9th International Conference on Ambient Systems, Networks and Technologies, ANT-2018 and the 8th International Conference on Sustainable Energy Information Technology, SEIT 2018, 8-11 May, 2018, Porto, Portugal

An empirical agent-based simulation system for urban goods transport (MASS-GT)

Michiel de Bok[a,b,*], Lóri Tavasszy[a]

aDelft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands
bSignificance, Grote Marktstraat 47, 2511 BH The Hague, The Netherlands

Abstract

Urban planners face a few challenges in making urban freight transport more sustainable: reduce urban congestion, provide reliable delivery windows, decrease logistic costs, reduce emissions, improve safety. New data may provide a key in tackling these issues. This paper presents an agent-based urban freight modeling framework: MASS-GT. Objective of the project is to develop a comprehensive simulation framework that describes logistic decision making in the context of urban transport planning. Empirical basis is provided by a large dataset with observed freight transport data for The Netherlands. Part of the data has been collected using an automated procedure to report complete freight trip patterns from the transport management system. This provides more dense and complete data compared to conventional internet surveys. The paper describes the design principles for agents, markets and logistic decisions. Furthermore we elaborate on the incremental development path of building a comprehensive agent-based simulation system. We describe the first baseline prototype of the agent based modeling framework that simulates all urban freight transport patterns for an urban area, in the case the agglomeration of Rotterdam. This baseline model applies a data driven simulation approach; future work will consists of further improving this framework with the implementation of discrete choice models for logistic decisions.

Keywords: Agent based simulation; urban freight; big freight transport data; agile model development; The Netherlands

1. Introduction

Simulation models are sometimes used as tools for strategic evaluation of freight transport policies, but most operational models do not have sufficient behavioral detail to simulate the impacts of developments in logistic services, policy measures, or planning scenarios in a representative and satisfying manner. However, simulation models are becoming increasingly disaggregate: microsimulation or a combination of aggregate and disaggregate models are finding its way in a growing number of logistic or freight transport models[1,2,3,4,5,6]. The dimensions and simulated choices that are simulated vary between these examples: usually it is the outcome of data availability or the scope of the model. Approaches can be trip based[7] or commodity based where shipments are simulated explicitly[8,4,5,6,9]. Shipments are a fundamental dimension in an agent based model, because

* Corresponding author. Tel.: +31-6-47226815
  E-mail address: m.a.debok@TUDelft.nl

many transport and distribution related decisions take place at the level of shipments. Simulations also vary in agent representation. Agent behavior is sometimes lacking or often simplified: shippers and carriers are sometimes distinguished explicitly[10], but the characteristics of shippers are often neglected. An important element is the distinction between shippers that organize their transport themselves (own account carriers) and shippers that outsource their transport to external carriers, third part logistic service providers (3PL's). This outsourcing decision is simulated in some more advanced agent based models[11,12] 3PL's have much more consolidation possibilities of shipments between different sender/receiver combinations, which affects greatly the transport- and distribution related choices downstream a logistic chain.

In a recent review of empirical studies on logistic decisions in freight transportation modeling efforts from the perspective of supply chain management (SCM), we distinguished a framework of logistic decisions across six strongly interdependent functional areas: sales, production planning, sourcing, distribution structures, warehousing and transportation[13]. From the review two important aspects came out that are relevant for building descriptive models of logistic decisions in freight transport demand. First of all, decisions take place in different functional areas with different agents and choice behavior. Secondly strong interdependencies exist between choices that are up- or downstream of the supply chain. Integration of these choices in a simulation framework is crucial in describing logistic choices in SCM. Agent based models seem to be the way forward for improving logistic choice behavior: it allows the simulation of agent specific behavior, taking into account the variation of decision makers.

It is challenging to develop empirical agent based models because of the data requirements. Most agent based models described in literature are developed with rich conceptual models, such as TAPAS[1], INTERLOG[5], FAME[9] or FREMIS[6], but finding sufficient empirical data behind the models remains challenging, in particular behavioral freight transport data.

Our aim is to contribute to the development of empirical agent based logistic simulation models for urban freight transport by using a large dataset with observed freight transport data for The Netherlands. We build the design of our simulation model around three main principles: a commodity based approach, representing agent based decision making explicitly, and by implementing empirically tested choice model. As agents we distinguish different types of agents in the simulation framework: producing firms, consuming firms, shippers, own account carriers and third-party logistics (carriers). Also, our objective is to simulate representative urban freight transport patterns and the underlying logistic decision making, using big data on freight transport as an empirical basis.

This paper describes the design principles for agents, markets and logistic decisions. Furthermore we elaborate the development path of building a comprehensive framework, in which we apply an incremental development path. We describe the first baseline prototype of the agent based modeling framework that simulates all urban freight transport patterns for an urban area, in the case the agglomeration of Rotterdam.

2. Agent based model for urban goods transport

2.1. Conceptual model

The aim of the MASS-GT research project is to develop an agent based simulation model for urban goods distribution. The scope of this model covers parts of the Transportation and Distribution system, as described in [13]. We apply a commodity based approach and distinguish different types of agent and their behavior, and different types of markets. Most advanced agent based models for freight transport distinguish different markets explicitly: [12] distinguishes commodity and freight market, [11] distinguishes the commodity, transport services, traffic services, and infrastructure markets.

In the MASS-GT framework we distinguish four markets. The commodity market is where interaction takes place between the producers (senders) and consumers of goods (receivers): the *sourcing* process. Figure 1 illustrates the markets, agents and logistic choices that take place at these markets.

At the logistic services market, the organization of *distribution structures* and *warehousing* takes place. This market is typically served by specialized third party logistics but may as well be served by own account carriers (typically large companies). Logistic decisions that take place at this market are network design, the location and selection of DC's, warehousing and storage, and packaging/shipment size.

At the transport market the *transportation* of goods is organized. This market is both served by specialized third party logistics as well as own account carriers. Logistic decisions that take place at this market include carrier selection, mode selection (road, rail, inland waterway, maritime, air), vehicle type choice and routing and scheduling choices.

We can also identify the infrastructure market: to a great extent this defines, or shapes, the supply side of the transportation market. Infrastructure networks and traffic flows determine the transport times and route choices for vehicles. It also determines other transport cost related factors such as reliability, or parking facilities at loading/unloading locations. The development and management of the infrastructure market is not so much the domain of the agents that are responsible for the freight transport demand or execution of goods transport, but lies in the public domain. Therefore we define policy makers as the last category of agents. Their decision making set the conditions for freight transport: pricing measures, infrastructure investments, environmental zones, subsidies, zoning schemes. Their behavior is not simulated explicitly in the framework but is contained in the urban freight input scenario. A simulation model for urban freight transport is typically designed to test the impact of public

planning measures, or other developments, on the freight transport demand and infrastructure performance (accessibility, reliability).
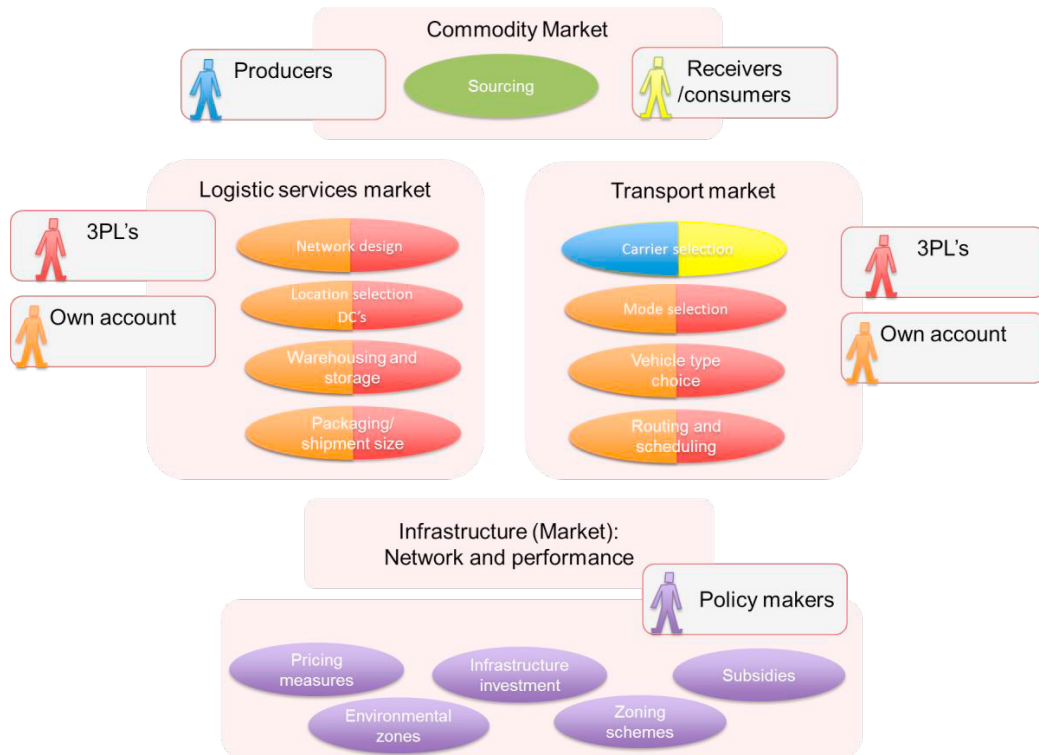

Figure 1: Agents, markets and logistic choices in the conceptual model for MASS-GT.

There are different types of 'agents' that are active in one or more of the freight transport markets: producers, receivers/consumers, shippers, carriers, own account carriers, third party logistics (3PL's). When we look closer, in many cases 'agents' are often one and the same person, so maybe it is better to speak of 'agent roles'. An agent is a firm, and this agent may fulfil one or more different roles. Advanced agent based simulation models usually distinguish between shippers and carriers. But typical to freight transport is that the shippers can be the producers of the goods, but instead the shipper may just as well be the consumer of the goods. The same bipolarity applies to carriers: the transport may take place by own account or by a 3PL's carriers. It is important to distinguish these different types of roles, and translate them correctly to agent behavior. The challenge in developing an agent based urban freight model lies in the correct representation of the different roles in the logistic choice models. We will operationalize this in the MASS-GT framework by simulating agent specific behavior, including the roles the agent has (sender/receiver and/or shipper/carrier).

2.2. Development strategy

The development of an agent-based simulation model for urban goods transport is complex due to the choices simulated, their interaction, and the heterogeneity in agent behavior. The presented project is data-driven and has a focus on empirical choice modeling and microsimulation. To manage complexity, development takes place following an incremental development path, starting with a baseline model with as little choice modeling as possible. We use Python as development platform. As a first step we developed a quick prototype based on the data that is available. This prototype contains the agents (producing and consuming firms), synthetic shipments, and a baseline tour formation procedure. In increments to follow we will extend this framework with choice behavior for the respective agents. The first prototype is a simple version, that simulates the transport market, and the simulation is completely based on observed distribution functions from the observed microdata.

3. Data

One of the main principles in our project is to contribute to the development of empirical agent based urban freight models. For this purpose we have access to the microdata in an extensive road transport database with transported shipments, that is being collected by the Central Bureau of Statistics Netherlands (CBS). This database offers a rich source for the formalization and

calibration of logistic simulation models of logistic choice behavior. The database contains over 30 thousand surveys with a very high data density. First of all, the survey is mandatory: transport companies are obliged to report the vehicle use of each truck that was randomly drawn by the CBS from the population of all registered license plates of trucks. As a result a database with over 30 thousand surveys is collected. On top of that large part of the data collection takes place using an innovative and efficient data collection method: transport companies can use an XML-interface to deliver their inputs automatically from their transport management system. As a result a database with 30 thousand surveys is constructed with an extremely high data density. The data that is collected through this XML-interface contains trip patterns at coordinate level. In addition to the transport database we use data on the firm population from the CBS. The table below gives an overview of all the data sources that we are using to develop the modeling system.

Table 1: Sources of data for baseline prototype of MASS-GT

Data	Statistic	Source:
Shipments	Shipment size: descriptive statistics	Commodity flow database: 'Basisbestand goederenvervoer' (CBS)
Tours	Observed vehicle type use, Observed tourcomposition (1,2,3,4+ stops)	Commodity flow database: 'Basisbestand goederenvervoer' (CBS)
Trip patterns	Detailed statistics on departure time, stop time, stoplocation	XML-data collection in commodity flow database (CBS)
Firm population	Location, size and sector of firms	Algemeen Bedrijven Register (ABR) (CBS)
Commodity Matrix	Flow of goods between region/zones	Aggregation of commodity flow database or Commodity forecast from strategic freight model Basgoed

4. Prototype

4.1. Introduction

The agent based simulation system is based on three main assumptions: commodity based, agent based and data-driven. As a first step in the development path of a complex agent-based simulation model we develop a simple quick prototype using the available data to simulate representative truck patterns for an average working day for an urban agglomeration in The Netherlands, applying the commodity- and agent based framework. Main idea is that we use observed commodity- tour and trip statistics and Monte Carlo simulation (MCS) to determine shipment- and tour characteristics.

The prototype simulates all urban freight transport taken place to/from and within the city of Rotterdam, for ten commodity types (NSTR chapters). The prototype has a modular structure: it comprises of a **Shipment synthesizer**, and a **Tourformation** model. The first step of the prototype is the simulation of the formation of (synthetic) shipments. The second step is the routing and scheduling of deliveries (tourformation). The output, freight tour patterns, can be assigned to the urban network to derive network performance indicators.

4.2. Shipment synthesizer

Objective of the shipment synthesizer is to build a dataset of individual firm-to-firm shipments from an aggregate commodity flow matrix, and disaggregate firm data. In microsimulation models, commodity generation typically takes place by a bottom-up approach applying firm level regression models estimating production and consumption based on firm level attributes[4,14]. In our approach we use an aggregate freight transport demand matrix, derived from a strategic freight transport demand model as input, to simulate shipments between producing and consuming firms. Aggregate commodity flows are broken down to shipments using the observed shipment size distribution, and next each shipment is allocated to individual firms, based on the firm's characteristics (size, industry type, location) and the make/use probability of the industry sector for the respective commodity type. Output is a dataset with firm-to-firm shipments, containing the commodity type of shipments, and the attributes of sending and receiving firms (location, firm size, industry). The flowchart describes the synthesizing procedure.

The size of shipment is drawn form an observed standard distribution:

$$f(x|\mu, \sigma^2)$$

(1)

The probability of firm f belonging to sector s, being the **sender** of shipment with commodity type $P_{s;gt}^{make}$ gt depends on firm size, E, 'make' probability for the sector, , and other firms in origin zone:

$$P_{f;gt}^{sender} = \frac{E_{f;s} * P_{s;gt}^{make}}{\sum_{i \in orig}[E_{i;s} * P_{s;gt}^{make}]} \qquad (2)$$

The probability of firm f belonging to sector s, being the **receiver** of shipment with commodity type gt depends on firm size, E, 'use' probability for the $P_{s;gt}^{use}$ sector, , and other firms in destination zone:

$$P_{f;gt}^{receiv} = \frac{E_{f;s} * P_{s;gt}^{use}}{\sum_{i \in dest}[E_{i;s} * P_{s;gt}^{use}]} \qquad (3)$$

Table 2: Shipment size from Commodity flow database (CBS).

	NST/R	Shipment size	
		Average	StdDev
0	Agricultural products and live animals	15.3	9.5
1	Foodstuffs and animal fodder	13.7	9.9
2	Solid mineral fuels	25.6	4.2
3	Petroleum products	25.4	11.5
4	Ores and metal waste	16.8	7.9
5	Metal products	14.8	10.1
6	Crude and manufactured minerals, building materials	22.2	9.9
7	Fertilizers	16.7	11.4
8	Chemicals	15.8	10.3
9	Machinery, transp. eq., manuf. articles and miscell. articles	7.7	8
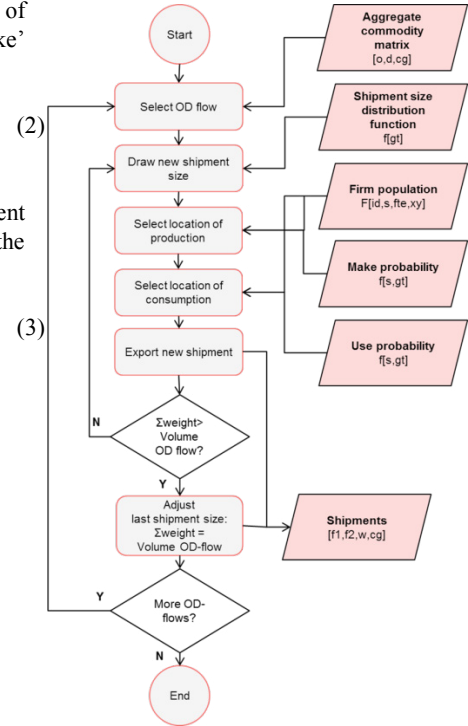
4.3. Tourformation

The second module in the prototype is a tour formation module. Objective of this module is to build tour patterns from the synthetic shipments and observed tour statistics. Similar simulation-based approaches exist where multiple trips or shipments are combined in a trip chaining or roundtour, such as Hunt and Stefan (2007) or Wisetjindawat et al. (2007). Output is a dataset with urban freight tours, containing the commodity type of shipments, a number of discrete shipments to be delivered, and the location and industry sector of sending and receiving firms for each shipment.

Submodels are based on observed commodity statistics; where relevant these steps will be improved by applying logistic choice model for the corresponding agent. First of all the probability density function of the vehicle type, chosen for each commodity type is used to allocate a vehicle type for a tour. This probability density function is shown in Table 3. The next step is the simulation of tour start time: again, this is allocated by using the observed start time of tours by vehicle type and commodity, available from the data. The detailed time schedule of truck patterns is not available in the standard survey, but only for the registrations collected from the automated trip registration procedure.

The next step is to simulate the decision to make an extra stop during the tour. The available data consists of observed truck tour patterns and provide information on the occurrence of multi stop tours (1,2,3,4,5 or more shipments per tour). From this observed statistic a conditional probability function is derived that describes the probability to make an additional tour during the tour formation procedure. This probability depends on the type of

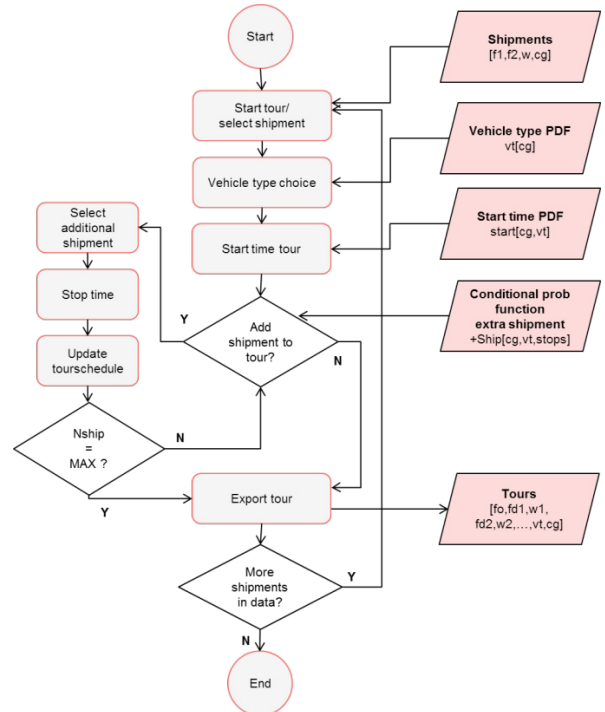Figure 2: Shipment synthesizer procedure

Figure 3: Tourformation procedure

good, and the vehicle type that was used. This statistic is illustrated in Table 4 for the first three commodity types. If an extra stop is made, the selection of additional shipment is conditional on commodity type. The baseline model selects the first shipment of the same commodity type that is available. In addition observed statistics on waiting times for loading and unloading shipments will be used to construct a complete timing for the tourschedule. The decision to carry- and selection of additional shipments for a round tour will be one of the first simulation steps that will be replaced by a choice model that is based on logistic choice behavior.

Table 3: Probability density function for vehicle type from 'deelrittenbestand'

NST/R	2: Lorry	3: Trailer truck	4: Special Vehicles
0 Agricultural products and live animals	20%	80%	0%
1 Foodstuffs and animal fodder	10%	90%	0%
2 Solid mineral fuels	10%	90%	0%
3 Petroleum products	39%	60%	0%
4 Ores and metal waste	61%	38%	1%
5 Metal products	19%	81%	0%
6 building materials, minerals	46%	54%	0%
7 Fertilizers	19%	77%	3%
8 Chemicals	36%	57%	6%
9 Machinery, transp. eq., manuf. articles and miscell. articles	19%	78%	3%

Table 4: Stop probability: conditional probability function additional tour: P(n+1|n) from 'deelrittenbestand'

	Conditional probability function additional tour: P(n+1|n)				
	2	3	4	5	Round
NST/R 0: Agricultural products and live animals					
2: Lorry	43%	82%	85%	85%	3%
3: Trailer truck	45%	81%	82%	83%	1%
4: Special Vehicles	0%	0%	0%	0%	0%
NST/R 1: Foodstuffs					
2: Lorry	83%	94%	92%	92%	0%
3: Trailer truck	64%	80%	80%	82%	2%
4: Special Vehicles	94%	97%	85%	94%	2%
NST/R 2: Solid mineral fuels					
2: Lorry	25%	100%	100%	45%	0%
3: Trailer truck	3%	100%	100%	76%	0%
4: Special Vehicles	0%	0%	0%	0%	0%
…..					

4.4. First results

Prototype produces a database with shipments from synthesizer and a database with tours, or truck patterns, describing the distribution sequence of the individual shipments, with all relevant attributes such as starting point, number of shipments, total weight carried, and for each shipment in the tour each relevant attribute. The results are also available as shapefiles for quick visualization.

The following figure illustrates the micro results. The map shows the distribution pattern of all truck trips within Rotterdam for commodity type NST/R 6 (Crude and manufactured minerals, building materials). One of the tours is highlighted on the map and in the attributes table of the tour shapefile. As can be seen, the highlighted tour illustrates the tour pattern for the delivery of two shipments for NST/R 6.

This paper introduces the agent based framework and we only want to illustrate the output level at which the model simulates urban truck patterns. The model is completely based on observed statistics and monte carlo simulation and does not contain any explicit logistic choice models yet. However, it does illustrate the first use of the rich dataset that is available in the study. The presented approach is a baseline prototype that is a simulated representation of the observed freight transport demand database that is being used for further developing the agent based modeling framework.
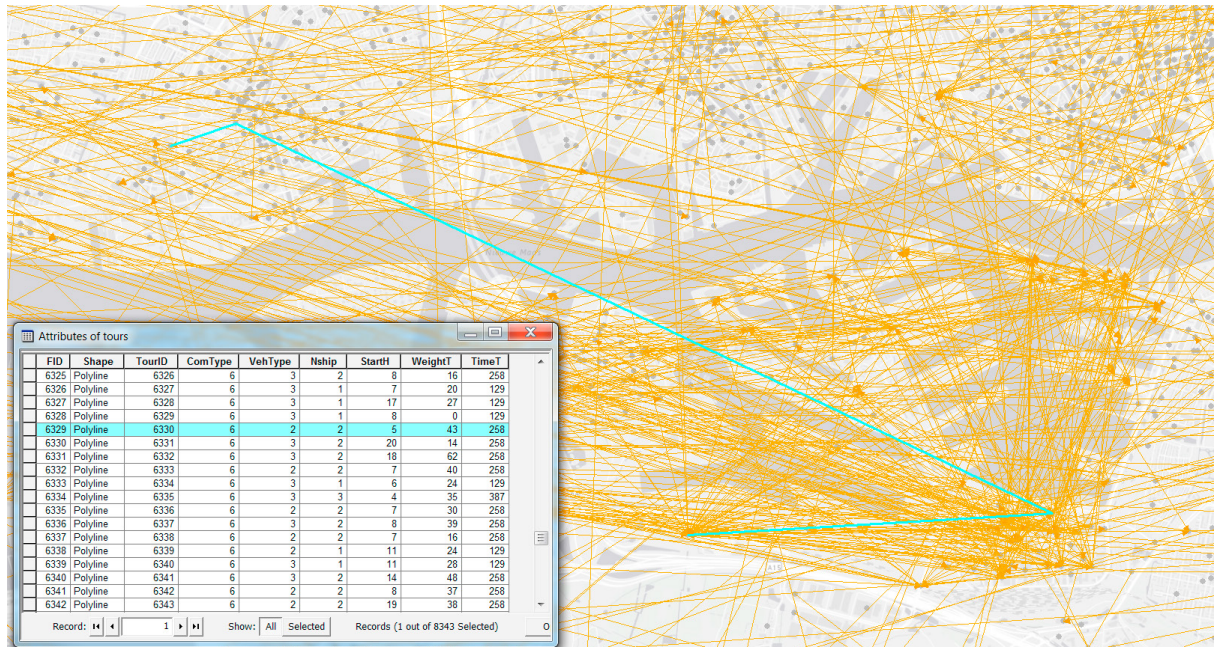
Figure 4: distribution pattern of all truck trips within Rotterdam for commodity type NST/R 6 (Crude and manufactured minerals, building materials)

5. Discussion and further research

We present a data driven simulation model for urban freight transport patterns. The prototype simulates representative truck patterns for an average working day for an urban agglomeration in The Netherlands: Rotterdam. We realize that this prototype is still completely based on observed descriptive statistics and it does not contain choice models for logistic agent behavior yet. However this prototype is a first step in the incremental development of an urban freight agent based simulation framework. To manage simulation complexity we have started with this baseline model with as little choice modeling as possible.

The prototype contains the agents (producing and consuming firms), synthetic shipments, and a baseline tourformation procedure. It is the objective of the next research step to extend this framework with choice behavior for the respective agents. The available data is extensive: above 30 thousand observed freight transport observations (from both own account carriers as 3PL's). The individual observations provide a strong basis for empirical analysis and the formalization of empirical choice models for logistic choice behavior. The described example of the first prototype already reveals a bit of the possibilities with the data that is available in this study, and the level of detail and potential for analysis in simulation outcomes.

In the following steps we will first implement the distinction between own account carriers and shippers that outsource their transports. The available data provide all statistics to implement this distinction. Simultaneously two choice models are being developed: one for tourformation and the second for combined shipment and vehicle time choice. The results from both models will be implemented into the framework. Another development step is to develop an interface with a network assignment model: first to generate network performance indicators and secondly to simulate route choice behavior.

Acknowledgements

References

1. Davidsson, P., L Henesey, L Ramstedt, J Törnquist, and F Wernstedt "An analysis of agent-based approaches to transport logistics." Transportation Research Part C: Emerging Technologies 2005 **13(4)**: 255-271.
2. Tavasszy, L. A. Freight Modelling: An overview of international experiences. TRB Annual Meeting 2006 Washington DC.
3. de Jong, G. and M. Ben-Akiva "A micro-simulation model of shipment size and transport chain choice." Transportation Research Part B: Methodological 2007 **41(9)**: 950-965.
4. Wisetjindawat, W., K Sano, S Matsumoto, and P Raothanachonkun. Micro-simulation model for modeling freight agents interactions in urban freight movement. 86th Annual Meeting of the Transportation Research Board, 2007 WashingtonDC.

5. Liedtke, G. "Principles of micro-behavior commodity transport modeling." Transportation Research Part E: Logistics and Transportation Review 2009 **45(5)**: 795-809.
6. Roorda, M. J., R. Cavalcante, R, S. McCabe, H. Kwan. "A conceptual framework for agent-based modelling of logistics services." Transportation Research Part E: Logistics and Transportation Review 2010 **46(1)**: 18-31.
7. Hunt, J. D. and K. J. Stefan. "Tour-based microsimulation of urban commercial movements." Transportation Research Part B: Methodological 007 **41(9)**: 981-1013.
8. Holguín-Veras, J, E Thorson, Q Wang, N Xu, C González-Calderón, Iván Sánchez-Díaz, J Mitchell. Urban Freight Tour Models: State of the Art and Practice. In: H. M. Moshe Ben-Akiva, Eddy Van de Voorde Emerald. Freight Transport Modelling. 2013. p. 335-351.
9. Samimi, A., A. Mohammadian, K. Kawamura. Behavioral freight movement modeling. 12th International Conference on Travel Behaviour Research. Jaipur, 2009, India.
10. Holguín-Veras, J. and I. Sánchez-Díaz. "Freight Demand Management and the Potential of Receiver-Led Consolidation programs." Transportation Research Part A: Policy and Practice 2016 **84**: 109-130.
11. Boerkamps, J., van Binsbergen, A, P. Bovy. "Modeling behavioral aspects of urban freight movements in supply chains." Transportation Research Record: Journal of the Transportation Research Board 2000 **1725**: 17-25.
12. Cavalcante, R. A. and M. J. Roorda. "Freight Market Interactions Simulation (FREMIS): An Agent-based Modeling Framework." Procedia Computer Science 2013 **19**: 867-873.
13. Tavasszy, L, M. de Bok, J. Rezaei and Z. Alimoradi. Descriptive Models of Logistics Decisions in Freight Transportation Modelling: a Review. Manuscript submitted to: Journal of Supply Chain Management Science 2018.
14. Abed, O., T. Bellemans, G.K. Janssens, D Janssens, A Yasar, G Wets. "An Agent Based Simulated Goods Exchange Market; A Prerequisite For Freight Transport Modeling." Procedia Computer Science 2015 **52**: 622-629.