળ હોય છે, તેથી સામાન્ય કાર ના પ્રમાણમાં આ માલ-સામાન પરિવહન કરતા સાધનો વધારે ભીડ પેદા કરે છે (રોડ પર જગ્યા રોકે છે).

હવાના પ્રદુષણની વાત કરીએ તો, માલ-સામાન પરિવહન કરતા વાહનો દર કિલોમીટરે ૨૦% થી ૩૦% હોય છે, પરંતુ તેમના હવામાં પ્રદુષકોનું પ્રમાણ ૧૬% થી ૫૦% સુધીનુ હોય છે. તેમના કદ, વારંવારના ફેરાઓ, રોડની બાજુમા માલ ભરવા અથવા ઉતારવા માટે ઉભેલુ વાહન હોય કે રોડ પર જતા વાહન હોય, આ માલની હેરફેર કરનારા વાહનો રોડ સુરક્ષા અંગેની ઘણી અડચણો ઉભી કરે છે. જ્યારે કોઇ ટ્રક શાંત વિસ્તાર અથવા રાત્રીના સમયે રહેણાક વિસ્તારમાંથી પસાર થાય છે ત્યારે તેનો ઘોંઘાટ ત્રાસદાયક લાગે છે. શહેરીકરણની અપેક્ષીત વૃદ્ધીને લીધે, શહેરોમાં થતી માલની હેરફેરની વૃદ્ધીને લીધે ઉપર દર્શાવ્યા મુજબની ઘણી નકારાત્મક સમસ્યાઓનો સામનો કરવો પડે છે. જે આપણને હવે પછીનાં શહેરોની ડીઝાઇન પર વધુ

વિચારવા માટે ફરજ પાડે છે, જેથી કરીને શહેરીજનોને જરુરી સામાન મળી રહે અને વધુ સમસ્યાઓ પણ પેદા થાય નહી.

શહેરી વિસ્તારોમાં થતી માલ – સામાનની હેરફેરની પ્રવૃતીઓ ને લગતા ક્ષેત્રને સીટી લોજીસ્ટીક્સ (City Logistics) કહે છે. સીટી લોજીસ્ટીક્સની પ્રવૃતીઓ જેવી કે ભારે વાહન ની અવર જવર, રોડ વચ્ચે સામાનનો ચઢાવ-ઉતાર તથા તેને લીધે ટ્રાફિક, પ્રદૂષણ અને અકસ્માત જેવી સમસ્યાઓ ઉભી થાય છે. આ સમસ્યાઓને સમજવા માટે તથા તેની અસરો ને હળવી કે નાબૂદ કરવા માટે વિવિધ ગાણિતીક, આંકડાકીય પ્રકારની સંરચના (Model) વિક્સાવવામાં આવે છે. જેને સીટી લોજીસ્ટીક મોડેલ કહે છે.

શહેરોમાં માલની હેરફેરની પ્રવુત્તીઓને લીધે ઉભી થતી સમસ્યાઓ મુખ્યત્વે સંસ્થાકીય ભાગીદારો વચ્ચેની એકરુપતાના અભાવે જ ઉત્પન્ન થાય છે. જે કંપનીઓ એક જ પ્રકારની વસ્તુઓ અથવા સેવાઓનું વેચાણ કરતી હોય તેમની વચ્ચે સાહજીક સહયોગ અને સહકારની ભાવના મોટા ભાગે હોતી નથી. આ સમસ્યા અંગે વધુ ઉંડાણપુર્વક વિચારતા આપણને ખ્યાલ આવે છે કે, સીટી લોજીસ્ટીક્સ ક્ષેત્રમાં અલગ અલગ ભાગીદારો (કાર્યકર્તા) હોય છે અને આ ભાગીદારો શહેરી વિસ્તારનાં માલના હેરફેરની વિવિધ કામગીરી અલગ અલગ રીતે કરે છે. આમ વ્યક્તિગત રીતે ભાગીદારને માલનાં હેરફેરની દરેક પ્રવુત્તી અસરકારક લાગતી હોય છે, પરંતુ સમગ્ર પ્રક્રિયાને જોતા ખ્યાલ આવશે કે, આખી પ્રક્રિયામાં જગ્યાના અસરકારક ઉપયોગની બાબતે, ટ્રકની ક્ષમતાની બાબતે અને અન્ય સાધન સમ્પત્તીના ઉપયોગની બાબતે તે પ્રવુત્તી બિનઅસરકારક પુરવાર થાય છે. ઘણી વખત આ ક્ષેત્રમાં કાર્ય કરતા લોકોને એ બાબતનો ખ્યાલ હોતો નથી કે, પરસ્પર નો સહયોગ સામાજિક પર્યાવરણને લગતી સમસ્યાઓને દુર કરીને વ્યાપાર ઉદ્યોગ માટે લાભકારક પુરવાર થાય છે. આ પ્રકારની એકરૂપતાનો અભાવ આંશિક રીતે શહેરી વિસ્તારમાં કાર્ય કરતા ભાગીદારો વચ્ચે યોગ્ય માહિતીના અભાવને આભારી છે.

પરસ્પરાવલંબી સીટી લોજીસ્ટીક્સ ની પ્રવુત્તીઓ, મર્યાદીત માહિતી સાથે લેવાતા નિર્ણયો અને હિસ્સેદારોની પધ્ધતીસરની કાર્યક્ષમતા કરતા વ્યક્તિગત હેતુઓ માટેની પસંદગી સીટી લોજીસ્ટીક્સ ક્ષેત્રને ઉપશ્રેષ્ઠ (દ્રિતીય કક્ષાનું) બનાવે છે. સીટી લોજીસ્ટીક્સ પધ્ધતીને લઇને આ વિજાતીય ભાગીદારોનાં અલગ પરિપેક્ષ્યોને લીધે તેઓની કાર્યશૈલીમાં સમાનતા લાવવી એ એક પડકારજનક બાબત છે. તેથી સીટી લોજીસ્ટીક્સ હિસ્સેદારોનાં પરિપેક્ષ્યોનાં સર્વગ્રાહી દ્રષ્ટીકોણને ધ્યાનમાં લેવો તે સીટી લોજીસ્ટીક્સની સમસ્યાઓના વાસ્તવિક કારણો સમજવા તરફનું જરુરી પગલું છે. આ દ્રષ્ટીએ સીટી લોજીસ્ટીક્સ નું મોડેલ હિસ્સેદારોના બહુવિધ દ્રષ્ટીકોણો વચ્ચેની જટીલ આંતરક્રિયાઓ સમજવા માટે સમર્થ હોવું જ જોઇએ. કુદરતી અને પરિવર્તનક્ષમ પધ્ધતીસરના મોડેલ તૈયાર કરવા માટે એક એજન્ટ બેઝ મોડેલિંગ (ABM) તકનિક સીટી

લોજીસ્ટીક્સ ક્ષેત્રના મોડેલિંગ માટે એક આશાસ્પદ વિકલ્પ છે. સીટી લોજીસ્ટીક્સ ક્ષેત્રમાં ABM નો ઉપયોગ થઇ શકે તે માટે સીટી લોજીસ્ટીક્સ ક્ષેત્રનાં ABM ના વિકાસને લગતા સંબંધીત વિવિધ પાસાઓનો અભ્યાસ જરુરી છે. તદનુસાર, આ પી.એચ.ડી. સંશોધનનો તે હેતુ છે.

"એજન્ટ બેઝ મોડેલિંગ તકનિક નાં ઉપયોગ અંગે સંશોધન કરવુ અને સીટી લોજીસ્ટીક્સ ક્ષેત્રમાં આ તકનિક ના સફળ અમલીકરણ માટે એક માળખાનો વિકાસ કરવો".

કોઇપણ ક્ષેત્રમાં પધ્ધતીસરનાં વિશ્લેષણ માટે નમુનાઓ અગત્યના સાધનો છે. સીટી લોજીસ્ટીક્સ માટે વિવિધ માહિતી માટે સ્તરો સાથેના વિવિધ પ્રકારના નમુનાઓ તૈયાર કરવા માં આવે છે. સીટી લોજીસ્ટીક્સ ક્ષેત્રમાં મોડેલિંગની ભુમીકાની ઝાંખી મેળવવા માટે સીટી લોજીસ્ટીક્સ નમુનાની એક પધ્ધતીસર સમીક્ષા પ્રકરણ –૨ માં હાથ ધરવામાં આવી છે. આ સમીક્ષા પરિણામોનું વિશ્લેષણ દર્શાવે છે કે, વર્તમાન મોડેલ વિવિધ હિસ્સેદારો વચ્ચેની નિર્ણયશક્તિઓને કાં તો અસર કરતાં જ નથી અથવા બહુ જ નહિવત પ્રમાણમાં અસર કરે છે. શહેરી પરિવહન પધ્ધતીની પરિણામી બિન કાર્યક્ષમતાઓ એ ખરેખર મોટા ભાગે બહુવિધ ભાગીદારો વચ્ચે વહેચાયેલા (અલગ અલગ નિર્ણય) નિર્ણયોને આભારી છે. આમ છતાં મોટા ભાગનાં મોડેલ માં દર્શાવવામાં આવતા ઉકેલો એ વ્યક્તિગત હિસ્સેદારનાં પરિપેક્ષ્યનાં હોય છે. સીટી લોજીસ્ટીક્સ ક્ષેત્રમાં વિવિધ હિસ્સેદારો હોય છે અને તેઓ પોતાના વ્યક્તિગત હેતુઓની પુર્તી માટે એકબીજા નો સંપર્ક કરે છે. કોઇ એક હિસ્સેદાર ના બુદ્ધીકક્ષા પ્રમાણે વિકસાવેલા ઉકેલને મોટા ભાગનાં અન્ય હિસ્સેદારો દ્વારા અમલમાં નથી લવાતાં, તેથી આ પ્રકારનો ઉકેલ સીટી લોજીસ્ટીક્સ ક્ષેત્રની સમસ્યા હલ કરવા સમર્થ બનતો નથી.

આ સંદર્ભમાં સીટી લોજીસ્ટીક્સ ક્ષેત્રમાં કાર્ય કરતા વિવિધ વિજાતીય હિસ્સેદારોની ક્રિયા પ્રતિક્રિયા સમજવી એ આ ક્ષેત્રમાં બિનકાર્યક્ષમતા માટેના કારણો સમજવા માટેની એક અગત્યની બાબત છે. તદનુસાર સીટી લોજીસ્ટીક્સ ક્ષેત્ર અંગેના ઉકેલ દર્શાવતું જે મોડેલ બનાવવામાં આવ્યુ હોય તેમાં બહુવિધ હિસ્સેદારોની ક્રિયાપ્રતિક્રિયા ઉપરાંત તેઓ ના વિવિધ પરિપેક્ષ્યોનો પણ સમાવેશ થવો જ જોઇએ. વર્તમાન સીટી લોજીસ્ટીક્સનાં નમુનાઓ અને તેની મર્યાદાઓ વિશેની આ પૃષ્ટભુમી સાથે સંશોધન તક સીટી લોજીસ્ટીક્સની પધ્ધતી અંગેના ઉભરતા વર્તનને સમજવા માટે વિવિધ સ્વતંત્ર કર્તાઓની (દા.ત. કંપનીઓ, દુકાનો, પરિવહન સેવા પુરી પાડનાર, ટ્રક) ક્રિયા પ્રતિક્રિયાઓને ધ્યાનમા રાખે છે. વ્યાપક દ્રષ્ટી એ જોઇએ તો હિસ્સેદારો અને તેમની પ્રવુતીઓ વચ્ચેના આંતરીક સબંધો તેમના વ્યવ્સાયિક નિર્ણયોને કઇ રીતે અસરકર્તા છે તે અંગે સંશોધન થવુ જ જોઇએ. આ પ્રકારનુ વિશ્લેષણ ટેકનોલોજી પ્રવાહની, વ્યાપાર પ્રવાહની અને નિતિ પ્રવાહની વિવિધ અસરો નક્કી કરવા સક્ષમ છે.

આ પી.એચ.ડી. સંશોધન, સીટી લોજીસ્ટીક્સ ક્ષેત્ર અને ABM તકનિક ની લાક્ષણિકતાઓ વચ્ચેના પધ્ધતીસર સંબંધને વ્યાખ્યાયિત કરવા પર અને મોડેલિંગ ટેકનોલોજીનાં સફળ અમલીકરણ માટે તબક્કાવાર ડીઝાઇન બનાવવા પર ધ્યાન કેન્દ્રીત કરે છે.

આ પીએચડી સંશોધન દરમ્યાન વિક્સાવવામાં આવેલ માળખાના ચાર મુખ્ય તબ્બકાઓ છે.

૧) સિટી લોજિસ્ટિક ઓન્ટોલોજી (Ontology)

સિટી લોજિસ્ટિક ઓન્ટોલોજી એ એક વિશેષ પ્રકારનુ ડેટાબેજ છે. જેમા સિટી લોજિસ્ટિક ક્ષેત્રને લગતા વિવિધ મુદ્દાઓ (જેવા કે હિસ્સેદાર, પ્રવૃતિઓ, સાધનો, હેતુઓ વગેરે) ને આવરી લેવામાં આવ્યા છે. માત્ર આ અગત્યના મુદ્દાઓ જ નહીં પરંતુ તેમને જોડતા સંબંધો (જેવા કે દુકાનદાર અને ગ્રાહક વચ્ચે વ્યાપાર નો સંબંધ) નો પણ સમાવેશ કરવામાં આવેલ છે. આ ઓન્ટોલોજી સિટી લોજિસ્ટિક ક્ષેત્ર ના ABM માટે જરૂરી આધાર પુરો પાડે છે.

૨) સિટી લોજિસ્ટિક ઓન્ટોલોજી ચકાસણી

સિટી લોજિસ્ટિક ઓન્ટોલોજીમાં સમાવવામા આવેલ મુદ્દાઓ તેમજ તેમની વચ્ચેના સંબંધ પ્રમાણભૂત છે કે નહીં તે ચકાસવું ખુબ જ જરૂરી છે. આ ચકાસણી કરવા માટે અમેરિકામાં ૧૨ હિસ્સેદારો સાથેની મુલાકાત અને ૩૦ જેટલા સિટી લોજિસ્ટિક મોડલનો અભ્યાસ કરવામાં આવ્યો. આ અભ્યાસથી એકત્ર કરેલ માહિતીની ઓન્ટોલોજીમાં સામેલ માહિતી સાથે સરખામણી કરવામાં આવી. આ સરખામણી થી એમ સાબિત થયું કે, સિટી લોજિસ્ટિક ઓન્ટોલોજીમાં સમાવેલ માહિતી સિટી લોજિસ્ટિક ક્ષેત્રનો સચોટ ખ્યાલ આપે છે.

૩) સિટી લોજિસ્ટિક ક્ષેત્ર માટે ABM ની રચના

સંશોધનના ત્રીજા તબ્બાકામાં સિટી લોજિસ્ટિક ઓન્ટોલોજીમાં સમાવેલ માહિતીનો ઉપયોગ કરી સિટી લોજિસ્ટિક ક્ષેત્ર માટે ABM વિકસાવવામાં આવ્યું. આ મોડેલમા વિવિધ હિસ્સેદારો અને તેમના દ્વારા માલ-સામાનની હેરફેર માટે કરવામાં આવતી ક્રિયા અને પ્રતિક્રિયાઓને સાંકળવામાં આવી. આ મોડેલની મદદથી સિટી લોજિસ્ટિક ક્ષેત્રને લગતી સમસ્યાઓને હળવી કરવા તથા આ ક્ષેત્રને કાર્યક્ષમ બનાવવા માટે વિવિધ પ્રકારના કાયદા અને નીતિઓ નું વિશ્લેષણ કરી શકાય. તેથી આ કાયદાઓ અને નીતિઓ ને અમલમાં મુક્તા પહેલા તેની અસરો વિશે અભ્યાસ કરી શકાય.

૪) ABM ના પ્રમાણ માટેની રીત

સંશોધન ના છેલ્લા તબ્બકામાં ABMનુ પ્રમાણ મેળવવા માટેની રીત વિક્સાવવામાં આવી છે. ABM માં દર્શાવેલ હિસ્સેદારો સ્વાયત્ત અને સ્વતંત્ર રીતે નિર્ણયો લે છે. તેમ જોતા, મોડેલનુ અંતિમ પરિણામ તમામ હિસ્સેદારના નિર્ણય પર આધારીત છે, પરંતુ અલગ અલગ નિર્ણયો નો સરવાળો પણ સમાન પરિણામ લાવી શકે છે તેમ જોતા માત્ર મોડેલ નું પરિણામ ચકાસવાથી મોડેલ સાચું છે કે ખોટું તે જાણવું અઘરું છે.

આ દ્રષ્ટિએ જો આપણે એમ સાબીત કરી શકીએ કે, મોડેલમાં લેવામાં આવતા નિર્ણયો અને ક્રિયા પ્રતિક્રિયાઓ સાચી રીતે મોડેલમાં દર્શાવવામાં આવ્યા છે, તો મોડેલનું અંતિમ પરીણામ સાચુ છે એમ કહી શકાય. મોડેલમાં દર્શાવેલ ક્રિયા પ્રતિક્રિયા અને નિર્ણયો ચકાસવા એક કમ્પ્યુટર ગેમ વિક્સાવવામાં આવી. આ ગેમ 'participatory simulation game' કહેવાય છે. સિટી લોજિસ્ટિક ક્ષેત્ર ના હિસ્સેદાર આ ગેમમાં ભાગ લે છે અને તેના દ્વારા તેમણે લીધેલ નિર્ણયો, ક્રિયા પ્રતિક્રિયા ની જાણકારી મળે છે. આ માહિતીને મોડેલ ના નિર્ણયો અને ક્રિયા પ્રતિક્રિયા સાથે સરખાવી મોડેલ ની ચકાસણી કરી શકાય છે.

TRAIL Thesis Series

The following list contains the most recent dissertations in the TRAIL Thesis Series. For a complete overview of more than 100 titles see the TRAIL website: www.rsTRAIL.nl.

The TRAIL Thesis Series is a series of the Netherlands TRAIL Research School on transport, infrastructure and logistics.

Anand, N., *An Agent Based Modelling Approach for Multi-Stakeholder Analysis of City Logistics Solutions*, T2015/12, September 2015, TRAIL Thesis Series, the Netherlands

Hurk, E. van der, *Passengers, Information, and Disruptions*, T2015/11, June 2015, TRAIL Thesis Series, the Netherlands

Davydenko, I., *Logistics Chains in Freight Transport Modelling*, T2015/10, May 2015, TRAIL Thesis Series, the Netherlands

Schakel, W., *Development, Simulation and Evaluation of In-car Advice on Headway, Speed and Lane*, T2015/9, May 2015, TRAIL Thesis Series, the Netherlands

Dorsser, J.C.M. van, *Very Long Term Development of the Dutch Inland Waterway Transport System: Policy analysis, transport projections, shipping scenarios, and a new perspective on economic growth and future discounting*, T2015/8, May 2015, TRAIL Thesis Series, the Netherlands

Hajiahmadi, M., *Optimal and Robust Switching Control Strategies: Theory, and applications in traffic management*, T2015/7, April 2015, TRAIL Thesis Series, the Netherlands

Wang, Y., *On-line Distributed Prediction and Control for a Large-scale Traffic Network*, T2015/6, March 2015, TRAIL Thesis Series, the Netherlands

Vreeswijk, J.D., *The Dynamics of User Perception, Decision Making and Route Choice,* T2015/5, February 2015, TRAIL Thesis Series, the Netherlands

Lu, R., *The Effects of Information and Communication Technologies on Accessibility,* T2015/4, February 2015, TRAIL Thesis Series, the Netherlands

Ramos, G. de, *Dynamic Route Choice Modelling of the Effects of Travel Information using RP Data,* T2015/3, February 2015, TRAIL Thesis Series, the Netherlands

Sierzchula, W.S., *Development and Early Adoption of Electric Vehicles: Understanding the tempest,* T2015/2, January 2015, TRAIL Thesis Series, the Netherlands

Vianen, T. van, *Simulation-integrated Design of Dry Bulk Terminals,* T2015/1, January 2015,

TRAIL Thesis Series, the Netherlands

Risto, M., *Cooperative In-Vehicle Advice: A study into drivers' ability and willingness to follow tactical driver advice,* T2014/10, December 2014, TRAIL Thesis Series, the Netherlands

Djukic, T., *Dynamic OD Demand Estimation and Prediction for Dynamic Traffic Management,* T2014/9, November 2014, TRAIL Thesis Series, the Netherlands

Chen, C., *Task Complexity and Time Pressure: Impacts on activity-travel choices*, T2014/8,

November 2014, TRAIL Thesis Series, the Netherlands

Wang, Y., *Optimal Trajectory Planning and Train Scheduling for Railway Systems,* T2014/7, November 2014, TRAIL Thesis Series, the Netherlands

Wang, M., *Generic Model Predictive Control Framework for Advanced Driver Assistance Systems*, T2014/6, October 2014, TRAIL Thesis Series, the Netherlands

Kecman, P., *Models for Predictive Railway Traffic Management*, T2014/5, October 2014, TRAIL Thesis Series, the Netherlands

Davarynejad, M., *Deploying Evolutionary Metaheuristics for Global Optimization,* T2014/4, June 2014, TRAIL Thesis Series, the Netherlands

Li, J., *Characteristics of Chinese Driver Behavior*, T2014/3, June 2014, TRAIL Thesis Series, the Netherlands

Mouter, N., *Cost-Benefit Analysis in Practice: A study of the way Cost-Benefit Analysis is perceived by key actors in the Dutch appraisal practice for spatial-infrastructure projects*, T2014/2, June 2014, TRAIL Thesis Series, the Netherlands

Ohazulike, A., *Road Pricing mechanism: A game theoretic and multi-level approach,* T2014/1, January 2014, TRAIL Thesis Series, the Netherlands

Cranenburgh, S. van, *Vacation Travel Behaviour in a Very Different Future,* T2013/12, November 2013, TRAIL Thesis Series, the Netherlands

Samsura, D.A.A., *Games and the City: Applying game-theoretical approaches to land and property development analysis,* T2013/11, November 2013, TRAIL Thesis Series, the Netherlands

Huijts, N., *Sustainable Energy Technology Acceptance: A psychological perspective,* T2013/10, September 2013, TRAIL Thesis Series, the Netherlands

Zhang, Mo, *A Freight Transport Model for Integrated Network, Service, and Policy Design*, T2013/9, August 2013, TRAIL Thesis Series, the Netherlands

Wijnen, R., *Decision Support for Collaborative Airport Planning*, T2013/8, April 2013, TRAIL Thesis Series, the Netherlands

Wageningen-Kessels, F.L.M. van, *Multi-Class Continuum Traffic Flow Models: Analysis and simulation methods*, T2013/7, March 2013, TRAIL Thesis Series, the Netherlands

Taneja, P., *The Flexible Port*, T2013/6, March 2013, TRAIL Thesis Series, the Netherlands