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Framework for modelling multi-stakeholder city logistics domain using the agent based modelling approach

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Abstract

Efficiency of city logistics activities suffers due to conflicting personal preferences and distributed decision making by multiple city logistics stakeholders. This is exacerbated by interdependency of city logistics activities, decision making with limited information and stakeholders' preference for personal objectives over system efficiency. Accordingly, the key to understanding the causes of inefficiency in the city logistics domain is understanding the interaction between heterogeneous stakeholders of the system. 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. This research focuses on developing a framework for the successful implementation of the ABM approach for the city logistics domain. 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. Conclusively, the framework shows that a rigorous course can be taken to successfully implement agent based modelling approach for the city logistics domain.

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Keywords: City logistics; agent based modelling; multi-stakeholder; ontology; validation; particiaptory simulation game

1. Introduction and motivation

Heterogeneity of the stakeholders is a distinctive characteristic of the city logistics (CL) domain. Apart from sharing the goal of timely delivering of goods for consumption, these stakeholders have personal – often conflicting - objectives. For instance, a carrier wants to deliver goods on a certain day and/or time so that he can minimize the total

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travel-distance and use of personnel for the job. However, a receiver has preference for receiving goods on other day and-or time due to business hours or availability of staff. Similarly, the municipality introduces a rule for goods delivery during only specific hours to reduce congestion and pollution in the city. 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. The efficiency of city logistics activities suffers due to conflicting personal preferences and distributed decision making by multiple city logistics stakeholders. This is exacerbated by interdependency of city logistics activities, decision making with limited information and stakeholders' preference for personal objectives over system efficiency. Accordingly, the key to understanding the causes of inefficiency in the city logistics domain is understanding the interaction between heterogeneous stakeholders of the system. 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 inefficiency and problems related to urban freight activities.

Research in the city logistics domain aim to increase the efficiency of the city logistics system and to reduce negative externalities caused by goods movements in city areas. City logistics models work as forecasting and analysis tools to help gain insight into current (and future) city logistics transportation, commodity flow, infrastructure use, and information exchanges. Knowledge generated from such insights is useful to understand and predict city logistics trends and problems in an attempt to invent policy measures and initiatives that can create an efficient and sustainable city logistics domain. 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. This 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 the ABM approach for the city logistics domain.

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2. Need for the agent-based modelling approach

The field of city logistics research has advanced considerably in the last two decades (Lindholm & Behrends, 2012; Taniguchi & Thompson, 2014). Interest about problems and opportunities associated with the city logistics domain has spread not only to researchers but also industry and administrative authorities. Countries in Europe, USA and Japan have shown strong interest in this field; however, countries from other parts of the world are also started realizing need for action for solving goods transportation problems in city areas (Turblog, 2011).

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 (Nilesh Anand, van Duin, Quak, & Tavasszy, 2015) . 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 (Hensher & Puckett, 2005; Holguin-Veras, Thorson, & Ozbay, 2004) capture the interactions between stakeholders, albeit between limited types of stakeholders. Furthermore, current modelling efforts include stakeholders in a static way. On the contrary, city logistics is a distributed decision making system where the system emerges due to dynamic interactions between different entities. Therefore, interactive stakeholder responses in decision making are important to incorporate in the model to understand the emerging macro pattern. This is very important gap to fill while modelling the city logistics domain.

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 there is a need for a clear description of the type of entities and events involved in the city logistics domain. Such description should 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 need for research 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, a city logistics system should be modelled from different stakeholders' perspective (Nilesh Anand, Van Duin, & Tavasszy, 2010). Such model allows exploring various interrelations between stakeholders and their activities by representing business decision processes. Such analysis is capable of assessing the effects of a variety of technology trends, business trends, and policy scenarios. Conventional models with static description of the domain are not capable of modelling the city logistics domain to capture such dynamics of distributed decision making.

An agent based modelling (ABM) approach is suitable for modelling the city logistics domain as it can include the distributed decision making of heterogeneous city logistics stakeholders. This approach enables modelling the actors (i.e. roles) of the logistics chain as individual autonomous agents to capture the emerging system and analyse the effect of their decision making on the system.

3. Framework for the multi-stakeholder agent based modelling approach

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 them. Thus, the first step in order to model the city logistics domain using multi-stakeholder perspective is to build a 'conceptual map' that represents the city logistics domain by depicting the concepts and relationships of city logistics entities 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 1 shows the outline of multi-stakeholder agent based modelling approach.

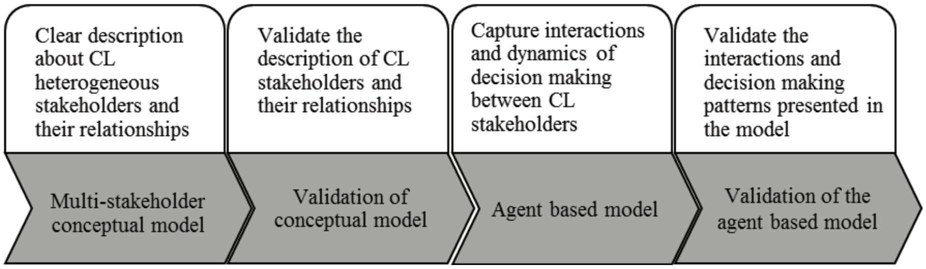

Fig. 1. Outline of the multi-stakeholder agent based modelling approach (Nilesh Anand, 2015)

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 is 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 proposed agent based modelling approach for multi-stakeholder analysis of city logistics solutions is described in detail.

3.1. Multi-stakeholder ontology – a conceptual model for the city logistics domain

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 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 modellers on the conceptual map of the real world. For instance, Roorda, Cavalcante, McCabe, and Kwan (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.

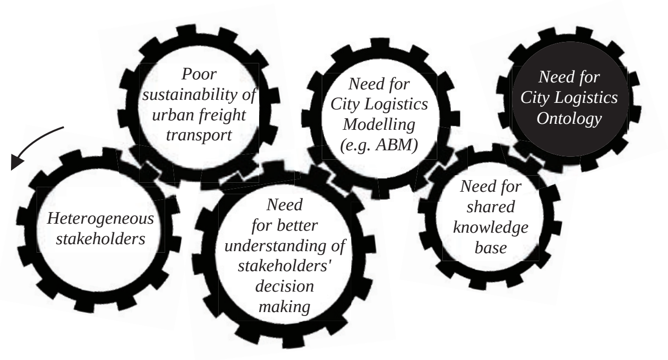

Fig. 2. Need of a semantic database (i.e. ontology) for the city logistics domain (Nilesh Anand, Yang, van Duin, & Tavasszy, 2012)

An intuitive problem forming mechanism for the need of an ontology is given in Figure 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 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 characterize 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 & van Dam, 2010). All of these merits should greatly decrease development time while improving the robustness and reliability of the resulting knowledge bases.

Since, the goal is to study distributed decision making and interaction of the stakeholders, the ontology should include perspective of different city logistics stakeholders. Consequently, the step towards building a multi-stakeholder ontology is identifying heterogeneous stakeholders and their respective objectives. Table 1 shows different stakeholders in the city logistics domain and their objectives.

Table 1. Objectives of city logistics stakeholders [Adapted from (Macário, Galelo, & Martins, 2008)]

Stakeholder	Objective
Administrator	Accessibility, Economic competitiveness of the city, Governance and legislation, Negative environmental impact
Suppliers	Market growth Profitability
Carriers	Congestion Cost effectiveness, minimum use of resources
Receivers	Competitiveness, profitability, On-time delivery
Residents, Visitors	Accessibility, Liveability, Goods availability

Keeping the stakeholders in the centre, the ontology can be developed to include other associated concepts such as activities, resources, objective, KPI and so on. The resulting ontology structure represents city logistics domain from heterogeneous stakeholders' perspective.

3.2. 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 big (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.

3.3. Agent based model

The domain of city logistics has been modelled using different approaches including operations research techniques, differential equation modelling and system dynamics. Simulation is one of the most widely used approaches 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. 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. ABM enables to capture these interactions between independent actors. 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.

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 (Davidsson, Henesey, Ramstedt, Törnquist, & Wernstedt, 2005; Eppstein, Grover, Marshall, & Rizzo, 2011; Holmgren, Davidsson, Persson, & Ramstedt, 2012; Taniguchi & Tamagawa, 2005; van Duin, van Kolck, Anand, Tavasszy, & Taniguchi, 2012). 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. The information contained in the ontology can be used mainly in two ways for modelling the city logistics domain. The ontology can be used as a knowledge document where the knowledge about the stakeholders and their objectives, resources, activities can be gained by browsing the ontology. This knowledge is used to develop city logistics model without directly using ontology parts. Alternatively, the more effective way is to use city logistics ontology as building blocks for the ABM. In the latter case, the concepts and relationships of the ontology are extracted to use in the model or the ontology is coupled with the simulation (Nilesh Anand et al., 2012).

3.4. Participatory simulation game for validation of ABM

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. Next, an ABM 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).

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 & 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.

4. Proof of concept for multi-stakeholder agent based modelling approach for the city logistics domain

To successfully use the potentials of agent based modelling approach for modelling the city logistics domain, this research paper proposes the following framework. Figure 3 shows the proposed framework depicting different stages.

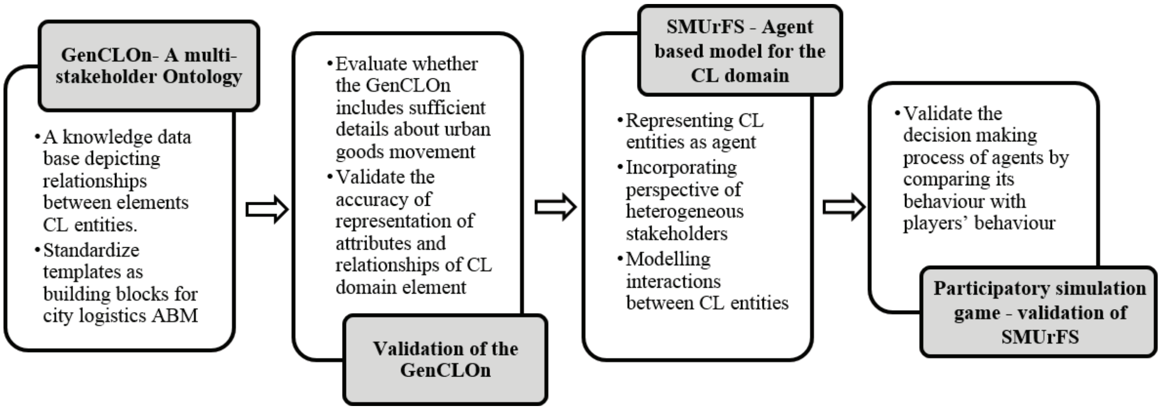

Fig. 3. Multi-stakeholder agent based modelling approach for the city logistics domain

Each stage of the framework is explored practically by developing a proof of concept for the city logistics domain. The following text gives overview of the proof of concept developed for each stage of the framework.

4.1. GenCLOn – a city logistics ontology

Driven by motivation of developing a semantic database, a formal ontology for the city logistics domain – GenCLOn (Generic City Logistics Ontology) - is developed by Nilesh Anand et al. (2012) - the second component of the framework. GenCLOn comprehensively specifies the city logistics domain in terms of the concepts involved along with their relations. Figure 4 shows schematics of the GenCLOn.

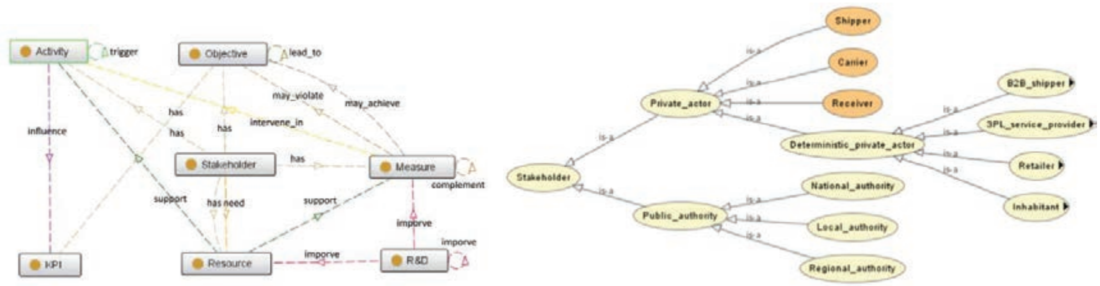

Fig. 4. (a) Top-level hierarchy of GenCLOn (b) Hierarchical structure of class 'Stakeholder' (Nilesh Anand et al., 2012)

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'. Figure XYZ shows the top-level hierarchy of the city logistics ontology.

4.2. Validation of GenCLOn

Ontology metrics are prepared to evaluate the scope of city logistics ontology [Refer (N Anand, van Duin, Tavasszy, & Wigan, 2014) for details]. 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, GenCLOn was validated against Data collected from interviews with 12 real-world stakeholders as well as more than 30 city logistics models and various other scientific sources. 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: 1) System component validation - tests whether all-domain people understand and utilize the concepts in the same manner and 2) Knowledge representation validation - checks the structural integrity of the ontology and ensures that entity-relationships are correctly constructed. 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.

4.3. SMUrFS – An agent based model for the city logistics domain

Using ontology components as building blocks a proof of concept agent based model SMUrFS for the city logistics domain is developed by Nilesh Anand, van Duin, and Tavasszy (2014). Situated Multi-agent Urban Freight System – SMUrFS – takes the city logistics ontology as a starting point by using concepts and relationships presented in the ontology.

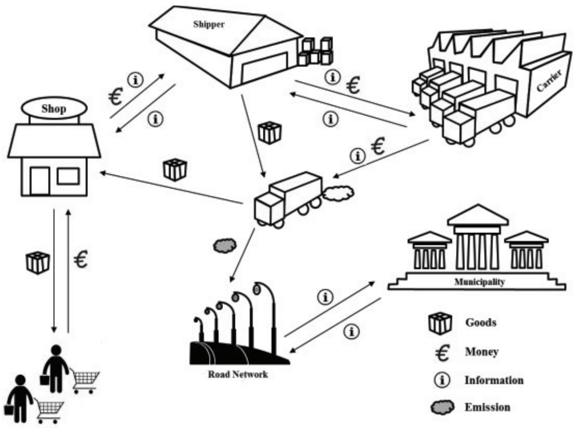

Fig. 5. Agents and interactions in SMUrFS (Nilesh Anand et al., 2014)

In the SMUrFS model, agents such as customer-agent, shop-agent, shipper-agent, carrier-agent and administrator-agent are created using city logistics ontology GenCLOn. Figure 5 shows the agents and their interaction in SMUrFS. 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. Based on the information obtained from the ontology the model incorporates interactions between city logistics stakeholders. With different types of autonomous agents incorporated in the model, the SMUrFS is a multi-perspective ABM for the city logistics domain.

4.4. Participatory simulation game for SMUrFS

A participatory simulation gaming framework for the validation of an agent based model is proposed. Figure 6 shows the framework for the validation of an ABM using a participatory simulation game. 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.

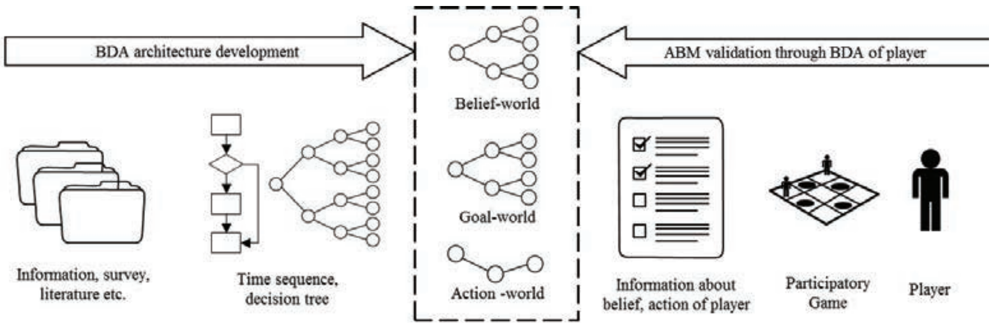

Fig. 6. Framework for the validation of an ABM using a participatory simulation game (Nilesh Anand, 2015)

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. 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.

5. Concluding remarks

Autonomy of multiple stakeholders creates distributed decision making in the city logistics domain. The stakeholders act to achieve their objectives. However, the decision making processes between the stakeholders change as per the situation. The resulting system, therefore, emerges from the interactive decision making by the stakeholders. Hence, a city logistics modelling platform must be able to capture such dynamic domain. Agent based modelling approach allows to represent the city logistics domain in its natural form by modelling city logistics entities as autonomous agents. However, for systematic implementation of the ABM approach for city logistics domain, we must explore the methodological relations between characteristics of the city logistics domain and ABM, and design the stages that facilitate ABM development. Working on this need, this research describes a comprehensive framework for multi-stakeholder analysis of city logistics solutions using ABM approach. The framework encompasses different stages where each stage describes an important step for the systematic implementation of the ABM. 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.

The framework developed in this research starts with a need for semantic conceptual map (i.e. Ontology) of the domain. 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 are connected with each other. A domain ontology abstract the domain in the form of concepts and relationships. It is a structured semantic database which provides necessary building blocks for developing an ABM. GenCLOn – a city logistics ontology – is developed to abstract the city logistics domain in a structured way. 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 semantic database requires evaluation and thus, in the next stage, the ontology must be validated. Accordingly, GenCLOn is validated against information collected from city logistics stakeholders' interviews.

The third step of the framework is developing an ABM from the validated ontology. An ABM developed from the validated ontology gives structural integrity of the agents and their relations. Furthermore, an ABM developed from the multi-stakeholders ontology allows incorporating perspectives of heterogeneous stakeholders. 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. Thus, the distributed decision making of the city logistics domain can be very well captured in such ABM. A proof of concept model SMUrFS – an ABM for the city logistics domain – is developed based on the GenCLOn. The model depicts a generic situation of the city logistics domain and can be used as a tool for preliminary analysis of different scenarios. It integrates multiple stakeholders and can be used to analyse city logistics solutions satisfying domain stakeholders. 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. By comparing the agents' decision making mechanisms with that of players playing a role of that stakeholder, an ABM can be validated for the decision making process presented in the model. The proof of concept game developed for the SMUrFS model validates the shop-agent's decision making process.

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 based modelling approach for the city logistics domain.

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