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, 2010.

Overview

Purpose

The purpose of the model is to generate disaggregated traffic flow distribution of cyclists at the regional scale level. The model is fuelled by statistical and topographical data as well as by generalized assumptions derived from survey data on mobility behaviour. It results in emergent flow patterns at a high spatial and temporal level of detail.

State variables and scale

The bicycle flow model consists of entities described below together with their low-level state-variables (Table 1). Higher-level variables are described in table 2. They characterize groups of entity individuals. Finally, table 3 lists parameter variables and their default values for the whole model. They parameterize the model and keep general information for entities to use. Some values are too broad and not included in the table. The model simulates 1 day with 1 minute time step that is able to show daily pattern of bicycle mobility. 1 minute simulation step adequately correlates with a cycling speed for model to catch all the nuances of movements. It also eases computational process, taking up approximately 5 hours of machine time.

The spatial scope of the model is that of a city region. The model was initially designed for a medium-sized city (150.000 inhabitants) and its adjacent municipalities, which were included in order to overcome the edge effect. The model simulates trips in the whole study area, and examines trips that have their origin and/or destination within the city.

Table 1. Low-level state variables

Variable	Description
City outline	spatial extend of city area
shape	geographical representation of location
Home	cell where people live
id	id
home_population	number of residents
male_below_5…	number of residents by gender and age group
male_employed…	number of residents by employment status and gender
pupils_6_14, pupils_15_19, students	number of residents currently involved in studies by educational status
createdPeople	number of residing people agents
maleByAge	list of number of male residents by age group
femaleByAge	list of number of female residents by age group
shape	geographical representation of location
People	residents of simulated area

age	age between 0-104
gender	gender
employmentStatus	employment status
homeLocation	location of agent's home
myHomeWithinCity	boolean value of whether home location is in city
forbiddenActivities	list of forbidden activities
status	movement status of agent
move	boolean value of whether agent moves or is transferred
activityProbabilities	distribution of activity type probabilities
nextActivity	boolean value of whether next activity is selected
lastActivity	boolean value of whether next activity is the last
sourceLocation	location of trip origin
targetLocation	location of trip destination
sourceWithinCity	boolean value of whether source location is inside city
targetWithinCity	boolean value of whether target location is inside city
activityType	activity type
activityTypePrev	type of previous activity
startingTime	departure time of trip to activity location, in minutes
endingTime	end time of stay at activity location, in minutes
durationTime	amount of time to stay at activity location, in minutes
travelTime	amount of time to travel to activity location, in minutes
mode	transport mode
oldmode	transport mode that is replaced only for one trip while agent is not at home
changeMode	boolean value of whether mode has to be changed
maxDistance	maximum distance that can be travelled with a particular mode, in meters
minDistance	minimum distance that can be travelled with particular mode, in meters.
finished	boolean value of whether agent is finished with current activity
activityDistance	travelled distance, in meters
activityId	id
traversedRoads	list of traversed roads per trip
traversedIntersections	number of intersections per trip
cityShare	share of trip inside city, in %
passedStation	counting station the traveller passed by lastly
track_geom	geometrical representation of travelled track
location	geographical representation of location

Facility	point of interest
facilityType	type
facilityPopulation	number of places that facility provides
shape	geographical representation of location
color	

Road	network links
linkId	id
reversedRoad	road with opposite direction
brunnel	existence of bridge or tunnel
baseType	lane usage type
bicycleInfrastructure	bicycle infrastructure type
mitVolume	daily traffic volume of motorized vehicles per segment (24h)
designatedRoute	existance of bicycle route
roadCategory	road category
maxSpeed	maximum speed allowed by regulations
adjacentEdge	number of adjacent edges at the crossings
parking	parking lane availability
pavement	pavement type
widthLane	width of lane, in meter
gradient	gradient category
rails	value of whether road is a railway
numberLane	number of lanes
landuse	landuse type
oneway	existance of ways in one or two directions

restriction	restriction for bicycle movement
safetyIndex	level of safety
intersectionId1	intersection id at one of road ends
intersectionId2	intersection id at one of road ends
intersections	number of intersections that a road has
city	road location according to city boundaries
shapeLength	road length
weight	road weight, needed for calculation of routes.
cyclists	number of traversed cyclists
cyclistsTotal	number of traversed cyclists on both ways (if road has its reversed road)
cyclistsNumberPrev	saved number of traversed cyclists over previous hour
cyclistsByHour	number of traversed cyclists every hour
roadWidth	width of road in regard to number of traversed cyclists, used for visualization purpose
roadColor	display color
shape	geographical representation of location
Counting station	station that records passing cyclists every selected time interval
stationName	name of station
cyclistsCurrent	current total number of traversed cyclists
cyclistsPrev	total number of passed cyclists at previous "countingStationTimeInterval"
cyclists	number of passed cyclists for the last "countingStationTimeInterval"
realCounts	number of passed cyclists from real-world data
shape	geographical representation of location
color	display color

Table 2. High-level state variables

Variable	Description
Environment	
simulationStartTime	machine time at the beginning of simulation run
Work facilities	
workFacilityList	list of work facilities
Network	
theGraph	bidirectional network graph composed of road species
perimeterWeights	list of eights for every road based on its perimeter
safetyIndexWeights	list of eights for every road based on its safety index
Mode	
oldModes	list of modes that are not assigned due to a failure to meet a threshold of maximum distance between origin and destination
People	
sharePupil	share of pupil among pupils and students together
shareStudent	share of students among pupils and students together

Table 3. Parameter variables with default values

Parameter variables	Description	Value
shape	spatial extend of simulation world	Street network
step	amount of time per step	1 min
countingStationTimeInterval	time interval to save passed cyclists at stations into output file	60 min
activeCylistsTimeInterval	time interval to save passed cyclists at roads into output file	15 min
showFacility	facilities to be visualized by type	none
bicycleInfrastructureWeight	attribute weight used for network assessment	0.2
mitVolumeWeight	attribute weight used for network assessment	0.0
designatedRouteWeight	attribute weight used for network assessment	0.1
roadCategoryWeight	attribute weight used for network assessment	0.3
maxSpeedWeight	attribute weight used for network assessment	0.1

adjacentEdgeWeight	attribute weight used for network assessment	0.0
parkingWeight	attribute weight used for network assessment	0.1
pavementWeight	attribute weight used for network assessment	0.1
widthLaneWeight	attribute weight used for network assessment	0.0
gradientWeight	attribute weight used for network assessment	0.1
railsWeight	attribute weight used for network assessment	0.0
landuseWeight	attribute weight used for network assessment	0.0
designatedRouteAdjusted	adjusted attribute weight used for network assessment	2.0
railsAdjusted	adjusted attribute weight used for network assessment	0.6
pavementAdjusted	adjusted attribute weight used for network assessment	0.4
gradientAdjusted	adjusted attribute weight used for network assessment	0.4
bridgeValue	bridge value used for network assessment	3.0
pushValue	push value used for network assessment	3.0
activityProbabilities	probability distribution of activity types by position in activity chain	
startTimeProbabilities	probability distribution of trip departure time by activity type and position in activity chain, in minutes	
modeProbabilities	probability distribution of trip mode by activity type and spatial extend	
fixedDuration, shortestDuration, longestDuration	trip duration time by activity type, in minutes	
closingTime	closing time of facility based on activity type, in minutes	

Process overview and scheduling

Figure 1 illustrates the life cycle of the model

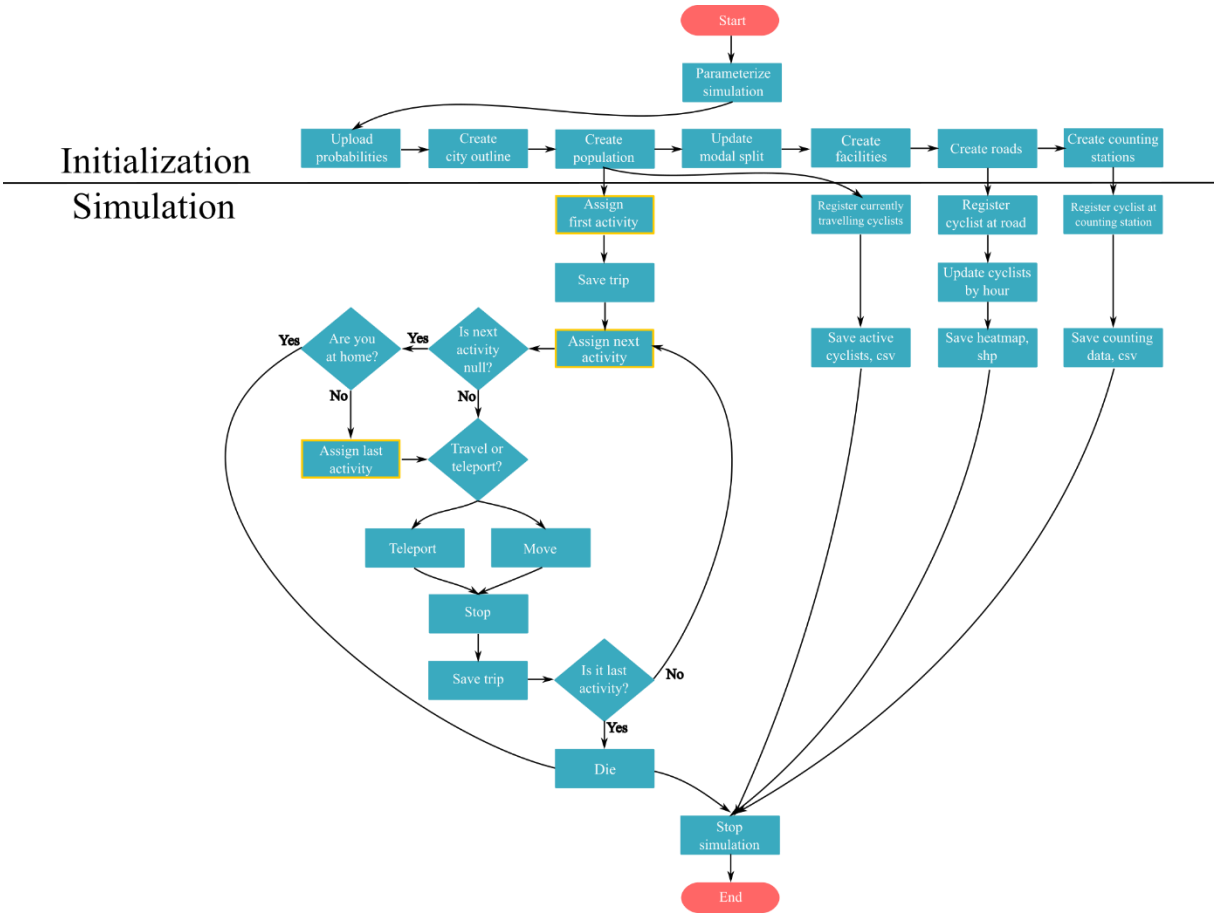

Figure 1. Flowchart of conceptual model

As mentioned, the temporal increment of the model is 1 minute. There are processes that are executed at a particular time step for the whole entity (table 4):

Table 4. Synchronous processes of model entities

Entity	Process	Time step
people	- register currently travelling cyclists	every 15th step
	- save currently travelling cyclists	every 15th step
	- assign starting activity	0 step
roads	- update list 'cyclists by hour'	every 60th step
	- save heatmap	1440 step (end of simulation)
counting stations	- save counting data	every 60th step

Additionally, there are processes that happen individually and asynchronously for every agent (Table 5).

Table 5. Asynchronous processes of model entities

Entity	Process	Time step
people	- assign next activity	Ending time
	- start	Starting time
	- move	From starting time until agent reaches destination
	- stop	When agent reaches destination
	- save trip	When agent reaches destination
roads	- register cyclists	When people agent traverses over road agent
counting stations	- register cyclists	When people agent traverses over station agent

Design concepts

Emergence: The spatial distribution of bicycle flows emerges from cyclists' responses to its internal characteristics and the physical environment. These variables are represented by respective data sources (statistical and topographical data, assumptions derived from survey data).Large number and heterogeneity of people as well as stochasticity embedded in decision making are significant triggers of emergent mobility pattern.

Sensing: All entities in the model are aware of their own characteristics. In addition, homes have access to location, age, gender, employment and educational status of people that live there. People have information about location of city outline and road attributes, like safety index, perimeter, intersections and location. On the other hand roads also sense people that traverse them. People and counting stations interchangeable know their positions as well, when they happen to be in the near proximity.

Stochasticity: Stochasticity is implemented in many aspects of the model. It was done due to resolution of input data and to avoid over-fitting of the model. The model has to be transferable and robust towards input data. Model uses normal distribution for calculating next activity location and duration time. Exception is work activity, for which probability function is employed. Further, model uses probability function to assign people characteristics, like age, gender, employment status, home location, and characteristics of people's next activities, like activity type, departure time, mode, maximum and minimum travelling distance.

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

Observation: There are two types of output in the model. Firstly, the model produces dynamically updated plots describing the states of individual agents and aggregated values of activities, travelling people in general and at stations. There are also static diagrams representing share of people by age, gender and employment status. Secondly, data about currently travelling people, number of traverses at counting stations and the whole network, carried out activities and trips are saved in csv documents and shapefiles.

Basic principles: The model considers basic principles of transport modelling. It simulates the determination of all origins and destinations, as well as mode choice and route choice. Extended capabilities of this model increase temporal resolution and spatial accuracy of resulted bicycle flows, by simulating every single agent and facilitating agents to make decisions about their daily schedule during simulation.

Details

Initialization

During initialization phase the model is populated with all the entities. Roads appear as a directed network graph. People are created at their home locations with defined age, gender. In addition, activity types for each person is assigned with regard to employment and educational statuses. For instance, "unemployed" person cannot select "work" activity type. Furthermore, simulation removes people, younger than 6 years old. They are assumed to be incapable of making trips on their own. "School" and "university" probabilities in probability distribution of activity types are altered in accordance to generated split between pupils and students. Such procedure is due to generalized probability value for both mentioned activity types in input data. Every simulation run, content of generated people differs because of stochasticity in assignment of basic attributes to people.

Input

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

Submodels

Assign next activity. Next activity is assigned once the time is equal to ending time of previous activity. As discussed above, probability functions and normal distribution functions are employed for different activity uses.

- Activity type: is calculated using activity probability based on people's position. Assignment is restricted to potential activities.
- Departure time: is based on selected activity type and restricted by current time of simulation.
- Duration of stay: is also based on selected activity type. The following types have additional calculation specifications. "School" activities depend on agent's age, "work" activities on gender.
- Mode: is defined depending on selected activity type and spatial extend. City and region have different modal splits. Based on source location inside or outside city,

respective modal split is used. An important moment here is that agents are able to change their mode only at home. Although, there is an exception that will be explained later.

- Minimum and maximum distances: selected mode defines these distances that can be travelled.
- Traveling speed: selected mode also defines speed of travelling person.
- Target location: all suitable locations are defined by facility type that should match selected activity type. Agent randomly selects location from a list of suitable locations. Target has to be located within minimum and maximum distances from source. If the last condition is not fulfilled, agent has to change its mode and recalculate trip characteristics that depend on mode. The change occur depending on current location of agent. If it stays at home, it takes another mode for all consequent trips until it arrives to home again. This old mode is then reassigned to the next agent. When agent is not at home, it changes mode only for one trip. This concludes next activity assignment. If an agent does not select type, departure or duration time for the next activity, then it travels home. In case the agent is already at home, it is removed from simulation.

Start. When current time is starting time of the next activity trip agent decides to start travelling. While the mode choice is simulated for every agent, only cycle trips are modelled. Trips, made by other modes, are not simulated and agents are directly transferred to their destinations with a certain time delay.

Move. After agent decides to travel by bicycle, the route is calculated. Two different algorithms are used for route optimization. An exact shortest path algorithm minimized the trip length. A safest path algorithm is based on an indicator-based route choice model that prefers safe environments. The algorithm is a user-defined parameter for all trips. Every simulation step cyclist moves further along the selected route on a network.

Stop. All people stop when they arrive to target location. Transferred people calculate travel and ending time, whereas travelled people additionally calculate number of passed intersections, share of trip inside city, trip distance and its geometry.

Save trip. All trip characteristics are saved in an output file, when people stop. When agent arrives at its last activity it dies.

Register currently travelling cyclists. All people travelling at specific moment are registered.

Save currently travelling cyclists. Number of travelling people at specific moment are saved by their trip purposes (activity types of target locations).

Register cyclists. This process is triggered by traversing people, where roads and counting stations register travelling cyclists.

Update cyclists. Every hour, roads update their lists with numbers of cyclists traversed over the last hour.

Save heatmap. At the end of simulation total network with numbers of registered cyclists by hour is saved into output file.

Save counting data. Every station calculates total number of registered cyclists over an hour and saves it into output file.