MASS-GT
Model documentation

Document control page

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Contributors	Michiel De Bok, Ali Nadi, Lorant Tavasszy, Sebastiaan Thoen, Larissa Eggers

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3.0	06/07/2023	MASS GT version for developed in project HARMONY as Tactical Freight Simulator

Content

1 Introduction

MASS-GT is an agent-based freight simulation package that models urban and regional logistics and freight transport activities. This model simulates individual firms, shipments, and logistic choices of freight stakeholders. It synthesizes the disaggregated freight demand and assigns it to truck tours and their corresponding trips. It consists of four functional modules: the shipment synthesizer which simulates the choices on a long-term tactical level; the parcel demand synthesizer which identifies the parcel demand; the shipment scheduling module which deals with decisions on a short-term tactical level; and the parcel scheduling module that simulates short-term parcel related decisions. In addition auxiliary modules are used for firm synthesis, network analysis, or calculation of KPIs.

About the implementation of the model:

- The model is developed in Python as open-source
- Access to the model's code can be obtained through the GitHub page: https://github.com/mass-gt
- For visualisation of input data or results, the use of GIS software is highly recommended (ArcGIS or QGIS)
- More information about the background of the MASS-GT project see the department's project page for further information: https://www.tudelft.nl/transport/onderzoeksthemas/goederenvervoer-logistiek/sleutelprojecten/mass-gt

The purpose of this model documentation is to provide a reference for users that intend to use the model. As such is provides a description of the model itself. Application of the model is very much dependent on the use case. As an illustration a manual is provided for one of the use-cases.

About this version: MASS-GT v3 was developed as a new release in the H2020 project HARMONY. In this project MASS-GT was further developed as the Tactical freight Simulator and integrated in the HARMONY MS.

This documentation describes the model structure, specifications of each functional module, and provides an overview of input- and output files. Finally, some guidance is provided about applying the model: it gives some general comments for starting to use the model, and provides a user manual for one of the use cases that was implemented in the model.

2 Model structure

2.1 Conceptual model

MASS-GT is a multi-agent simulation model of urban freight transport activities. In the real world, decisions related to freight transport can be divided into two levels. The first level includes the decisions related to shipments. MASS-GT models these decisions explicitly. The second level relates to the tour planning decisions. A manifold number of actors influence the decisions made in freight transport markets (Marcucci, et al., 2017). Thus, MASS-GT simulates choices on the level of individual firms. This accounts for behavioural decision-making, costs, and constraints that are in many cases, agent-specific.

The first step in developing the conceptual framework of MASS-GT is to define the markets, the agents and their choices and decisions. To accurately conceptualise the logistics process, we first need to distinguish between consumers and producers of goods. The flows of shipments start from the production firms and end with the consumers. These flows can either be direct or via one or more logistics nodes (i.e. distribution centres - DCs - or transhipment terminals). Figure 2-1 illustrates the possible flows of shipments between producers and consumers and identifies the connections between logistic choices. These logistic choices are vehicle type choice, distribution channel choice, shipment size choice, tour formation and time of day choices. MASS-GT has specific modules to model each of these logistic decisions.

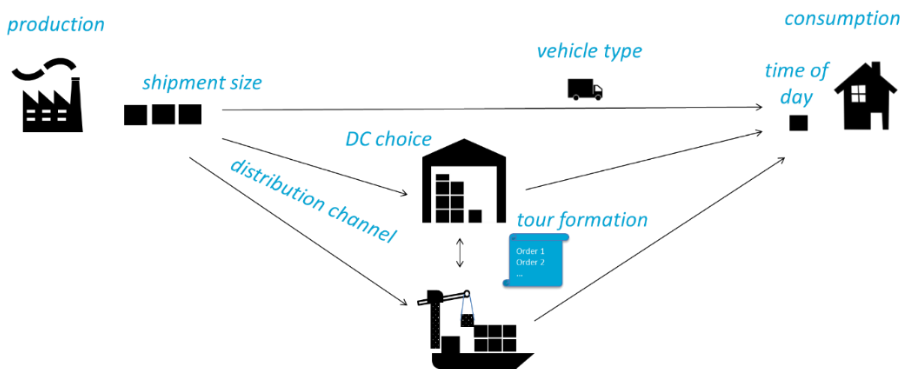

Figure 2-1: Conceptual model MASS-GT (de Bok & Tavasszy, 2018)

MASS-GT defines three types of decision-makers (agents) who can make the above logistic decisions. (1) Producers and, in the case of outsourced transport, Logistics Service Providers (LSPs) define the size of shipments and the choice of distribution channels; (2) Carriers and LSPs with their own-account transport choose the type of vehicle and then decide on the sequence of pickups and deliveries (Tour formation); (3) Receivers of goods set the time-of-day delivery requirements.

Although local authorities provide the transport infrastructure, they are not represented directly in MASS-GT. However, their policies and behaviours can be seen as a part of the use cases and what-if analysis.

2.2 Technical design

This section presents the structure of MASS-GT. Figure 2-2 shows all functional modules and main (intermediate) outcomes of these modules. MASS-GT uses a number of strategic scenario inputs and results can be used as input to traffic simulators, either macroscopic or microsimulation.

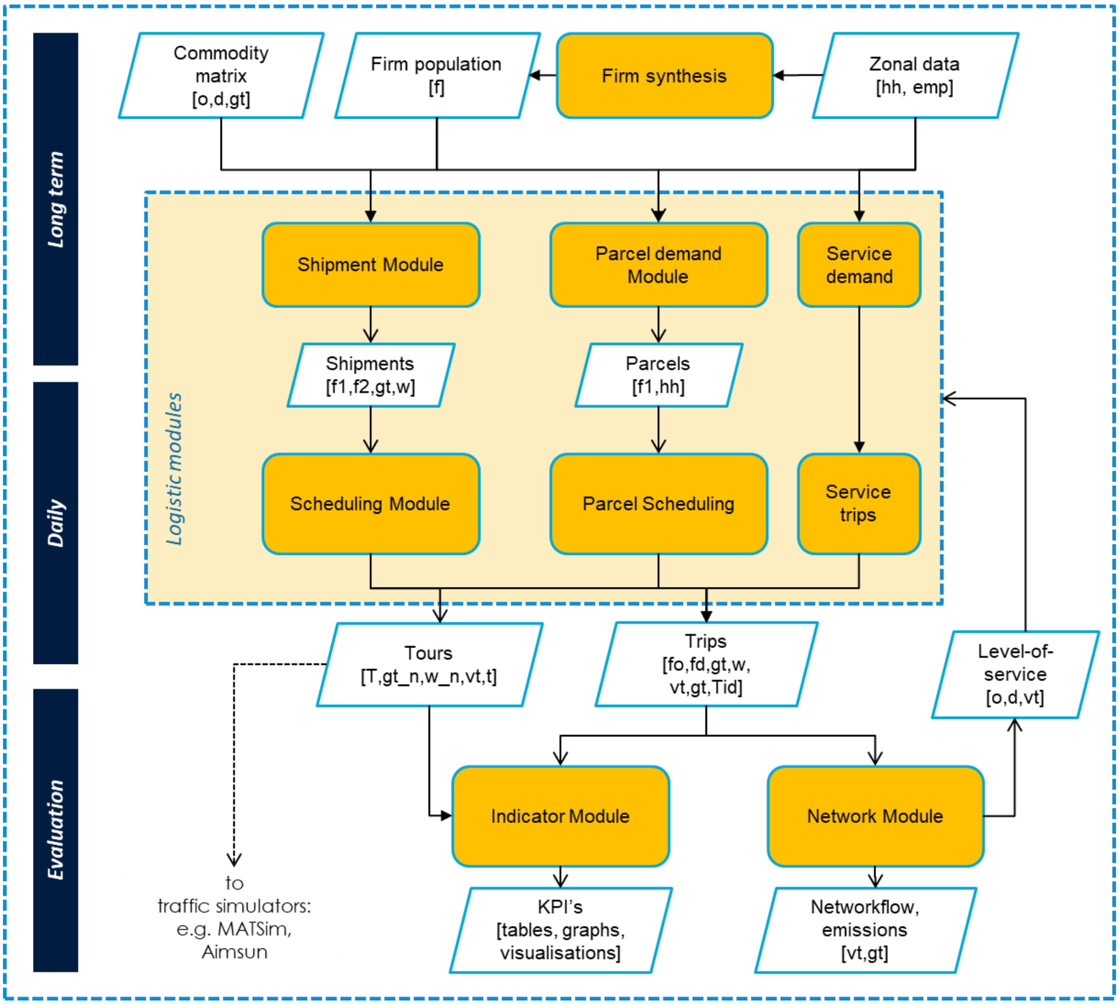

Figure 2-2: MASS-GT v3

MASS-GT distinguishes three main segments of urban commercial vehicle movements: Freight Shipments, Parcels, and Services. The model also distinguishes two phases. The first phase is the long-term tactical level that simulates shipment- and parcel demand in the shipment synthesis or demand modules. The second phase is the daily scheduling of the final transport movements in the scheduling modules. Separate scheduling modules are developed for freight shipments and parcel delivery because the size and consolidation of individual products (shipments or parcels) are inherently distinct.

Specifically, the shipment synthesizer builds a set of shipments that are transported in the study area. To create this set of shipments, an event-based simulation is used for the following logistic processes: producer selection; distribution channel choices; shipment size & vehicle type choice; and desired delivery time. On the other hand, the scheduling module simulates the formation of tours, chooses the time for each tour based on the desired delivery times, and optimizes the vehicle type choice.

Time-of-day decisions are simulated both in the Shipment Synthesizer module, and the Scheduling module. In the shipment module first, a choice for the desired delivery time for each shipment is determined. In the scheduling module, the desired delivery time is taken into account in the selection of shipments that are considered for consolidation, the delivery order, and the tour departure time.

Parcel deliveries follow different transport patterns compared to other types of goods flows. They are delivered by Light Commercial Vehicles (LCVs) with distribution patterns that usually originate from a DC. Parcel delivery is hardly ever represented in conventional freight models. However, parcel delivery is an important component in city logistics since it creates a large number of vehicle movements in the urban environment. The parcel demand module simulates the demand for parcels and creates a synthetic set of parcel demand for households and businesses (receivers) that are allocated to a parcel carrier and its DC (origin). The parcel scheduling module simulates the allocation of parcels to vehicles and creates delivery tours. These can be used as input for network modules for emission calculations or for traffic assignment in the Operational simulators.

MASS-GT is also equipped with auxiliary modules to generate a synthetic firm population or to analyse the outcomes of the logistic modules:

- The indicator module: this module calculates the Key Performance Indicators (KPIs) that assess the effect of the different policies and future development scenarios on the system.
- The network module: this module simulates route choice for each vehicle and calculates emissions that can be used for policy evaluation.

Most of the inputs to MASS-GT are based on standard data from conventional transport models: networks, socio-economic data and additional data on the location of logistic nodes. The firm population is synthesized from the zonal employment by industry sector. The aggregate commodity demand matrix is derived from an external source, preferable an intermodal freight transport demand model. MASS-GT was developed using a freight commodity demand matrix (for base year and forecast years) from the Dutch National Freight Model BasGoed. Also, other sources can be used for the aggregate commodity demand forecast, e.g. in one of the scenario applications the regional freight demand forecasts were derived from the European transport model TRUST.

In the following chapter the technical modules are described for each of the main segments in the simulator: Freight Shipments, Parcels, and Services.

3 Technical specification of modules

3.1 Simulation of freight shipments

3.1.1 Shipment module

The shipment simulator follows a stepwise procedure where different logistics choices are simulated one after the other. Figure 3-1 represents the steps described below.

- step 1: The first step is to assign, on an aggregate level, the total freight transport demand to distribution channels. This step calculates the share of each logistics segment for transporting goods directly, via a distribution channel, or via a multimodal transshipment terminal. At the end of this step, a flow matrix of origin and destination pairs per flow type and per logistics segment is created.
- step 2: In this step, the simultaneous choice of the shipment size and the vehicle type is defined using a discrete choice model. The result is that commodity flows are broken into individual shipments with preferred vehicle types.
- step 3: From this step onwards, simulation is done on a disaggregate firm/shipment level. In this step, each shipment is assigned to a receiver (destination of the shipment). This allocation is based on I/O statistics: the receiver probability of a firm *f* of a shipment in a logistics segment *ls* depends on the firm size and the ‘use’ probability for the industry sector.
- step 4: Next the supplier of the shipment is selected on the same principle: the supplier probability of firm *f* belonging to sector *s*, being the supplier of a shipment belonging to a logistics segment *ls* depends on the firm size and ‘make’ probability for the sector. Hence, the origin of each shipment is defined.
- step 5: In this last step the desired time window for delivery is simulated. This time-of-day choice is modelled using a multinomial logit (MNL) model that predicts the probability of each time period, based on the logistic segment, vehicle type, and location types of the loading and unloading zone. Five time periods are distinguished (00–08;08-11;11-16;16-19;19-24).

The final output of the synthesizer is a set of synthetic shipments with origin (sending firm/logistic node), destination (receiving firm), shipment size, commodity type (NSTR code), the vehicle type and the desired delivery time.

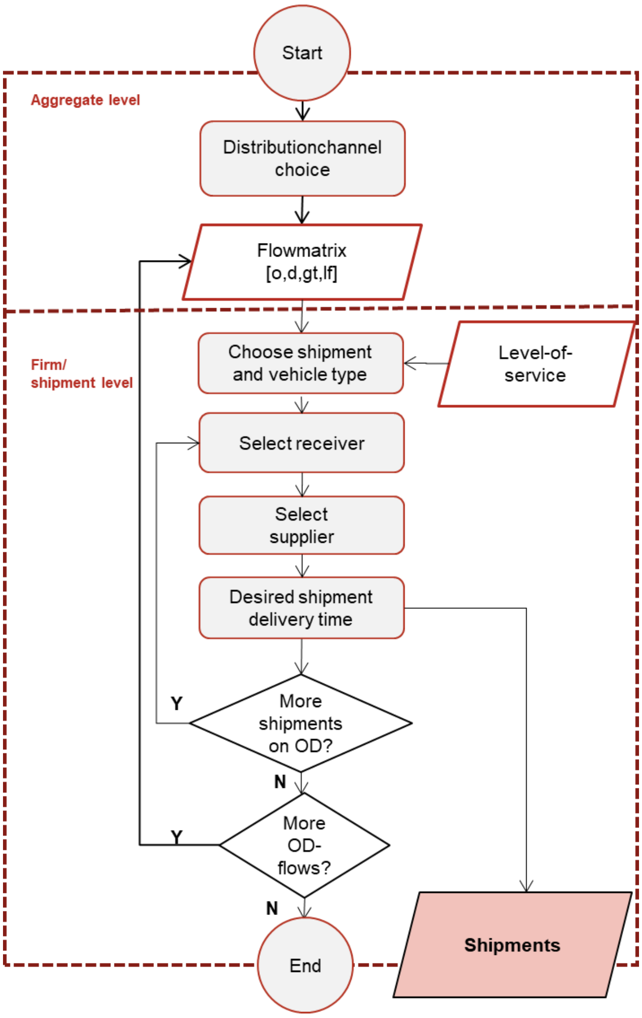

Figure 3-1: Shipment synthesizer structure

3.1.2 The Shipment Scheduling module

The objective of the shipment scheduling module is to simulate the daily round tours of freight vehicles. This daily decision-making involves two choice dimensions: first tour-formation and secondly delivery time optimisation. Starting point is the shipments created in the shipment synthesizer module. The synthetic shipments provide the information to take into consideration several logistical constraints, such as the size of shipment or vehicle, and the available set of shipments to build tours with. The procedure developed is based on the principle that carriers build tours by repeatedly selecting shipments from the pool of shipments created in the shipment synthesizer, until the tour is long enough (Thoen et al., 2020). The two logistic choices modeled in this approach are (1) whether a tour can be completed or not; adding, in the latter case, an additional shipment (the “End Tour” choice) and (2) which shipment to add to the tour from those not yet served (“Select Shipment” choice). In selecting the shipments, the desired delivery time is taken into consideration to build logical consolidation patterns. Finally, the order of shipments is optimized using an effective two-phased optimization procedure: first the nearest neighbour search is applied to form a logical order of loading locations and then unloading locations. In a second step, the order within this final consolidation set of shipments is optimized using the 2-opt local search algorithm.

The scheduling is applied at the level of all carriers. By looping over all carriers, the following heuristic approach is applied:

- Step 1: Determine the universal choice set of shipments to be collected/distributed during that day.
- Step 2: Select the first shipment of the tour. The first order is picked randomly. This would add a certain level of randomness to the model. However, its impact on the overal result of the simulation is negligible.
- Step 3: Construct tour schedule.
- Step 4: Simulate consolidation decision: add shipment? Based on an empirical binary choice model (see Calibration section).
- Step 5 (conditional): Conditional: determine a feasible choice set. This set contains only shipments from the same logistic segment and of two aligning time periods.
- Step 6 (conditional): Choose the most efficient shipment to add to the round tour based on distance.
- Go back to Step 3.
- Step 7: When step 4 gives No: end the tour.
- Step 8: Initial route order of loading and unloading locations using the nearest neighbour search.
- Step 9: The second stage of optimisation of route order, using 2-opt local search algorithm.

Figure 3-2 shows the flow of the overall scheduling module for all carriers within a simulated day.

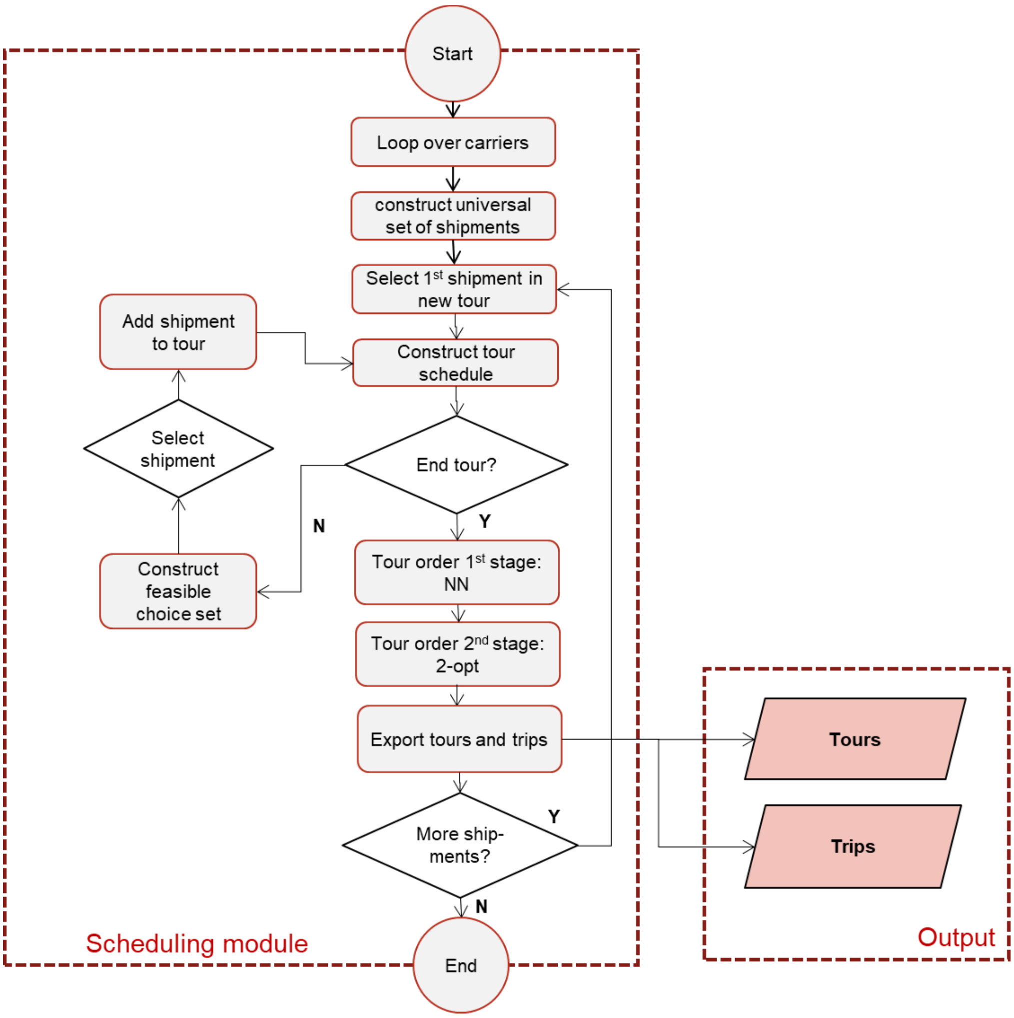

Figure 3-2: Flow graph of the scheduling module

In the shipment scheduling module, It is assumed that all the shipments will be assigned and scheduled within the simulation day.

3.2 Simulation of parcels

Parcel delivery is not represented in conventional freight models. However, parcel delivery is an important component in city logistics: it creates a large number of vehicle movements between DC's and delivery locations. Most vehicle movements are with LCV. Therefore in MASS-GT parcel delivery is simulated explicitly.

For the simulation of parcels, we have developed a simple but logical procedure that is mostly built on inputs that are already used in freight demand simulation (like networks, household data, and employment location), and publicly available data (such as the size of the B2C and B2B parcel markets and market shares of parcel carriers). The design of the module includes a number of scenario parameters:

- Demand parameters for parcel demand by households and businesses;
- Growth parameters for parcel markets;
- Probability of delivery success;
- Parameters for vehicle capacity.

The demand and delivery patterns of parcels in the study are simulated using two modules:

- The Parcel Demand Module simulates the demand for parcels and creates a synthetic set of parcels, with origin (DC) and receiver (TAZ)
- The Parcel Scheduling Module simulates the allocation of parcels to vehicles and creates delivery tours.

The output can be used as input to network assignment to determine the emissions of the parcel delivery tours, or the schedules and trips can be input to the operational simulator. Furthermore, the impact of different delivery success rates or market growth assumptions can be tested.

3.2.1 Parcel Demand Module

The parcel demand module estimates the demand for B2C and B2B parcels using household and employment populations on the one hand, and the networks of parcel and express carriers (CEP) in the study area on the other hand. It considers only one parcel type and takes into account general demand parameters for the B2C and B2B market segments. Figure 3-3 shows the simulation procedure.

The module first calculates the B2B parcel demand by multiplying zonal employment and a parameter for the daily number of parcels per employee. The latter is derived from the statistics of the total B2B parcel market size which is available in the official Market Monitor data[1] and publicly available sociodemographic data.

Next, the module calculates zonal B2C parcel demand. It is fair to assume that the frequency with which a person receives parcels greatly differs between individuals and is among other factors dependent on their age, income, location of residence and personal preferences. To capture this, we developed an ordered logit model and estimated it on data from the MPN (Mobility Panel

[1] https://www.acm.nl/nl/publicaties/post-en-pakkettenmonitor-2019

Netherlands). The model explains the online shopping frequency of a person as a function of their personal and household characteristics (age, household income, urbanization level at their location of residence). As the household composition differs between zones in the study area, the obtained parcel demand also differs between zones, in absolute numbers as well as in terms of the number of parcels per person per day.

To correct for the year of observations in the MPN and the base year of MASS-GT, the B2C demand is then calibrated to match the observed parcel market size from the official Market Monitor data for the base year of MASS-GT. This procedure preserves the differences in demand between zones while ensuring that the total demand is accurate.

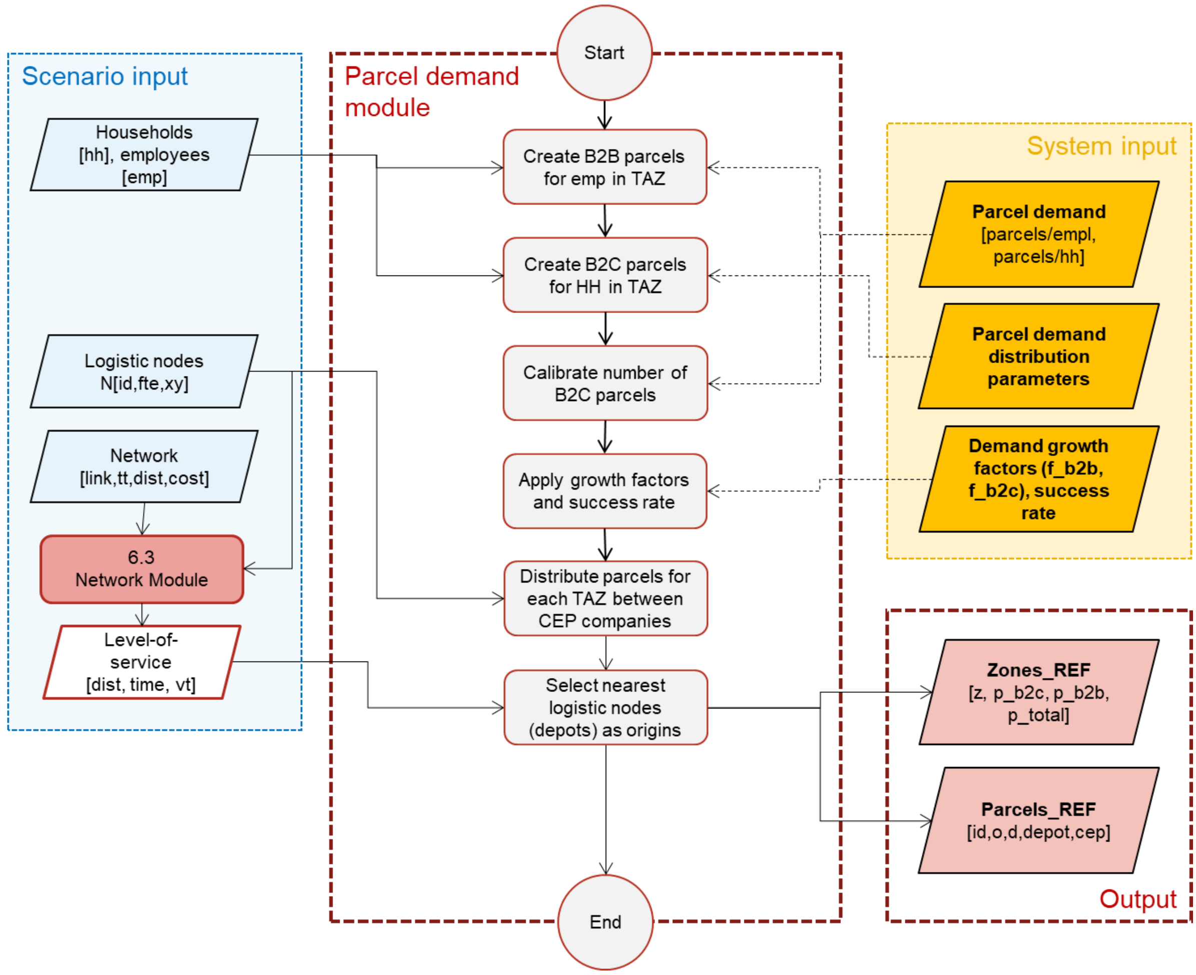

Figure 3-3: The parcel demand module structure

After this step, growth factors and delivery success rates can be applied. The delivery success rate (B2C and B2B separately) is a number between 0 and 1 and reflects the share of parcels for which the delivery attempt fails. Failed deliveries need to be repeated and thus increase the number of tours. The growth factors (again B2C and B2B) are applied to the market size and can be used to test future growth assumptions. Both can be set to 1 in the control file if no effect is desired.

Next, parcel demand (for both segments combined) is allocated to parcel and express companies (CEP). The CEP's observed market shares in the domestic parcel market are applied here. This data is available from open market data publications.

In the final step, the parcels are assigned to a depot from the corresponding CEP. It is assumed that each CEP has optimized its operations to deliver each parcel from the nearest depot. The output is a set of parcels with an origin (a depot) and a destination (a zone in which households and/or businesses are located).

3.2.2 Parcel Scheduling Module

The parcel scheduling module considers the parcel demand and consolidates them to create delivery tours. The parcel scheduling module uses as input the parcels predicted by the parcel synthesizer. It then simulates the formation of delivery tours for the distribution of these parcels. (See Figure 3-4)

First, a list of parcels that are to be delivered in a specific zone is created and each list is assigned to a specific depot based on the proximity to the destination. Then for each depot, a pool of parcels is created.

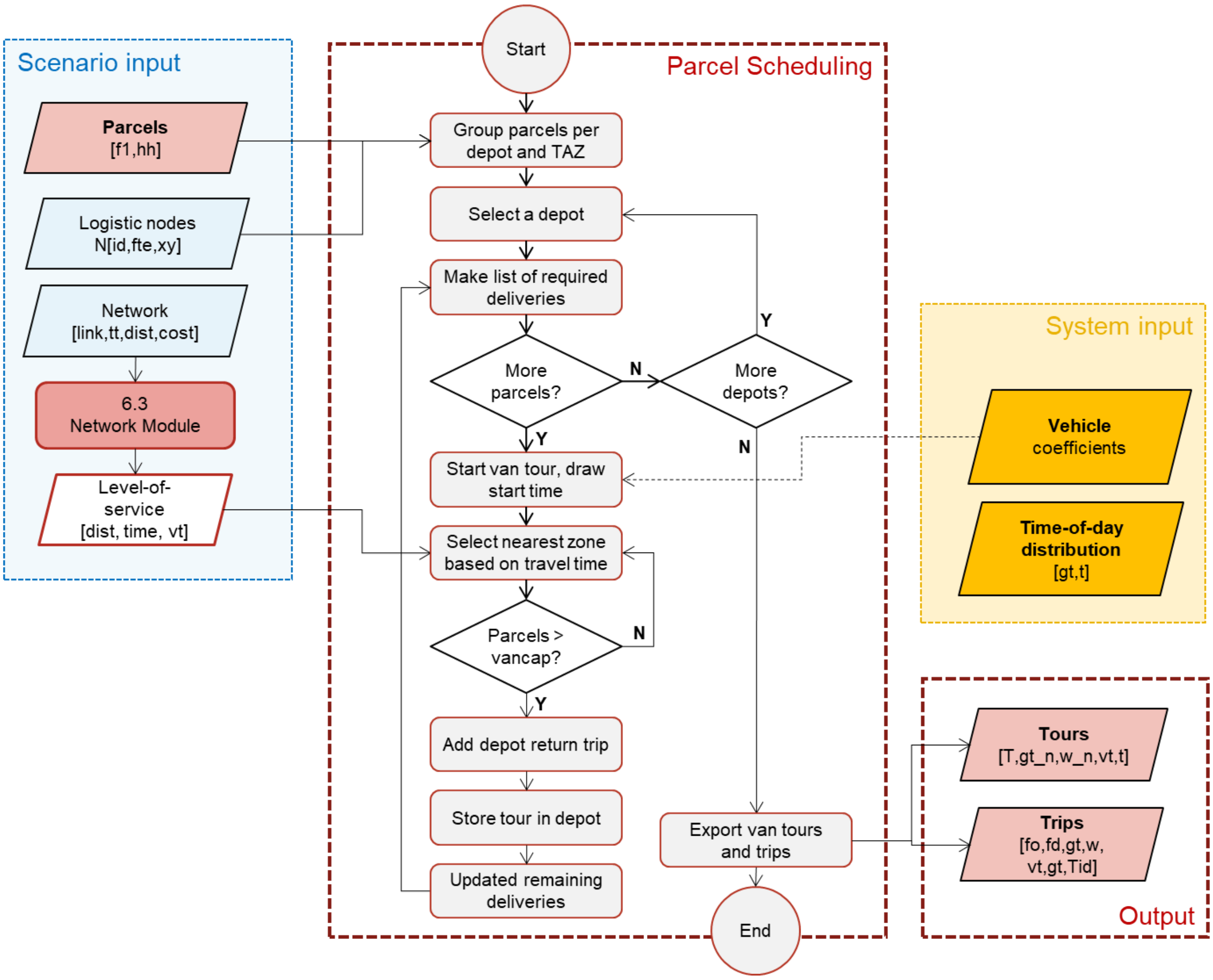

Figure 3-4 The parcel scheduling module

Based on the delivery location more parcels are added to the tour. The maximum number of parcels in a tour is assumed to be equal to the maximum capacity of the vehicle. For this we assumed 180 parcels. Once all parcels from the pool are allocated to delivery tours, the start time of the tour is drawn from a time-of-day distribution. The selection of the nearest zone is based on travel time. In case the delivery of the parcel was unsuccessful, then the van returns and stores the parcels in the depot. The list of remaining parcels is updated and they are again put in the loop to be added to new parcels lists. Once all parcels are scheduled then a matrix of tours and trips is created. Each tour is described by its trips (*T*), the vehicle type (vt), the start time (t) and the parcels it consists of (type of parcel: gt_n and weight of parcel: *w_n*). Each trip is described by its origin and destination (*fo, fd*) by the goods type (*gt*) the weight (*w*), the vehicle type (*vt*), and by the tour ID (*Tid*).

3.3 Simulation of service trips

The purpose of the service trip module is to calculate the service trips that are made in light-commercial vehicles (LCV's) and can also be considered a relevant segment in city logistics. The module simulates the LCV trips for the services and construction segments. The module first predicts the number of trips generated per zone (trip production and attraction model), and then the OD pattern of trips (gravity model). This module consists of two main steps i.e. Service demand (production/attraction of service trips) and service trips (trip distribution).

3.3.1 Service demand

This module estimates the trip production and attraction per zone for service trips: how many trips are leaving per traffic analysis zones (TAZ) and how many trips are arriving per TAZ. To do this, regression analysis at the zone level was used. In these equations, zone-level socioeconomic data are multiplied by the estimated production/attraction factors. The service demand module uses separate equations for the service and construction segments. The regression equations, like those for freight traffic, have a linear-additive form.

3.3.2 Service trip distribution

In the service trip distribution, the productions and attractions from the Service demand module are used to form a matrix with the number of trips between the TAZ zones. After determining the productions and attractions, the number of trips between each OD is determined with a gravity model. For this, the module uses the productions and attractions (number of rides) of the TAZ zones and the travel costs per OD as inputs. It calculates the travel costs using the off-peak travel times and distances with unit cost (costs per hour and per kilometre). See Table 3-1 for the LCV unit costs from BasGoed. the fixed costs are assumed to be fixed even over time. They are made up of wages for the drivers and general costs that a transport company has, such as management and planning. They are not corrected for inflation based on the assumption that inflation does not influence choice behaviour. A small proportion of trips is at a small distance, within the zone, therefore for intra-zonal relations, we assume that the travel cost is half of the travel cost to the nearest zone.

Table 3-1: The cost indicators for delivery vans (LCV), from BasGoed

Year / scenario	Variable costs (€/km)	Fixed (€/hour)
2014	0.1644	29.00
2018	0.1551	29.00
2026	0.1548	29.00
2030H	0.1532	29.00
2030L	0.1895	29.00
2040H	0.1565	29.00
2040L	0.1975	29.00
2050H	0.1599	29.00
2050L	0.2017	29.00

An initial OD matrix is constructed using the following gravity equation:

$$M_{ij} = \frac{100}{1 + \exp(alpha) * \ c_{ij}{}^{beta}} * p_i * \ a_j$$

With:

M_{ij} : The initial number of journeys between origin i and destination j.

c_{ij} : Travel costs between origin i and destination j (euro).

p_i : The production of trips in zone i.

a_j : The attraction of trips in zone i.

For the estimation of alpha and beta see the calibration chapter.

Once the initial OD matrix is filled, it should be scaled to the totals of production and attraction per TAZ. This is done with a FRATAR method. The desired convergence (maximum allowable deviation of initial row total/column total compared to scaled row total/column total) and the maximum number of iterations can be set in the control file.

Finally, the journeys are divided over three day periods according to the shares in the following table.

Table 3-2: time-of-day distribution for service trips

Time of day	Share
Morning	0.151
Rest of the day	0.683
Afternoon	0.166

3.4 Auxiliary Simulators

3.4.1 Firm synthesizer

The objective of the firm synthesis is to generate a synthetic population for firm agents. These agents are input for the tactical simulators, for freight and passenger demand. In this case, an individual firm is defined as a business premise, as it determines the location where freight and mobility demand is generated. The characteristics of the population that needs to be generated include firm sector, firm size, and location for each individual firm.

Existing examples of firm population synthesis include works by Ryan, Maoh, & Kanaroglou (2009), Samimi et al. (2014) and Abed et al. (2014). Each approach differs based on available data or scope of application. In the types of approaches applied for firm synthesis, three types of methodologies can be distinguished: Iterative Proportional Updating (IPU), Combinatorial Optimization and Simulation Methods. As an alternative to firm synthesis techniques, also dynamic firm demographic approaches have been applied, such as Moeckel (2007); De Bok (2009). However, the scope of these approaches is to study the dynamic evolutionary development of the population, where in MASS-GT the aim is to generate a synthetic firm population as a starting point for freight transport demand predictions. The synthetic firm population plays an important role in the generation of freight transport demand.

3.4.1.1 Methodology

The Firm Synthesizer (FS) uses a simulation-based approach and discretises zonal employment data into individual firms using draws from a joint distribution of firm sizes and industry sectors. This works with macro-level input data that is readily available for most areas. The required input data is as follows:

- A zoning system (spatial scale?)
- Zonal data: Number of employees per sector
- Joint distribution (cross table) of firm sizes (in categories) and sectors (same as in zonal data)
- Optional: table with logistic nodes (distribution centres and trans-shipment terminals)
- Optional: table with employment in logistics

The module, developed for the Rotterdam area (MRDH zones), distinguishes the six employment sectors retail, manufacturing, service, agriculture, public sector and other, as well as six firm size categories, defined by the number of employees (in terms of Full Time Employees units, FTE) per firm (see Table 3-3).

Table 3-3: Employment size categories

Employment size S	Number of employees (CBS definition)
Micro	1 2 3-5
Small	5-10
Medium-small	10-20
Medium	20-50
Medium-large	50-100
Large	>100

Logistic freight agents

Figure *3-5* shows a flow chart of the firm synthesizer. The first step is to quantify the logistic freight agents. Since the freight agents are crucial in the simulation of urban freight patterns, the logistic nodes (distribution centres and trans-shipment terminals) are fixed agents in the firm population. This means they are exogenous input, that are combined with the synthetic population of producing and consuming firms. To avoid double counting, the employment of these logistic nodes is subtracted from the zonal employment data before starting the synthesizing procedure that generates the producing and consuming forms. The following approach is used for these two types of agents:

- Employment in distribution centres (DCs) are known and given by a separate input file; the jobs in DCs are removed from the zonal employment data so as to avoid double counting
- Zones with trans-shipment terminals are treated separately in MASS-GT; in the zonal data, the employment in the sector INDUSTRIE is set to zero.

Synthesizing firms

In the next steps of the synthesizer, the firm population of producing and consuming firms are synthesized based on the zonal employment. The module loops over all zones in the study area, and for each zone over all industry sectors. For a given zone and sector, a firm with size class S is drawn from the sector's corresponding firm size distribution. The joint distribution of firm size and sectors is based on data from Statistics Netherlands (CBS).

In the next step, the exact number of employees is drawn from a uniform distribution between the lower and upper limit of the size category S; only for the largest size category, a triangular distribution is used, with upper limit b and mode c as system input. In the current version if the FS, the parameters b and c were determined heuristically such that the total number of synthesized firms closely matches the actual number of firms in the study area. Finally, the firm is given a random location within the transport zone. Firms are allocated to the surface area of the zones, so this should at least cover land surface only and avoid large water areas, e.g. rivers, lakes.

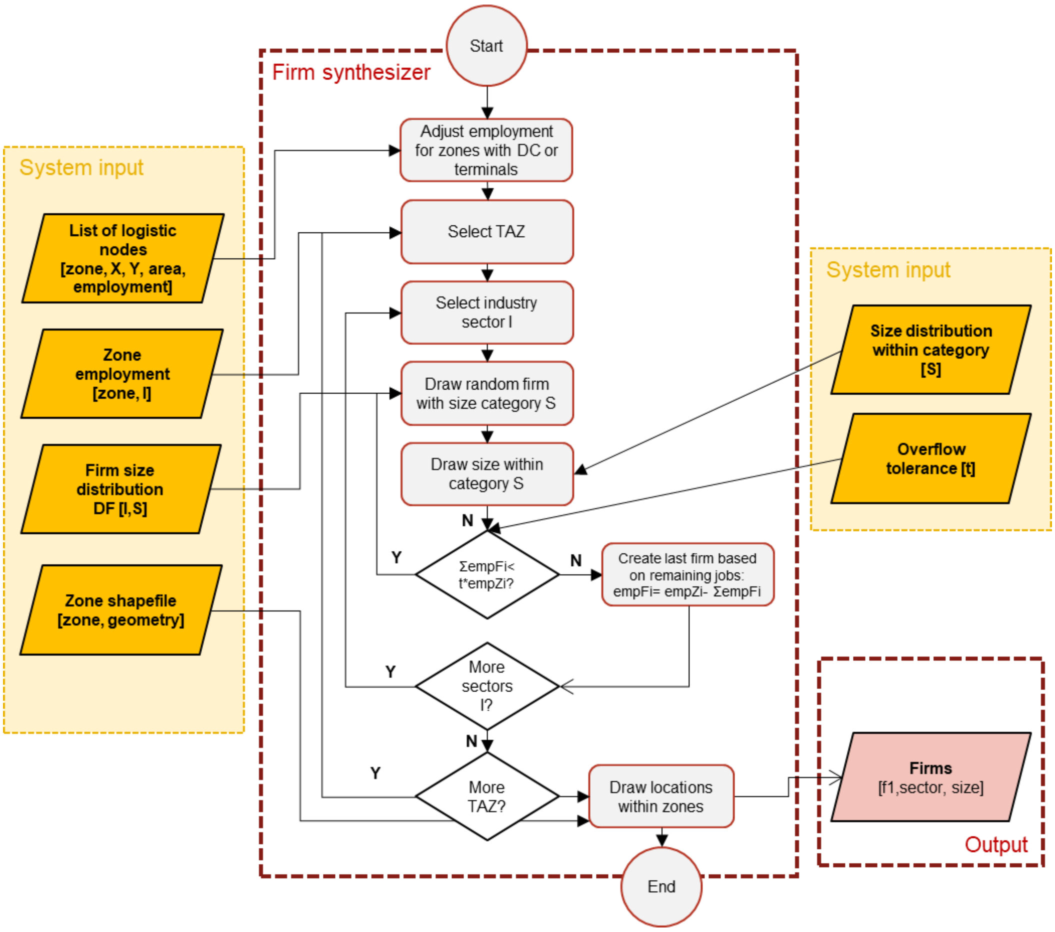

Figure 3-5 : Flow chart Firm Synthesizer

Finally, Figure 3-6 shows an illustration of the simulated firm population in a part of the study area, with a zoom-in to the city centre area of Rotterdam.

Figure 3-6: Simulated firm population

3.4.2 The Network Module

The network module simulates route choices for each freight trip. The module has two objectives: first of all, to derive travel time and distances for each transport, and second, the emissions of each freight vehicle.

Step 1. Route choice

Based on Dijkstra's algorithm using a congested traffic network from the static traffic assignment of the V-RMDH model.

Step 2. Emission calculation

Emissions are calculated for each vehicle route. The emissions are calculated for CO2, SO2, PM, and NOX using emission factors for the g/km emissions. For this, an average-speed approach is used with emission factors segmented by:

- Road type (urban, highway, country rural)
- Vehicle type
- Load factor

The unit emission factors are derived from the European STREAM method (CE Delft, 2021). The emission factors are provided for an empty vehicle and a full vehicle. Interpolation between the emission factor for an empty vehicle and a full vehicle allows selecting the right emission factor for a given loading rate. For each trip, we calculate the emissions on each visited link by multiplying the link distance with the according emission factor.

The outputs of the module consists of a network with intensities of freight traffic (individual vehicles) and the emissions on each network link.

3.4.3 The Indicator Module

The HARMONY simulators generate the KPI's that are required for evaluation of policies or use cases. MASS-GT has an auxiliary module that generates the KPI's from the simulation results. As the outputs of the simulator are very detailed (at the firm, shipment, and tour level), and cover a large study area, a dedicated module was created to have a systematic derivation of KPI's.

The following table specifies the KPI's that are calculated in the Indicator Module. For each indicator, it is specified how it is measured and what is the intended use.

Table 3-4: KPI's from the indicator module

KPI	Unit to be counted	Description & Objective
Nr of trips per flow type	Nr of trips per flow type	Measure local freight
Trips per vehicle type	Nr of trips per vehicle tye	Measure local freight vehicle flow
Trips per logistics segment	Nr of trips per logistics segment	Measure flow patterns per logistics segment
Transported weight	Weight in tonnes per logistics flow type	Measure transport demand
Transported weight per logistics segment	Weight in tonnes per logistics segment	Measure transport demand
Transported weight per vehicle type (and combustion type)	Weight in tonnes per vehicle type (and combustion type)	Measure transport demand
Tonkilometers	Ton x KM	Measure transport demand
Vehicle type use	Kms per vehicle type	Nr of vehicle kilometers per vehicle type. Measure transport performance
Average load carried in trip by LS	Weight in tonnes per trip per logistics segment	Measure transport efficiency
Average load carried in trip by vehicle type	Weight in tonnes per trip per vehicle type	Measure transport efficiency
Number of shipments	Number of shipments per tour per logistics segment	Measure transport efficiency
Vehicle kilometers by LF	kms per logistics flow	Measure transport performance
Vehicle kilometers by LS	kms per logistics segment	Measure transport performance
Vehicle kilometers by vehicle type	kms per vehicle type	Measure transport performance
Transport costs	Euros	Total costs

In addition, some indicators are measured at the level of network links. These indicators are calculated in the Network Module, described in paragraph 3.4.2. For completeness, the following table specifies the relevant indicators from the network module.

Table 3-5: KPI's from the network module

KPI	Unit 16ob e counted	Description & Objective
Traffic delay	Minutes	
Emissions (total)	Kgrs (CO2, SO2, PMw, NOx)	Measure total GHG emissions per gas type
Emissions by LS	Kgrs (CO2, SO2, PMw, NOx) per logistics segment	Compare logistic segments in terms of emissions
Emissions by vehicle type	Kgrs (CO2, SO2, PMw, NOx) per vehicle type	Measure total GHG emissions per gas type
Emissions by municipality (or other zonal aggregation)	Kgrs (CO2, SO2, PMw, NOx) per municipality	Measure spatial spread of impact on emissions
Traffic intensities HGV by vehicle type	Nr of vehicles per vehicle type	Measure transport performance

KPI	Unit 16ob e counted	Description & Objective
Traffic intensities HGV by commodity type	Nr of vehicles per commodity type	Measure transport performance

4 Overview of input, output and parameter files

Previous sections introduced the modules of MASS-GT. This section gives an overview of the input, output and parameter files.

MASS-GT first of all works with a control file that sets the main parameter for the simulations. For different use cases, the modeler can turn on or off some modules or change the initial parameters. A specification of all parameters in the control file are described in Table 4-1.

Table 4-1: Control parameters of the tactical freight simulator

Other control file parameters	Used by module(s)	Description
YEARFACTOR	SHIP, SERVICE	Factor to go from year level to daily level tonnes
NUTSLEVEL_INPUT	SIF	NUTS zone level of input commodity matrix (2 or 3)
PARCELS_PER_HH	PARCEL_DMND	Number of parcels per household per day
PARCELS_PER_EMPL	PARCEL_DMND	Number of parcels per job per day
PARCELS_MAXLOAD	PARCEL_SCHD	Maximum number of parcels carried in a van
PARCELS_DROPTIME	PARCEL_SCHD	The time in seconds that it takes to deliver a parcel
PARCELS_SUCCESS_B2C	PARCEL_DMND	The delivery success rate of B2C-parcels
PARCELS_SUCCESS_B2B	PARCEL_DMND	The delivery success rate of B2B-parcels
PARCELS_GROWTHFREIGHT	SHIP	Factor to let the consolidated freight flows of parcels between distribution centers increase
IMPEDANCE_SPEED_FREIGHT	TRAF	Which field in links.shp to use for link travel times in route search for freight vehicles
IMPEDANCE_SPEED_VAN	TRAF	Which field in links.shp to use for link travel times in route search for vans
CRW_PARCELSHARE	PARCEL_DMND	Share of parcels that are eligible for crowdshipping (only used in crowdshipping use case)
SHIPMENTS_REF	SHIP	In the UCC scenario, which reference shipments to reroute (path to output CSV)
N_CPU	TOUR, TRAF	Number of cores over which to parallelize tasks (default to the number of available cores minus 1)

For an overview of the input-output connections of the files used by the modules a graphical representation is also visualized in the following figure. It gives a graphical representation of inputs, outputs, and interaction between the modules in MASS-GT.

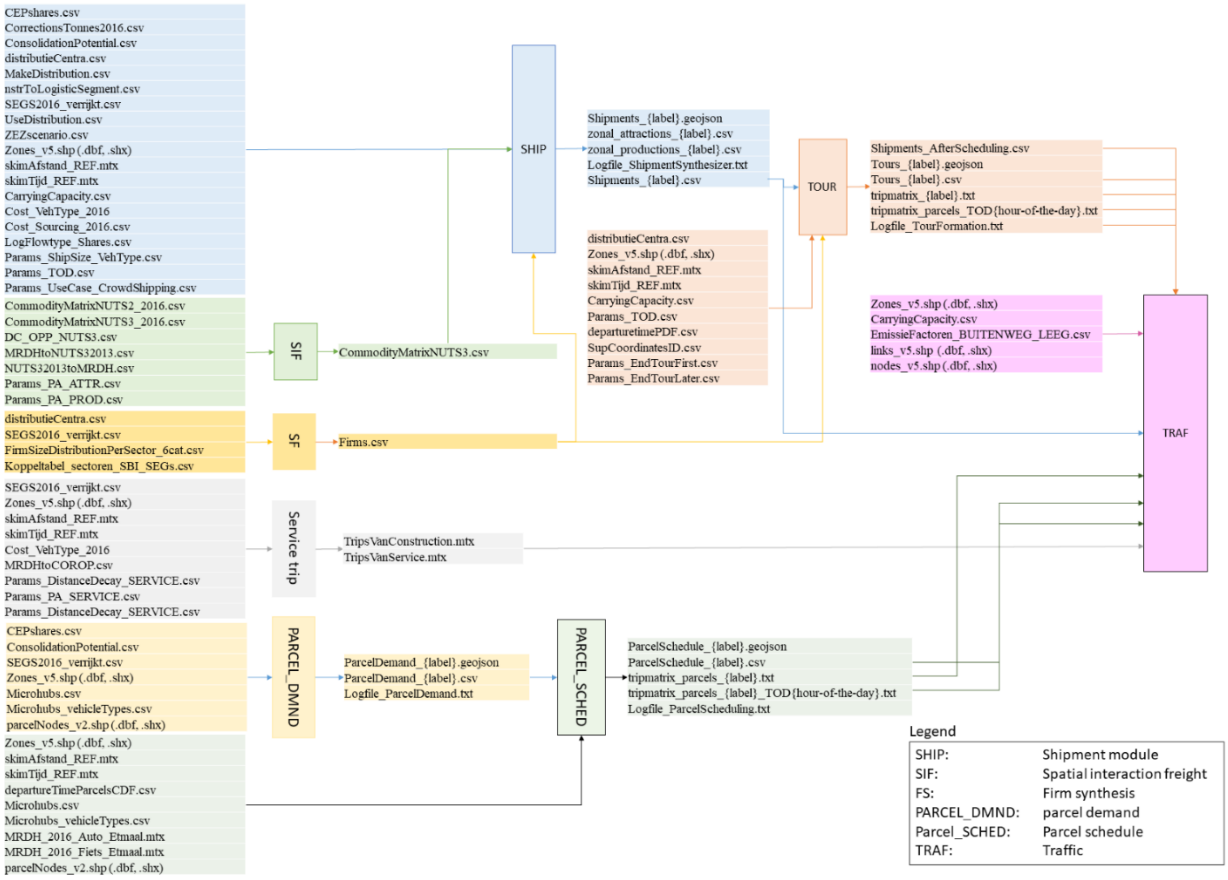

Figure 4-1: Input and output connections between the modules and associated files

Table 4-2 provides a description of each file in more detail.

Table 4-2: Description of the input and output files

File name	Input for module	Output of module	Description
CEPshares.csv	SHIP, PARCEL_DMND		Market shares of different parcel couriers
CommodityMatrixNUTS2_2016.csv	SIF		Matrix with tonnes per day between combinations origin/destination/goods type, at the level of NUTS2-regions (2014)
CommodityMatrixNUTS3_2016.csv	SIF		Matrix with tonnes per day between combinations origin/destination/goods type, at the level of NUTS3-regions (2014)
ConsolidationPotential.csv	SHIP, PARCEL_DMND		For UCC-scenario: Per logistic segment the probability that a shipment of this type is rerouted through a UCC
CorrectionsTonnes2016.csv	SHIP		Correction factors (in tonnes/day) to account for special OD-relations with a large flow.

File name	Input for module	Output of module	Description
DC_OPP_NUTS3.csv	SIF		The surface of distribution centers per NUTS3-region
departureTimeParcelsCDF.csv	PARCEL_SCHD		Cumulative probability distribution of departure hours for the parcel tours
departuretimePDF.csv	TOUR		Cumulative probability distribution of departure hours for the freight tours
distributieCentra.csv	FS, SHIP, TOUR		Distribution centers in the Netherlands with their postal code and surface
EmissieFactoren_BUITENWEG_LEEG.csv	TRAF		Emission factors to calculate emissions from kilometers in traffic assignment (Different files per road type and for a full and empty vehicle)
EmissieFactoren_BUITENWEG_VOL.csv	TRAF		
EmissieFactoren_SNELWEG_LEEG.csv	TRAF		
EmissieFactoren_SNELWEG_VOL.csv	TRAF		
EmissieFactoren_STAD_LEEG.csv	TRAF		
EmissieFactoren_STAD_VOL.csv	TRAF		
ExternalZones.shp (.dbf, .shx)	-		*Polygons representing the external zones (only used for visualization purposes).*
FirmSizeDistributionPerSector_6cat.csv	FS		The observed number of firms per sector and size category
Koppeltabel_sectoren_SBI_SEGs.csv	FS		Link table from SBI-code to employment category in SEGS-file.
links_v5.shp (.dbf, .shx)	TRAF		The links that form the road network (edited from VRMDH Omnitrans model)
MakeDistribution.csv	SHIP		Probabilities that firm from sector [row] produces goods from goods type [column]
Microhubs.csv	PARCEL_DMND, PARCEL_SCHD		The microhubs (only used in microhubs scenario)
Microhubs_vehicleTypes.csv	PARCEL_DMND, PARCEL_SCHD		The vehicle types to/from the microhubs and other scenario definitions for the microhubs scenario
MRDH_2016_Auto_Etmaal.mtx	PARCEL_SCHD		Car travellers demand OD-matrix for the crowdshipping use case.
MRDH_2016_Fiets_Etmaal.mtx	PARCEL_SCHD		Bike travellers demand OD-matrix for the crowdshipping use case.

File name	Input for module	Output of module	Description
nodes_v5.shp (.dbf, .shx)	TRAF		The nodes that form the road network (edited from VRMDH Omnitrans model)
nstrToLogisticSegment.csv	SHIP		conversion table from NSTR to logistic segment
parcelNodes_v2.shp (.dbf, .shx)	PARCEL_DMND, PARCEL_SCHED		The location of depots for parcel delivery
SEGS2016_verrijkt.csv	FS, SHIP, PARCEL_DMND, SERVICE		Socio-economic data for each zone (e.g. number of inhabitants and jobs)
SupCoordinatesID.csv	TOUR		Coordination of the external (super) zones that lie outside of the study area.
UCC_point.shp (.dbf, .shx)	-		*Points representing Urban Consolidation Centers for ZEZ use case (only used for visualization purposes).*
UseDistribution.csv	SHIP		Probabilities that firm from sector [row] receives goods from goods type [column]
ZEZscenario.csv	SHIP		For UCC-scenario: Per logistic segment the probability that the vehicle type is switched to the vehicle type in the column
Zones_v5.shp (.dbf, .shx)	SHIP, TOUR, PARCEL_DMND, PARCEL_SCHED, SERVICE, TRAF		The polygons of the zones, with some additional zonal information in the DBF-file.
skimAfstand_REF.mtx	SHIP, TOUR, PARCEL_SCHED, SERVICE		Travel distance (meters) between each combination of zones.
skimTijd_REF.mtx	SHIP, TOUR, PARCEL_SCHED, SERVICE		Travel time (seconds) between each combination of zones.
CarryingCapacity.csv	SHIP, TOUR, TRAF		The weight (kg) that each vehicle type can carry
Cost_VehType_2016	SHIP, SERVICE		Costs for each kilometer and hour that are driven per vehicle type
Cost_Sourcing_2016.csv	SHIP		Costs for each kilometer and hour that are driven, average over all vehicle types
LogFlowtype_Shares.csv	SHIP		Per logistic segment [column] the probability of different logistic flow types (e.g. distribution center to firm, firm to port)
MRDHtoCOROP.csv	SERVICE		Linktable MRDH zones to COROP zones
MRDHtoNUTS32013.csv	SIF		Linktable MRDH zones to NUTS3 areas (2013 codes)
NUTS32013toMRDH.csv	SIF		Linktable NUTS3 areas (2013 codes) to MRDH zones

File name	Input for module	Output of module	Description
Params_DistanceDecay_SERVICE.csv	SERVICE		Distance decay parameters for gravity model for service/construction vans
Params_EndTourFirst.csv	TOUR		Coefficients for discrete choice model
Params_EndTourLater.csv	TOUR		Coefficients for discrete choice model
Params_PA_ATTR.csv	SIF		Attraction coefficients freight
Params_PA_PROD.csv	SIF		Production coefficients freight
Params_PA_SERVICE.csv	SERVICE		Distance decay coefficients service/construction vans
Params_DistanceDecay_SERVICE.csv	SERVICE		Production/attraction coefficients service/construction vans
Params_ShipSize_VehType.csv	SHIP		Coefficients for discrete choice model
Params_TOD.csv	SHIP, TOUR		Coefficients for discrete choice model
Params_UseCase_CrowdShipping.csv	SHIP		Parameters for crowdshipping use case
Firms.csv	SHIP, TOUR	FS	Synthesized firms with sector, size and location
CommodityMatrixNUTS3.csv	SHIP	SIF	Commodity flows in tonnes per year between NUTS3-regions
Shipments_{label}.geojson		SHIP	Synthesized shipments between firms / logistic nodes, with attributes such as weight, goods type, origin zone, destination zone
Shipments_{label}.csv	TOUR, TRAF, OUTPUT	SHIP	Idem, but in CSV-format and without coordinates
Shipments_AfterScheduling.csv	TRAF, OUTPUT	TOUR	Idem, but some shipments are cut up into smaller shipments to fit in a vehicle.
zonal_attractions_{label}.csv		SHIP	For each zone, the weight of all shipments that are sent to this zone
zonal_productions_{label}.csv		SHIP	For each zone, the weight of all shipments that are sent from this zone
Tours_{label}.geojson		TOUR	Constructed tours. Each record is a trip from zone A to zone B.
Tours_{label}.csv	TRAF, OUTPUT	TOUR	Idem, but in CSV-format and without coordinates
ParcelDemand_{label}.geojson		PARCEL_DMND	Synthesized parcels between parcel depots and consumers/firms. Each row is one parcel.
ParcelDemand_{label}.csv	PARCEL_SCHED	PARCEL_DMND	Synthesized parcels between parcel depots and consumers/firms. Each row is one OD-pair, the number of parcels on this OD-pair is specified.

File name	Input for module	Output of module	Description
ParcelSchedule_{label}.geojson		PARCEL_SCHED	Constructed tour for parcel delivery.
ParcelSchedule_{label}.csv	TRAF, OUTPUT	PARCEL_SCHED	Idem, but in CSV-format and without coordinates
tripmatrix_parcels_{label}.txt	TRAF	PARCEL_SCHED	For each OD-pair the total number of trips made for parcel deliveries.
tripmatrix_parcels_{label}_TOD{hour-of-the-day}.txt	TRAF	PARCEL_SCHED	One file per hour of the day. For each OD-pair the total number of trips made for parcel deliveries.
tripmatrix_{label}.txt	TRAF	TOUR	For each OD-pair the number of trips made for freight, by logistic segment and vehicle type.
tripmatrix_parcels_TOD{hour-of-the-day}.txt	TRAF	TOUR	One file per hour of the day. For each OD-pair the number of trips made for freight, by logistic segment and vehicle type.
TripsVanConstruction.mtx	TRAF, OUTPUT	SERVICE	OD-matrix with number of trips made by vans for construction purposes
TripsVanService.mtx	TRAF, OUTPUT	SERVICE	OD-matrix with number of trips made by vans for service purposes
links_loaded_{label}.shp (+ .dbf + .shx)		TRAF	The links of the road network, with geometries and traffic intensities and emissions coded on the links.
links_loaded_{label}_intensities.csv	OUTPUT	TRAF	The links of the road network, without geometries, but with more elaborate fields regarding traffic intensities and emissions.
Logfile_OutputIndicator.txt		OUTPUT	Log-file with progress and error messages.
Logfile_ParcelDemand.txt		PARCEL_DMND	Log-file with progress and error messages.
Logfile_ParcelScheduling.txt		PARCEL_SCHED	Log-file with progress and error messages.
Logfile_ShipmentSynthesizer.txt		SHIP	Log-file with progress and error messages.
Logfile_TourFormation.txt		TOUR	Log-file with progress and error messages.
Logfile_TrafficAssignment_REF.txt		TRAF	Log-file with progress and error messages.
Output indicators\Output_OutputIndicator_{label}.csv		OUTPUT	Tables summarizing the results of the simulator. E.g. kilometers, tonnes, number of trips by vehicle type, goods type…
Output indicators\{figName}.png		OUTPUT	Figures/charts summarizing the results

5 Applying the model

5.1 Introduction

MASS-GT is developed as an academic open-source simulator for urban freight analysis. It is not a commercial platform, with a user-interface. This means running the model, and setting up a scenario for analysis requires self-study.

Some general guidelines to consider when starting to work with the model:

- First request access to the code on GitHub (this is to know possible users; all requests will be granted)
- GitHub provides a complete set-up of all modules (Python scripts)
- There is a Readme file on Github (https://github.com/mass-gt) with practical software tips to get started
- Scenarios are coded. Aim: manual for each case. Repositiry of scenarios. Now: exchange experiences/settings/scripts.
- .ini file: for a description see Table 4-1. Most important arguments for a run, for example:
    - Modules: which ones to run
    - Label: for identifying which scenario (REF, UCC, MIC)
- Excel overview file: contains dimensions of output files

To help users to gain some insights in how the model can be used, here the workprocedure is described to set up a use case.

5.2 Use case micro hubs

5.2.1 Description of use case

In this use case, the introduction of microhubs in a part of the study area is modelled. It was implemented as one of the use cases in the HEU project HARMONY. A microhub is “a logistics facility where goods are bundled inside the urban area boundaries, that serves a limited spatial range, and that allows a mode shift to low-emission vehicles or soft transportation modes (e.g., walking or cargo bikes) for last mile deliveries” (Urban Freight Lab, 2020). The use case is implemented for the study area South-Holland with a green-vehicle zone and microhubs for parcel delivery in the city of Rotterdam.

The purpose of this section is to provide a brief description of the use case and its implementation in the MASS-GT to enables other users to apply the microhubs use case to their study area and/or to answer research questions.

The main characteristics of the use case are as follows:

- A green-vehicle zone in the city of Rotterdam is defined
- Candidate microhub locations are identified
- Two different consolidation approaches are implemented: horizontal collaboration (all microhubs are shared by all CEP companies) and individual CEP (each microhub is used by one CEP company only)
- Vehicles that are allowed to operate in the GVZ are defined
- The scope includes parcel deliveries by the CEP companies operating in the area

5.2.2 Scenario input

The use case affects the parcel demand and parcel scheduling modules as well as the output indicator module. The scenario set-up consists of 4 steps:

1. Activate the scenario in the control file [Run*.ini]
2. Define the green vehicle zone operated by the micro hubs [zones_v6.shp]
3. Define the locations of microhubs [Microhubs.csv]
4. Define operational characteristics of the last-mile vehicles operating the hub [Microhubs_vehicleTypes.csv]

5.2.2.1 Control file settings

The scenario can be called upon by providing the corresponding label in the control file [Run*.ini]. The label consists of the letters ‘MIC’, the specification of the collaboration approach (the use of microhubs by individual CEP companies or horizontal collaboration between CEP companies in the use of microhubs) and the type of vehicle operating between microhubs and final delivery locations.

```
# ------------------- Scenario name ----------------------------------------------
LABEL = MIC_collab_EB

#Label options are: REF, UCC, MIC_collab_[mode] (horizontal collab), MIC_individual_[mode] (individual CEP)

# Modes for MIC: "AR" (autonomous robot),"EB" (el. bicycle), "ET" (el. tricycle)
# "EQ" (el . quadricycle), "EM" (el. moped), "EDV" (el. distribution vehicle), "LEV" (light el. vehicle)
```

Figure 5-1. MASS-GT control file

Label in control file: MIC_[consolidation]_[mode]

- Consolidation approach: ‘collab’ for horizontal collaboration or ‘indiv’/ ‘individual’ for individual-CEP microhubs
- Mode: one of the tags from vehicle types input file (see below)

5.2.2.2 Green-vehicle zone

The area to which parcels are delivered through microhubs is referred to as the Green-vehicle zone (GVZ). The definition of the GVZ is scenario input; the zones that are part of the GVZ are marked in the [zones_v6.shp] input file in the column ‘ZEZ’ (which is also used in the zero-emission zone use case). Zones in the GVZ are indicated by ZEZ=2. In the Rotterdam case the GVZ lies completely within the zero-emission zone, meaning that the zero-emission zone now includes zones with ZEZ=1 and ZEZ=2.

5.2.2.3 Microhub locations

The locations of microhubs need to be provided in terms of the number of the TAZ in which they are located. Additionally, the CEP company that is assumed to operate the hub in case of individually operating CEPs needs to be given (in case of horizontal collaboration, microhubs are shared by all CEPs, in this case the input can be left blank).

[microhubs.csv]: List of (candidate) microhubs with zone number (AREANR) of the model TAZ system and the name of the CEP company operating. Rows can be added.

Table 5-1: Example of Microhubs.csv input file

ID	AREANR	CEP
1	5345	GLS
2	5335	FedEx
3	5359	DPD
4	6200	PostNL
5	5356	DHL
6	5300	UPS
7	5314	PostNL
8	5327	DHL
9	5477	PostNL
10	6175	GLS
11	6199	DHL
12	5309	UPS
13	5306	FedEx
14	5330	DPD

5.2.2.4 Green vehicles and their operational characteristics

In this second new input file, [Microhubs_vehicleTypes.csv], the vehicles used for microhub-to-end location deliveries are characterized. One vehicle type is characterized per row and there is no limit to the number of rows. The next figure shows the content of the vehicle type input file.

Every vehicle type is given an ID (integer), which will be used in the output file of the parcel scheduling module. For better readability of the results, it is recommended to ensure that these do not overlap with vehicle IDs used in other scenarios, but this is not technically required.

The vehicle name can be any string.

The vehicle tag is a 2- or 3-digit string and part of the scenario label given in the control file; if the tag from the control file is not found in this input table, the scenario cannot be run.

Vehicle capacity and average range are required for the parcel scheduling process; average speed is also needed in the demand module to match microhubs and delivery destinations. All can be any numeric value.

The last two columns include the IDs of the microhubs that are included in the scenario. For each vehicle type, two configurations are given, depending on the selected type of consolidation.

The vehicle type used for the parcel delivery from the depots to the micro hubs is by default truck [Veh_ID=1], but can also be chosen in the parameter.

	A	B	C	D	E	F	G	H
1	Veh_ID	Name	Tag	Capacity	AvgRange	AvgSpeed	collab_microhubs	individual_microhubs
2	1	Truck	TR	1800	10000	20		
3	2	Van	VAN	180	10000	18		
4	13	Autonomous robot & electric bicycle	AR	5	6.5	4.5	5,6,9,11,13,14	1,5,7,9,12,13,14
5	14	Electric bicycle	EB	13	45	17.5	1,2,5,6,9,10,11,12,13,14	1,5,7,9,12,13,14
6	15	Electric tricycle	ET	50	20	21	1,2,5,6,9,10,11,12,13,14	1,5,7,9,10,12,13,14
7	16	Electric quadricycle	EQ	33	23	17.5	1,2,5,6,9,10,11,12,13,14	1,5,7,9,10,12,13,14
8	17	Moped	EM	13	70	16.5	1,2,5,6,9,10,11,12,13,14	1,5,7,9,12,13,14
9	18	Electric distribution vehicle (EDV)	EDV	49	94	16.5	1,2,5,6,9,10,11,12,13,14	1,5,7,9,10,12,13,14
10	19	Light electric vehicle (LEV)	LEV	180	240	18	1,2,4,5,6,9,10,11,12,13,14	1,2,3,4,5,6,7,9,10,11,12,13,14
11	190	Light electric vehicle (LEV) - fewer hubs	LE2	180	240	18	1,5,6,9,10,11,12	1,2,6,7,11,12,13

Figure 5-2. Example of Microhubs_vehicleTypes.csv input file

5.2.3 Output data

The output from the microhub scenario is the simulated flows of parcels through the microhubs and the vehicle patterns to distribute them. The outputs are added to the existing output files for Parcel Demand and Parcel Schedules.

The output files ParcelDemand_MIC_[tier]_[vehicle].csv/.geojson have three additional columns:

- VEHTYPE: the Veh_ID as used in the input file Microhubs_vehicleTypes.csv of the vehicle used to deliver the parcel
- TO_MH: {=ID of microhub for parcels going to microhubs, =0 otherwise}
- FROM_MH: {=ID of microhub for parcels from microhubs to households or businesses, =0 otherwise}

This is analogous to the UCC/ZEZ use case.

```
In [79]: parcels
Out[79]:
        Parcel_ID  O_zone  D_zone  DepotNumber     CEP  VEHTYPE  FROM_MH  TO_MH
0               1    1008       1            9     DHL        7        0      0
1               2    1008       1            9     DHL        7        0      0
2               3    1008       1            9     DHL        7        0      0
3               4    4604       1           14     DPD        7        0      0
4               5     979       1           27  PostNL        7        0      0
...           ...     ...     ...          ...     ...      ...      ...    ...
```

Figure 5-3: Dataframe 'parcels' in a MIC run

- The parcel delivery schedules are written to the output files ParcelSchedule_MIC_[tier]_[vehicle].csv/.geojson. The file has no additional columns, and contains all schedules, including the vehicle tours to and from the micro hubs.DESTTYPE / ORIGTYPE: if an origin or destination is microhub “MIC”

5.2.4 Output indicators

Output indicators:

- Green-vehicle km
- Table: Parcels per CEP per microhub, see example table below. Output of parcel demand module as *ParcelsPerMicrohubCEP_MIC.csv*

	A	B	C	D
1	CEP	FROM_MH	O_zone	ParcelCount
2	DHL	5	5356	3815
3	DPD	14	5330	1694
4	FedEx	13	5306	439
5	GLS	1	5345	688
6	PostNL	7	5314	4825
7	PostNL	9	5477	3575
8	UPS	12	5309	1495
9				

Table 5-2. Example output: MIC, individual CEP, LEV

CEP	Microhub no.	MH zone	No. of parcels
DHL	0		126217
	5	5356	3254
	11	6199	561
DPD	0		56048
	3	5359	408
	14	5330	1286
FedEx	0		14419
	2	5335	64
	13	5306	375
GLS	0		22816
	1	5345	478
	10	6175	210
PostNL	0		278126
	4	6200	2148
	7	5314	3199
	9	5477	3053
UPS	0		49373
	6	5300	303
	12	5309	1192