ODD protocol

Model name: Bicycle model
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The model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al., 2006).

Overview

Purpose

The purpose of the model is to generate the distribution of daily bicycle traffic flows at a regional scale level. The traffic pattern emerges from travel demand and human decision-making within an existing transportation system. The decision-making is governed by probabilistic rules based on assumptions from the mobility survey data. The spatial resolution of traffic flows is a network link. The temporal resolution is a minute.

State variables and scale

The model consists of entities: person, facility, road, intersection and counting station. Their low-level state-variables are listed in Table 1. The heterogeneity of persons is represented through demographic attributes. Throughout the simulation run, they also store travel information about their trips and activities. Facilities are characterized by type. Additionally, workplace facilities store information about the number of registered employees. Roads are described by routing attributes. They also store information about the number of traversed cyclists. Intersections have the location attribute. Counting stations also store information about traversed cyclists. Higher-level variables are described in table 2 and relate to roads.

Table 3 lists parameter variables with default values. The time interval parameters set the frequency of model output's values. The rest of the parameters define the network assessment and the calculation of safety index.

The model simulates one day with a one minute time step. The spatial extent of the model is the greater region of Salzburg city (approx. 180.000 residents). The model is designed for a medium-sized city and its adjacent municipalities, which were included to overcome the edge effect. The further analysis of the simulated mobility pattern is done for the city extent only.

Table 1. Low-level state variables

Variable	Description
Person species	residents of simulated area
location	current point location
age	age between 0-104
gender	gender
employmentStatus	employment status
homeLocation	home location
status	movement status: “moving”, “staying”
activityId	position of activity in activity chain
activityType	activity type
lastActivity	boolean value of whether calculated activity is the last one
startingTime	departure time of a trip, in minutes
endingTime	ending time of an activity, in min
durationTime	amount of time to stay at activity location after arrival, in min

mode	transportation mode
speed	speed in m/min
minDistance	minimum travel distance, in m
maxDistance	maximum travel distance, in m
sourceLocation	point departure location in the respective coordinate reference system (EPSG:32633)
targetLocation	point target location in the respective coordinate reference system (EPSG:32633)

Facility species	points of interest
location	point/polygon location
facilityType	type
facilityPopulation	number of registered employees (only for workplaces)

Road species	network links
location	linestring location
id	unique id
safetyIndex	level of safety
weight	link weight, needed for calculation of routes (perimeter or safety index)
restriction	restriction for bicycle movement
linkLength	link perimeter
oppositeRoad	road with an opposite direction
cyclistsRoad	number of traversed cyclists every interval of time (default=60 min)
cyclistsByInterval	list of numbers of traversed cyclists every interval of time
cyclistsTotal	total amount of traversed cyclists

Intersection species	road intersections
location	point location

Counting station species	counting stations that register traversing cyclists
location	point location
stationName	name
cyclistsStation	number of traversed cyclists every interval of time (default=60 min)
observedCounts	number of traversed cyclists from observed data

Table 2. High-level state variables

Variable	Description
Network	
theGraph	bidirectional network graph composed of road species
perimeterWeights	list of weights for every road based on its perimeter
cyclingWeights	list of weights for every road based on its safety index

Table 3. Parameter variables with default values

Parameter variables	Description	Value
networkTimeInterval	time interval of exporting the number of traversed cyclists on a network to an output file, in min	60
countingStationTimeInterval	time interval of exporting the number of traversed cyclists at counting stations, in min	60
activeCylistsTimeInterval	time interval of exporting the number of actively travelling cyclists at the moment of a simulation, in min	60
routingAlgorithm	routing algorithm based on a specific weight type	safest path
bicycleInfrastructureWeight	attribute weight for network assessment	0.2
mitVolumeWeight	attribute weight for network assessment	0.0
designatedRouteWeight	attribute weight for network assessment	0.1
roadCategoryWeight	attribute weight for network assessment	0.3
maxSpeedWeight	attribute weight for network assessment	0.1
adjacentEdgeWeight	attribute weight for network assessment	0.0
parkingWeight	attribute weight for network assessment	0.1

pavementWeight	attribute weight for network assessment	0.1
widthLaneWeight	attribute weight for network assessment	0.0
gradientWeight	attribute weight for network assessment	0.1
railsWeight	attribute weight for network assessment	0.0
landuseWeight	attribute weight for network assessment	0.0
designatedRouteAdjusted	adjusted attribute weight for network assessment	2.0
railsAdjusted	adjusted attribute weight for network assessment	0.6
pavementAdjusted	adjusted attribute weight for network assessment	0.4
gradientAdjusted	adjusted attribute weight for network assessment	0.4
bridgeValue	bridge value for network assessment	3.0
pushValue	push value for network assessment	3.0

Process overview and scheduling

The model consists of initialization and simulation parts (Fig.1). During the initialization, persons and a built environment are created. After the network assessment, a routable network graph is computed. Persons select initial activities.

During the simulation part, persons iteratively assign activities and travel. At the end of each activity, the values of a person's trip attributes are exported to an output file "trips". Persons are registered at counting stations and the network while they travel. The information about the number of traversed cyclists at counting stations is exported every interval of time, defined by a user. At the end of the simulation, the heatmap of bicycle traffic flows on the network is generated and saved into an output file. The list of all synchronous and asynchronous processes are demonstrated in Table 4. Time step and frequency is given for each process.

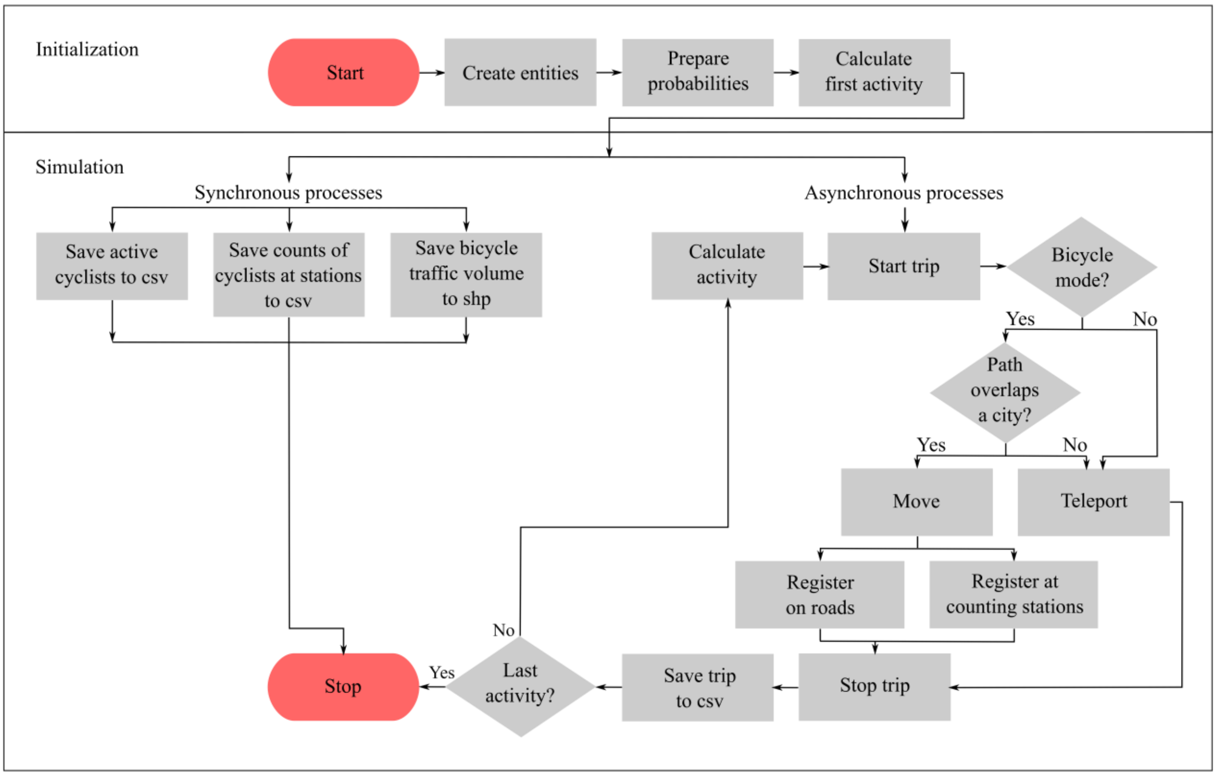

Figure 1. Flowchart of the conceptual bicycle model

Table 4. Processes of model entities

	Process	Time step
simulation world	create facilities	initialization
	create roads and network graph	initialization
	create intersections	initialization
	create counting stations	initialization
	create persons	initialization
	prepare travel assumptions as probabilities	initialization
	calculate the first activities of persons	initialization
	start the simulation	0 step
	update time thresholds for time probabilities	every 60th step
	save currently travelling cyclists to an output file	parameter: activeCylistsTimeInterval
	Save the heatmap of bicycle traffic flows on the network	1441 step
	Stop the simulation	1441 step
person	calculate an activity	at the ending time of a previous activity
	start	starting time of an activity trip
	move	from starting time until a destination is reached
	stop	when a destination is reached
	save trip attribtues to an output file	when a destination is reached
road	register traversing cyclists	when cyclists traverse
	calculate the total number of traversed cyclists per interval	networkTimeInterval
counting station	register traversing cyclists	when cyclists traverse
	save bicycle traversed cyclists per interval to an output file	countingStationTimeInterval

Design concepts

Emergence: The spatio-temporal distribution of bicycle flows emerges from cyclists' responses to their travel demands and physical environment. In particular, the heterogeneity of many individuals with their travel preferences represented through probabilistic rules facilitates the uncertainty of the distribution outcome.

Sensing: Persons sense the environment. They have information about the city borders, intersections along the network and road attributes, such as safety index and perimeter. Besides, roads and counting stations also sense persons that traverse them.

Stochasticity: Stochasticity is implemented in many aspects of the model. It was done due to the available resolution of input data and to avoid over-fitting of the model. The age is randomly assigned to persons based on the distribution of age groups (5 years increment) by gender within each residential cell. The employment status is similarly assigned to persons. Probabilities and random function are used during the activity assignment.

Collectives: Individual people falling into the same demographic groups by age and employment statuses share similar behavioural traits. However, they never act together as a group.

Observation: There are two types of output in the model. Dynamically generated actual simulation data are visualized on the displays of the GAMA platform for verification purposes. The diagrams represent population demography, city display with the built environment and persons. The dynamically updated plots show currently travelling cyclists by trip purpose, visualize the number of bicycle traverses at counting stations. Secondly, simulation data is exported to output files for validation purposes. Among them are the information about computed trips and activities, currently travelling people by trip purpose, the number of traverses at counting stations and the network. These datasets are saved in CSV documents and a shapefile.

Basic principles: The model considers the basic principles of transport modelling. It calculates origins and destinations, as well as mode choice and route choice. Extended capabilities of this model increase the temporal resolution and spatial accuracy of results.

Details

Initialization

During the initialization phase, the model is populated with all the entities. Roads appear as the directed network graph. Persons are created at their home locations with defined age, gender and employment status. They are assigned with the first activities. The required for decision-making probabilities are imported from the CSV files. Activity type probabilities for “school” and “university” are altered following the generated split between pupils and students. Such a procedure is due to the input data constraint with a generalized probability value for both mentioned activity types.

Input

The model in its current version does not include any dynamic environmental variables that change over time.

Submodels

Trip assignment. The trips assignment occurs throughout the simulation day, as persons don’t have pre-calculated activity chains. The calculations are based on assumptions and probabilities from the mobility survey and several reports. If a person does not select type, departure or duration time of the next activity, then it travels home. In case a person is already at home, it is removed from the simulation.

- Activity type: calculation is based on activity type probabilities by activity number (position in activity chain) and employment status.
- Starting time: calculation is based on starting time probabilities by activity type and restricted by current simulation time.
- Duration time: calculation is based on duration probabilities by activity type. Additionally, the duration of a “school” activity depends on the age of a person, while “work” activity duration on a gender.
- Mode: calculation is based on mode probabilities by activity type and spatial extent. The city and region have different modal splits. If a trip overlaps the city, respective modal split is used. The mode change happens only when persons are at homes.
- Minimum and maximum allowed distances: calculation is based on probabilities by mode. These distances define how far can a person travel.
- Speed: calculation is based on the speed ranges by mode.

- Target location: A person randomly selects a location from the list of suitable facilities by type that should match a selected activity type. In the case of work facilities, the number of employees is also taken into account. Additionally, a target location has to be located within min/max distances from a source location. If the distance condition is not fulfilled, a person is not restricted by min/max distances and selects random location.

Start. A person starts travelling to the next activity at the activity's starting time. While there are trips by various transportation modes, only the explicit movements of cyclists that overlap the city area are simulated. Trips, made by other modes or outside the city, are not simulated. Their travel times are calculated, however, persons are directly transferred to their destinations.

Move. The route is calculated every simulation step when cyclists move towards destinations. Two different algorithms are used for route optimization. The shortest path algorithm searches for the shortest trip by length. The safest path algorithm takes the safety index of roads into account to calculate the safest routes for cycling. The algorithm choice is provided through the user-defined parameter "routingAlgorithm".

Stop. A person stops travelling when they arrive at a target location. Travel and ending times, the number of passed intersections, the share of a trip within the city, trip geometry and travel distance is calculated. A transferred person calculates only travel and ending times.

Save trip. Trip information from the previous step is saved in the "trips.csv" file. If a person is finished with activities, it is removed from the simulation.

Register currently travelling cyclists. The number of currently travelling cyclists is registered every user-defined interval of time.

Save currently travelling cyclists. The number of travelling cyclists by trip purpose are saved to the "active_cyclists.csv" file every user-defined interval of time.

Register cyclists. Roads and counting stations register travelling cyclists.

Save counting data. Every station calculates the total number of registered cyclists during a user-defined interval of time. The output is saved to the "counting_data.csv" file.

Update cyclists at roads. Roads update lists with numbers of traversed cyclists every user-defined interval of time.

Save heatmap. At the end of simulation bicycle traffic flows over the network is saved to "heatmap.shp" file.

Input data references:

Table 5. Input data references

Input data	Reference
Synthesized residential data	-
Synthesized employees data	-
Facilities	Doctors (Federal State of Salzburg - GIS Department, 2019a) Universities (Federal State of Salzburg - GIS Department, 2019b) City authorities (City Administration Salzburg, 2019) Federal authorities (Federal State of Salzburg - IT Department, 2020)

	Schools, shops, recreation, hospitals, kindergartens (OpenStreetMap, 2019)
Counting stations	Counting stations (GPV - Günther Pichler GmbH, 2020b, GPV - Günther Pichler GmbH, 2020a, Paris Lodron University of Salzburg - Interfaculty Department Z_GIS, 2020)
Network	Network (ASFINAG et al., 2019)
Intersections	Network (ASFINAG et al., 2019)
City outline	Administrative boundaries (Bundesamt für Eich- und Vermessungswesen, 2019)
Region outline	Administrative boundaries (Bundesamt für Eich- und Vermessungswesen, 2019)
Counting data	Counting data (GPV - Günther Pichler GmbH, 2020b, GPV - Günther Pichler GmbH, 2020a, Paris Lodron University of Salzburg - Interfaculty Department Z_GIS, 2020)
Activity probabilities	Mobility survey (Federal State of Salzburg - Transport Department, 2012)
Starting time probabilities	Mobility survey (Federal State of Salzburg - Transport Department, 2012)
Mode probabilities	Mobility survey (Federal State of Salzburg - Transport Department, 2012)
Work duration time probabilities	Social report (Austrian Institute of Economic Research, 2017)
Duration time probabilities	Guidelines for school administrators (State Education Authority Salzburg, 2010),
Duration time probabilities	ECTS guideline at the University of Salzburg (Paris Lodron University of Salzburg, 2005)
Speed probabilities	Mobility survey (Federal State of Salzburg - Transport Department, 2012)
Distance restrictions	Mobility survey (Federal State of Salzburg - Transport Department, 2012)

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