# Agent-based Simulation of Freight Stakeholders

by

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# Executive Summary

This paper attempts to contribute to the existing body of knowledge on agent-based simulation of freight entities by investigating a proposed framework for the modelling of stakeholder behaviour in a supply chain. Models such as this have place in the analysis of freight vehicle behaviour when policy changes are made within an organisation. Furthermore, multi-agent based simulation freight models make it possible to fully track the movement of commodities throughout the network while also giving full attention to the nature of shipment routing and vehicle tours, allowing for the economic impact and overall efficiency of supply chain to be assessed. It was intended that all the data requirements of a fully specified framework be determined so as to assist efforts to realise a full implementation in the future.

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# List of abbreviations and acronyms

**3PL** Third-Party Logistics

**API** Application Programming Interface

**FSM** Four-Step Model

**MATSim** Multi-Agent Transport Simulation

**mobsim** mobility simulation

**TSP** Transport Service Provider

**VRP** Vehicle Routing Problem

# Chapter 1

# Introduction

Transport plays a fundamental role in our daily lives as it is the primary source of time and location utility by making the appropriate resources available in the correct location at the time when they are needed.

In primitive times mankind was obliged to dwell where resources and conditions necessary to sustain life were readily available: a source of drinking water, building material for shelter, and a defensible geographic position, for example. As civilizations evolved, man became less constricted by the location of staple resources; more sophisticated and reliable methods of providing for basic needs were developed, all of which would have involved the transportation of goods in some form. The means to exploit resources for the accumulation of wealth and economic gain became a reality and this lead to the establishment of new industries and trades that went beyond the exchange of staple commodities and sought to meet the higher demands of a more opulent society. Thus the pursuit of wealth, and a means to sustain it, became the primary objective of society as it remains to this very day.

The need to move from one location to another, at a certain time, to achieve a specific outcome gives rise to the necessity of transport: (i) driving a car to work, (ii) riding a bus cross-country or (iii) delivering products to a supermarket. Invariably, a transport need is never addressed by a single event but rather by a chain of activities that allow an individual to complete the tasks necessary for survival and to serve a role in society: (i) it is inevitable that a person driving to work will have to purchase groceries and return home, (ii) the bus would make a return trip and undergo scheduled maintenance, and (iii) a delivery vehicle might have to make more than one delivery, finally reporting back to the depot.

These three examples, being distinctly different in nature and purpose, allude to the most common types of vehicle classifications by activity, namely those serving in: (i) private, (ii) public and (iii) commercial or freight roles.

In every case, it is reasonable to assume that a transportation event is the result of a *rational, justifiable need for the movement of commodities and resources* from one location to another and that the manner in which this need is fulfilled is the result of *numerous decisions* made by several *different, inter-dependent entities and stakeholders.* In light of this, commercial vehicle movement might be regarded as *"the manifestation of complex inter-dependent relationships between enterprises"* (Joubert and Axhausen, 2012). The adoption of modelling paradigms that acknowledge this and seek to simulate vehicle movement as a response to an identified need within a system will serve well in the study of vehicle behaviour.

The goods transported by freight vehicles on a nation's road networks are invariably of significant economic value: basic foodstuffs, livestock, consumer devices and building materials amongst all other things, are what satisfy the needs and wants of society throughout the country; and sustain the economy, facilitating its growth.

When considering private vehicles and the activities of their occupants in contrast to freight vehicle activities, it must be asserted that while workers are indispensable to the economy as a whole, the impact each person has on a nation's economy cannot be accurately measured. Commercial or freight vehicles, while numbering far less than private or public vehicles, have a significantly greater impact on the economy per vehicle.

The opportunity to accurately represent freight vehicles and gain a deeper understanding of their movement through road networks will eventually make it possible to determine a wide variety of parameters concerning, amongst other things: the economic impact of supply-chains and the effect they have on congestion patterns.

## 1.1 The MATSim toolkit

The Multi-Agent Transport Simulation (MATSim) toolkit is an open source platform designed to implement large-scale agent-based transport scenarios. It consists of numerous modules that can be used individually or collectively alongside code developed for specific studies.

MATSim provides an effective means of traffic flow analysis down to the most basic level where the activities of any single agent can be tracked. Until recently, real-world scenarios set up in MATSim accounted for freight traffic demand using plans with two activities: *freight-origin* and *freight-destination* with only a single leg between them. This meant that the only possible dimension of variation in agent behaviour was found in route choice, and this is because the planning and re-planning modules included in the MATSim toolkit are designed for representing private vehicle agent behaviour and cannot make relevant changes to freight vehicle agent plans (Schröder et al., 2012). These modules are based on the classical Four-Step Model (FSM) which is a highly aggregate approach to vehicle movement modelling and will be discussed in Chapter 2.

In a transport simulation, individual vehicles are represented by autonomous agents that move through a physical network; each agent is equipped with a plan when the simulation is first initialised, and each agent will endeavour to follow its plan as closely as possible. Plans incorporate information such as the times and locations of *activities* that the agent must participate in. Each activity is joined to the next by *legs* that can be travelled using specific transport *modes*. Different routes can be followed on certain legs, depending on the mode of transport and the physical network. The plans of all agents are simultaneously executed and then evaluated at the conclusion of each iteration using a *utility function* that takes time and cost into account. This assesses the effectiveness of the plan in response to what was experienced by the agent in the simulation. *Re-planning* then occurs at the beginning of the next iteration: agents are given a revised, possibly different, copy of their original plan which has been processed by several modules in the MATSim toolkit in effort to improve efficiency and effectiveness. The process is then repeated until the simulation completes, after which the results can be analysed with the extensive tools included in the MATSim package.

The state-of-practice freight movement model certainly leaves much to be desired as freight vehicle agent plans lack the depth required to realistically represent true freight behaviour.

## 1.2 Research question

Considering the critical role freight vehicles play within an economy, it would be expedient to pursue a greater understanding of how such vehicles behave and how their activities influence traffic congestion.

As will be discussed in Chapter 2, present methods of freight simulation lack the logical depth required to truly justify the movement of vehicle entities in the existing MATSim model. Strategic decision making and accurate planning will be more achievable with realistic freight stakeholder representation. Therefore, attempting to add to existing literature, the objective is to answer the following research question:

> *"What data and parameters are required to drive a behavioural model of decision makers (stakeholders) of a freight supply-chain operating in a real-world context?"*

## 1.3 Research design & methodology

This project aims to contribute to the body of knowledge on the agent-based simulation of freight stakeholders through the investigation of a behavioural model that replicates decision making made at each strategic level in a freight supply-chain.

The research will comprise of several phases, the first involving the investigation of existing freight vehicle simulation methods so as to highlight the relevant potential of multi-agent simulation approaches in freight modelling.

The second phase involves a study of the software agents proposed by Schröder et al. (2012) in their computational framework, to gain a better understanding of the interactions between entities within the model.

The third phase will address what data is needed to drive such a model.

## 1.4 Document structure

In Chapter 2 this work is placed in perspective within the existing body of knowledge on freight vehicle modelling; various approaches to freight vehicle simulation are discussed and justifications as to why freight behaviour has not yet been adequately modelled are presented. Chapter 3 discusses the work of Schröder et al. (2012) and more specifically the workings of the computational framework and its integration with a MATSim simulation. Chapter 4 deals with Carrier agents and the MATSim simulation controller. Chapter 5 presents a summary of the type of data required to implement the model.

# Chapter 2

# Literature Review: Freight modelling

In recent years, efforts have been made to accurately model the movement of vehicles on physical networks and the field of transport modelling has grown rapidly.

As it stands, freight vehicle modelling has not developed quite as swiftly as models of private vehicle behaviour. Many existing freight models have been based on the classical Four-Step Model (FSM) which was originally designed for the simulation of private vehicles. In their special issue on behavioural insights into the modelling of freight transportation, Hensher and Figliozzi (2007) assert that freight models based on the FSM paradigm simply cannot provide adequate answers in the global customer-driven economy we now find ourselves in. In the case of private vehicles, the type of data required to drive a FSM is readily available from GPS-logs and census data provided by the government and tracker companies. This is definitely not the case with commercial and freight vehicles as businesses are hesitant to disclose data recorded by their own vehicles for fear of revealing sensitive information. Furthermore, the number and complexity of decisions motivating the movement of a freight vehicle from one destination to another to address a need (and thus participate in certain activities) is significantly greater than in the case of private vehicles. One must acknowledge that freight vehicle movement patterns are vastly different to those expected from private vehicles (Joubert and Axhausen, 2011). It can be expected that most private vehicles would follow a regular daily cycle of activities as people travel to and from work, to the shops and schools etc. where a single freight vehicle might (although this is certainly not always the case) have to make infrequent and irregular trips between certain destinations. There may be many possible reasons for this: the vehicle might operate within a fleet and is assigned many different destinations each day, each changing with demand and the ability of the fleet to secure shipments; or demand might be completely irregular and unpredictable for reasons unknown.

To account for commercial vehicles is transport planning models, passenger and private vehicle models are often just inflated by some fraction to reflect comemrcial traffic as background noise (Joubert and Axhausen, 2012) confirming that the depth of the decision-making activity behind freight vehicle movement is very poorly represented, if at all, in the current state-of-practice in freight vehicle modelling in Multi-Agent Transport Simulation (MATSim).

## 2.1 The Four-Step Model (FSM)

Development of the classical FSM began in the 1950's and it has been the accepted basis for the analysis of transportation systems in the United States for several decades. A discussion presented by McNally (2000) on the FSM approach asserts that it was never intended for analyses of traffic flow below the sub-regional level. In applying this model, area(s) under study are divided into an appropriate number of Traffic Analysis Zones (TAZs) and representative information (usually socio-demographic data) is collected for each of them. Because of the aggregated methods of data collection employed by the FSM it is immediately apparent that the detailed movement of individual vehicles is not represented in any model based on the FSM approach.

In executing the four steps of *trip generation*, *trip distribution*, *mode choice*, and *route assignment*, the model seeks to establish the equilibrium flows for traffic volumes within a network. However, this raises serious concerns as to the accuracy of results produced by this model as there is *no equilibrium* on real-life road networks. Its idealistic objective of determining equilibrium traffic flows that could not possibly exist in any real-world scenario means that the results of such a model could not serve as a realistic representation of vehicle movement in general.

The motivations behind both private and commercial vehicle movement is lost, and this does not serve to meet the need for a greater understanding of freight vehicle behaviour.

## 2.2 Freight micro-models

Schröder et al. (2011, 2012) identify two distinct approaches to micro freight modelling, namely commodity flow-based and tour-based modelling. Both of these approaches have distinctly suitable applications and address certain facets of freight behavior.

### 2.2.1 Commodity flow-based models

Commonly used to model freight vehicle activity at inter-regional levels, commodity-flow based models examine the movement or transfer of commodities between regions, converting them into vehicle-flows through the transport network. As commodity volumes and flows are the primary source of data, the details of vehicles that transport these commodities and the routes that they might follow are not explicitly addressed. Because of this, such models often oversimplify vehicle tours and will not track specific vehicles, making the representation of common freight entities such as fleet vehicles impossible. Commodity-flow based models have place in the assessment of the economic impact of freight but cannot be used to develop a greater understanding of freight vehicle behaviour (van Heerden, 2011).

### 2.2.2 Tour-based modelling

Tour-based models, as the name might suggest, focus exclusively on the movement of vehicles through time and space, and are most commonly used in the simulation of urban freight vehicle movement. Joubert and Axhausen (2011) analysed commercial vehicle activities using a tour-based approach through a study of vehicle activity chains in Gauteng, South Africa. Activity-chains were extracted from the GPS-logs of more than 30 000 vehicles that had collected data over a time of six months. The analysis of these activity-chains laid the foundation for a more comprehensive understanding of disaggregate freight vehicle movement at an intra-provincial level.

Joubert et al. (2010) utilised these findings to model a combined traffic simulation of private and commercial vehicles in Gauteng and proved that commercial vehicle movement can be modelled accurately alongside private vehicles and the impact of such traffic can be assessed using the MATSim toolkit.

The work of van Heerden (2011) then proceeded to investigate inter-provincial freight vehicle movement following a similar approach.

An unfortunate drawback of tour-based modelling approaches is that commodity movement is not represented and upstream logistics decisions are disregarded entirely.

### 2.2.3 Multi-agent logistics modelling

Multi-agent modelling approaches make it possible to represent individual actors and decision makers within the logistics system which are made to interact with one another through specified communication channels as would be the case in the real world.

Liedtke (2009) developed one of the first approaches to multi-agent logistics modelling by reproducing behaviour associated with logistical re-organisations as the model predicted and simulated actual truck movement as a result of inter-organisational relationships. What makes this approach (and indeed all other multi-agent approaches) critically different from conventional methods is the fact that logistics structures and activities are not inferred from aggregate statistical data but are generated in the simulation itself.

The novel work of Borgatti and Li (2009) applies social network analysis principles to supply chain networks in order to better understand the dynamics of existing organisational relationships and also highlights the potential for the application of social network theory across several disciplines. In their research heavy emphasis is placed on the acknowledgement of the different types of relationships or "ties" that exist between parties in a supply chain. These ties are either tangible in the form of money or materials, or intangible where the relationship is manifest in an alliance between parties or in cases where parties are likely to share certain forms of information amongst one another. While this work is not based on multi-agent logistics modelling, it is important because it alludes to a critical element of multi-agent modelling: knowledge and contracts.

# Chapter 3

# Freight Logistics Modelling from a Multi-Agent Perspective

The work of Schröder et al. (2011, 2012) makes for a logical departure point in representing freight activities in a transport simulation from a multi-agent logistics perspective.

This approach is described as "*. . . the interface between commodity flow and tour-based approaches. . .*" (Schröder et al., 2012). The nature of the software agents proposed in the model ensure that consideration is given to many (if not all) of the elements that classical approaches have thus far failed to address individually. Cognisance is given to the preservation of commodity flow data through the traffic system, and the movement of the freight vehicles carrying the commodities is a result of simulated decision-makers interacting with each other by means of contracts (representing business transactions) to address a specific demand in a location; consequently, the identity of individual vehicles will be preserved, implying that the simulation of fleet vehicles will be possible.

In this framework, stakeholders within a supply chain are represented as three individual *software agents*, namely the (i) Shipper, (ii) Transport Service Provider (TSP), and (iii) the Carrier. These roles essentially divide the framework into different levels of decision making, each with specific objectives. As mentioned above, these agents can act as independent decision-makers or behave as a single entity, depending on the nature of the supply-chain and/or company being modelled.

It is also possible to modify the manner in which software agents interact with one another: depending on the company being modelled, a single person may perform the task of several agents, in which case those agents will be paired with full knowledge and capabilities shared between them. Compare this to Third-Party Logistics (3PL) providers which would of course have limited knowledge of their clients' broader industry and capabilities.

Contracts are present at each level of the framework and represent business obligations to entities that are immediately superior to them: that is to say that contracts can exist between TSPs and Shippers but not between Carriers and Shippers. It to be noted that although said "Contracts" represent literal contracts in reality, for the purposes of this discussion, they are in fact manifestations of programmed objects within a simulation. It is to be understood that it is still possible to simulate a contract between a Shipper and a Carrier by having the TSP act as a "transparent body" or mechanism by which the contract would then have to be formed.

Consider the following hypothetical scenarios where there are three industries/businesses that rely on freight or commercial vehicles: (1) truck owned by a beef cattle farmer, (2) steelmaking and (3) fast moving consumer goods. Let it be assumed that they have the following freight supply chain configurations: (1) the driver is the owner of the truck and he is solely responsible for all of its dealings, (2) the steelmaking firm e.g. ArcelorMittal outsources all of its logistics to a 3PL firm that has full knowledge of its supply-chain activities in the country and (3) the retail goods producer e.g. Hi-Tech is looking to minimise its logistics costs but has a long history with many different 3PL companies and is sometimes in a situation where there are two such firms operating out of a single facility – one handling in-bound logistics, the other handling out-bound; for the purposes of this discussion it can be assumed that the logistics firms have no knowledge of their competitor's activities beyond the scope of the facility which they share. Each of these cases are completely different with respect to their logistics and supply chain requirements and the role that each level of stakeholders will fulfil in terms of the computational framework will vary accordingly. These examples will be referred to throughout this chapter.

The carrier agents present within a simulation will make offers to fulfil TSP shipments, thereby forming a contract. For the sake of simplicity, it is understood that all offers made by carriers are accepted, though logic of any conceivable level of complexity can be introduced here.

As with real persons, software agents make decisions on the basis of their *knowledge* of the transport system, their *capabilities*, which could be regarded as resources that they have at their disposal, and *contracts* that define business relationships between agents within the system. The decisions made by these roleplayers produce plans that are provided to *vehicle agents* that are then injected into the MATSim simulation.

## 3.1 Shippers

Best described as producers with the need or desire to move goods of any description from one location to another, shippers are found at the highest level of the framework and are the origin of all shipment-based activities, essentially driving the rest of the model framework.

Contracts for shippers are manifestations of business obligations to transport products of any description to and from any location. Each shipper contract contains information pertaining to the source and destination of the goods to be shipped, as well parameters specifying their type, value and quantity. It is expected that shipper contracts would be generated in response to a demand contained within a specified time frame.

Shipper plans, as dictated by the contracts, handle commodity flows only. No consideration is given to the use and assignment of vehicles at this level.

Warehouses, intended for the consolidation of commodities over any duration of time, constitute the capabilities of each shipper agent and are treated as static attributes as they are not subject to frequent change. At present each shipper will have a warehouse located at each source and destination of a commodity flow.

Realistic examples of shippers might include: a mining company that needs to move ore from a mine to a refinery, a manufacturer of consumer electronics transporting components from one facility to another for final assembly or an automotive company, shipping new vehicles and/or service components to a central warehouse with the intent to distribute nationwide. Referring to the examples identified above, the following entities are identified as Shipper Agents: (1) the beef cattle farmer wants to transport his own livestock, (2) ArcelorMittal needs to transport steel products to a port for export and (3)

Hi-Tech needs to transport their latest designs from their main warehouse in Cape Town to Johannesburg.

## 3.2 Transport Service Providers

Transport Service Providers or TSPs, as the name might suggest, are occupied with providing Shippers with a means to transport their goods, handling the scheduling of Pick-Up and Delivery activities in the supply chain.

The capabilities of a TSP are manifest in transhipment centres that it can use to manage the flow of commodities through a network. The knowledge and experience a TSP has of its network and the offers made available to it from carriers in the area influence the fulfilment of its own contracts, a process for which it is responsible. For each shipment, a TSP will create a transport chain with specific Carriers assigned to each leg of the journey. Note that in the full implementation it will be possible for intermodal transport chains to be formed.

The use of a TSP makes it possible to simulate a hub-and-spoke network where applicable, and plans made by TSPs are still shipment focused.

A shipper agent can only contract **one** TSP to handle all of its shipments in an iteration. The selection process occurs prior to the running of the mobility simulation (mobsim).

TSP agents fill the following positions for each of the above examples: (1) The farmer is his own transport service provider, **not** because he is the owner of the truck, but because he is responsible for his own scheduling and because he will drive every leg of the journey himself. (2) In the case of ArcelorMittal, the TSP is the 3PL provider responsible for the storage of the steel products once they have arrived at the harbour ready to be loaded onto a ship (assuming there is a transhipment warehouse at the docks) and would have specified carriers for each leg of the journey. (3) Hi-Tech is a somewhat different scenario – because two different companies are handling supply chain logistics, and the model only allows one TSP per Shipper agent, it becomes necessary to represent Hi-Tech as two different companies. The commodity flows of the first Hi-Tech company would originate from the harbour and end at the facility where the change-over between TSP agents occurs, the first TSP would have thus been responsible for in-bound logistics at the facility. Similarly, the second TSP manages the out-bound logisitcs decisions. Statistics and results from both companies (representing Hi-Tech) could be aggregated later to assess the effectiveness of the supply chains as a whole.

## 3.3 Carriers

Carriers form the most fundamental level of the computational framework and are most closely related to the MATSim simulation.

Carrier contracts specifiy the origin, destination, type and quantity of goods to be transported as well as the time windows for pickup and delivery activities. It is these contracts which later give rise to shipments which are fulfilled by the carrier. The success of the carrier in meeting the stipulated conditions contained in each contract will determine the score awarded to the plan followed in each iteration of the simulation, and assists in the development of more effective plans that are either based on the one originally followed or are generated from scratch.

Vehicles used by carriers to complete shipments within the MATSim physical model make up their capabilities.

Each carrier has a designated location within a network which serves as its depot from where all carrier vehicles must originate at the commencement of the iteration and finally return once all other freight activities have been completed. This is a standard requirement of the existing Vehicle Routing Problem (VRP) algorithms presently available in the freight contribution code.

With reference to the above examples: (1) the farmer is his own carrier, (2) for ArcelorMittal the 3PL company may have selected a number of different carriers to transport the goods. (3) Hi-Tech will almost certainly have several carriers as they have two 3PL companies managing their warehouse, each of which can appoint a carrier for each leg of the supply chain.

The number of carriers that might be needed in order to transport goods from one location to another is often most depenedent on the distance over which the goods need to be transported, as it would be infeasible in many cases for a carrier to travel a significant distance from its base of operations.

# Chapter 4

# The MATSim Simulation Process & Carriers

This discussion begins with the introduction of the Multi-Agent Transport Simulation (MATSim) controller. The MATSim controller provides eight opportunities (controller events) to the user during which changes can be made to the mobility simulation (mobsim) parameters and data from the simulation can be extracted as shown in the following figure:

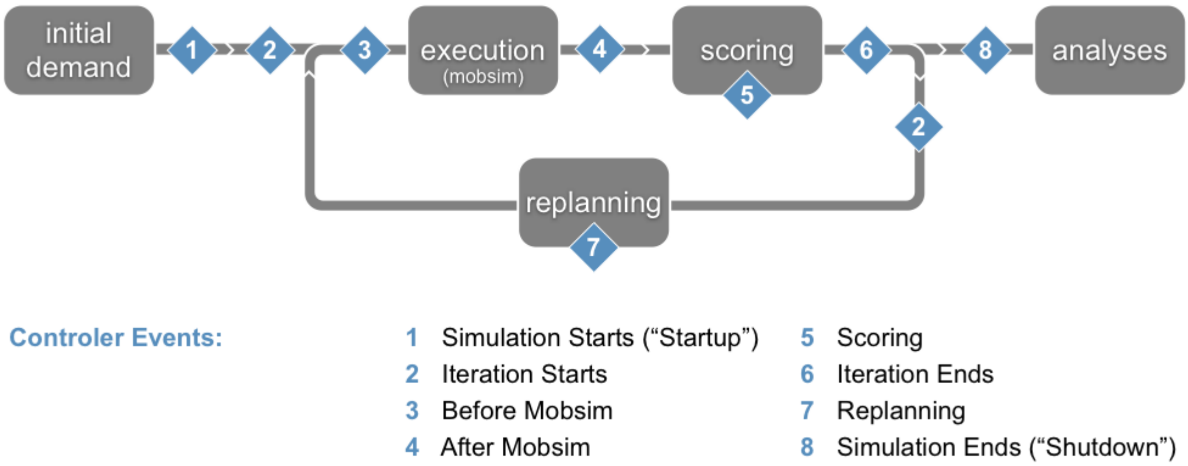


Figure 4.1: Stages of the MATSim controller during a mobility simulation (Online, 2011)

The controller is the main mechanism through which the behaviour of a MATSim simulation can be manipulated. Additional functionality is achieved through the inclusion of specific *controller listeners* which are best described as code structures that facilitate the exchange of various types of information at key points or stages in a MATSim simulation, and these stages are shown clearly in Figure 4.1. This core functionality allows for flexibility in modelling practically any transport scenario.

The Carrier agent, as presented by Schröder et al. (2012) will now be discussed in greater detail.

A bottom-up approach to unravelling the computational framework was adopted. Contribution source code and examples of carrier plans were examined to gain insight into the operational requirements of this fundamental level of the logical model.

Test-cases implementing sample carrier plans in a simple network structure revealed that carrier driver agents are injected into the MATSim simulation through the use of a listener in the controller. Injection of agents into the MATSim physical layer occurs at stage 3, just prior to the execution of the mobsim.

It has been observed that no plan generation takes place in any of these existing test-cases, as all routes have already been defined in the carrier plans file.

If a fully functional implementation of the framework was used in a simulation information regarding carrier capabilities and the shipments that have been assigned to each of them would be input into some form of planning modules within the freight contribution Application Programming Interface (API). It is here that initial plans with routes along the shortest possible path on an empty road network would be generated in stage 2 and proceed to be executed by the driver agents. At the conclusion of the mobsim, scoring modules for the freight framework are notified and the success of the plans as executed by the carriers in the current iteration are assessed. Replanning then commences with the initiation of the next iteration and should engage the upper levels of decision-makers which revise their plans as carriers once again make offers for legs in the transport chain.

# Chapter 5

# Data requirements

The data necessary for executing a mobility simulation using the framework might be separated into two categories: (1) predefined data and (2) generated data.

**Predefined data** includes all parameters necessary for the population of the model during the initialisation stage and would also contain information regarding initial demand for freight stakeholders. Such data is usually stored in .xml files.

**Generated data**, as implied, comprises of all data that would be produced by structures within the framework as the simulation is executed and stakeholders interact with one another. Depending on how many levels of the framework are implemented in a simulation, data that might otherwise have been regarded as generated data becomes predefined data as required inputs to the model.

At the time of writing, the code structures needed to implement the framework at Transport Service Provider (TSP) and Shipper level had not yet been released into the public domain. The inferred data requirements are as follows:

## Shippers – Predefined data

- name of the shipper
- geographical locations, or street addresses of warehouses where goods are stored – to be linked to the network file of the MATSim simulation
- records of any commodity flows to be shipped, must contain specific information such as: origin, destination, quantity and type of goods, time window in which the delivery must be made – this is essentially the **initial demand** that would drive the complete framework

## Transport Service Providers – Predefined data

- name of the TSP
- geographical locations, or street addresses of transhipment centres

## Carriers – Predefined data

- name of the carrier

- geographical location, or street address of the depot
- number of trucks available
- load capacity of each truck
- operating start and end times of each truck
- operating costs of each truck (fixed and variable, may be linked to driver remuneration)

# Chapter 6

# Conclusion

Multi-agent freight vehicle modelling techniques have the potential to drastically influence the manner in which government and prominent business stakeholders in the economy are likely to conduct their business in future. The traceability of costs, economic contributions and individual activities of every entity within a multi-agent freight simulation model implementing a framework such as the one discussed here makes for an undeniably potent tool that has potential applications in a broad range of professions including (but not limited to): town planning, supply chain managment, business process design & re-engineering and transport engineering.

The full development of this framework would allow organisations to assess the impact relocating a facility might have on their revenues, operating costs and service levels. Plans for the construction of new freeways and the modification of existing ones would be thoroughly tested for potential improvements in congestion and more effective use would be made of taxpayer's money.

This paper attempted to investigate the data requirements for the implementation of an agent-based simulation of freight stakeholders using the framework proposed by Schröder et al. (2012). As the framework approaches completion and all the components are released into the public domain it is hoped that it will have a significant impact on the future planning of transport systems and infrastructure and that its implementation become a reality.

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# Appendix A

# The Carrier Plan Generation Process

The following process is followed in order to generate carrier plans. This would be an automated process in the case of a fully implemented framework, but the functionality is there to be able to simulate freight vehicles alongside private vehicles.

STEP 1 – INITIALISE THE ENVIRONMENT

1. Initialise the network – link a string variable "networkFile" to the path of the "network.xml" file
2. Create a new scenario based on a default configuration
3. Associate the network with the scenario
4. Create a MatsimNetworkReader object based on the scenario
5. Invoke method of MatsimNetworkReader to read the network file
6. Invoke method of scenario to output the network to a Network object
7. Initialise a Collection of Carrier objects
8. Create a CarrierFactory object, use it to create Carrier objects – each carrier must have a name and a link ID that gives it a location in the network
9. Create a CarrierCapabilities object using the CarrierFactory

STEP 2 – CREATE VEHICLES FOR CARRIERS

1. Initialise a Collection of CarrierVehicle objects
2. Create vehicle types
3. Set capacities, types, and end times for these vehicles
4. Add each CarrierVehicle object to the Collection of CarrierVehicle objects
5. Link the carrier with the vehicles created by invoking the setCarrierCapabilities method on the carrier itself

STEP 3 – CREATE SHIPMENTS

1. Initialise a Collection of CarrierShipment objects

2. Create an Id object called “from” using a method of the Carrier object that is to receive shipments
3. Create a TimeWindow object using a method of the CarrierFactory for both the pickup and delivery time windows
4. Create an Id object for each shipment destination
5. Create a CarrierShipment object for each shipment by using the appropriate CarrierFactory method
6. Add each shipment to the Collection of CarrierShipment objects
7. Create/define appropriate vehicle operating and fixed costs

Step 4 – Allocate vehicles to shipments

1. Create DTWSolverFactory object
2. Create MatsimVrpSolver object using DTWSolverFactoy methods – this is done taking carrierShipments, carrierVehicles, the network, tourCost and operating costs of the truck as input
3. Create a Collection of ScheduledTour objects by the MatsimVrpSolver.solve() method
4. Create a CarrierPlan object using the appropriate CarrierFactory method
5. Set the selected plan using the “setSelectedPlan” method of the Carrier object
6. add the Carrier to the Collection of Carrier objects

Step 5 – Route vehicles

1. Create a new ScheduleVehicles object, use the “handleCarrier” method
2. Create a new RouteVehicles onject, sustituting appropriate variables

Step 6 – Write carrier plans

1. create CarrierPlanWriter object taking “carriers” as input
2. instruct writer to write to an appropriate output directory

Plans would now have been written to an .xml file and can be imported using controller listeners in MATSim. Freight vehicle agents will then travel in the network alongside private vehicles and their influence on congestion and traffic behaviour can then be assessed.