Reduced-MoTMo ODD

Gesine A. Steudle, Steffen Fürst, Sarah Wolf

December 2022

1 Introduction

The Reduced Mobility Transition Model (R-MoTMo) is a very much simplified version of the Mobility Transition Model (MoTMo, see `www.globalclimateforum.org/motmo` and references there). The latter has been developed to provide projections of a mobility transition in Germany, in particular, to investigate potential shifts to new technologies and new behaviours and to discuss sustainable mobility with different groups of people [1]. It simulates mobility demand under different combinations of options representing e.g. policy measures or investment strategies; in this way scenarios for different possible futures can be created. Simulations are spatially explicit and based on a synthetic population of Germany. MoTMo aims for some continuity with standard economic demand models by assuming that individuals determine their demand based on utility maximisation. At the same time going beyond the standard general equilibrium setting, individuals in MoTMo lack complete information and hence use information obtained from others, thus taking into account social influence from the agents' networks extending the utility maximisation paradigm with social interaction via imitation. Like other large scale agent-based models (ABMs) for socio-economic, -ecologic, and/or -technical simulations, MoTMo is a large compound of a big number of detailed submodels, also containing a lot of ad-hoc assumptions which makes it very difficult to grasp the whole model mathematically.

In order to study the underlying principles of MoTMo (that we consider relevant also for similar models) we have developed the very much reduced version R-MoTMo which is presented here. In R-MoTMo, persons' choices between different mobility types are very limited (there are only two options) and also their utility functions are very simple. However, both the utility gained from choosing one of the possible mobility options and the social network that influences the mobility decisions taken by persons change over time, depending on the previous choices. Studying such feedback mechanisms, in particular being able to formulate the model with a complete mathematical description (unlike in the large model version), is the main focus of R-MoTMo.

2 Overview

2.1 Purpose

The purpose of the Reduced Mobility Transition Model (R-MoTMo) is to model and analyze stylized behaviour of socio-economic, -ecologic, and/or -technical systems like the large scale empirically based mobility demand model MoTMo; these models, and more importantly the real world systems they intend to represent, are characterized by different kinds of feedbacks that can be described as *externalisation* and *internalisation* [2] in the sense that decision making transforms the environment decisions are taken in (externalisation) and the altered environment in turn changes the decision making in two ways, it changes the characteristics of available options and the expectations under which decision are taken (internalisation).

2.2 Entities, State Variables, and Scales

In R-MoTMo, there are two different kinds of agents, *persons* and *cells*. Further entities are *mobility types* and the *world*. Cells are arranged in a 2D grid, and each person is located in one of the cells. Furthermore, persons are connected to other persons, their "friends". This network of persons is a social network in which information about how happy persons are with their current mobility type is exchanged. An overview of R-MoTMo's network structures is shown in Figure 1.

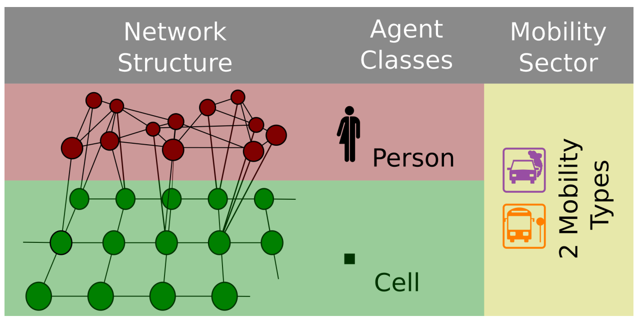


Figure 1: Structural overview of R-MoTMo. Every person is located in a cell and connected to other persons (social network). Cells are arranged in a regular grid (spatial network). Persons take decisions about which of two available mobility types to use.

The scales of the model are 1. a spatial extent of 36 cells arranged in a (6×6) square with 2. between 330 and 480 persons in total (depending on the chosen scenario), each of whom is located in one of the cells. There are different population distributions to choose from (see Section 4.2 and Figure 3 for details), for all of them the minimum number of persons per cell is 2 and the maximum 26. The model evolves by discrete time steps, but as it is not empirically grounded, the time scale remains abstract.

2.2.1 Persons

Persons in R-MoTMo take mobility decisions; that means they decide at every time step which of the two available mobility types, car or public transport, to use. As mentioned, persons are located in a defined cell within the model's regular 2D grid of cells. Each person is connected to a fixed number of other persons with whom information about the consequences of mobility choices is exchanged. These persons are called the person's *friends*.

Table 1 summarizes the attributes of a person, the constant parameters as well as the variables. Persons have a fixed number of friends, which are chosen in the beginning in a randomized way (see Section 4.1). Note that this relation is not (necessarily) reciprocal (but of course can be by chance). These persons are listed in the attribute `friends`. Persons know the cell they are located in, the respective attribute is `cell`. A person's state variables include the `mobility type` currently used, in R-MoTMo this can be either car, represented by value 0, or public transport, represented by 1. A further variable is the `utility` the person has. The utility concept is borrowed from standard economic models; in particular, it can aggregate preferences in different dimensions (such as costs, convenience, etc.) into comparable values, so that decisions can be taken on the basis of utility maximisation. In R-MoTMo, the utility function has only one dimension, convenience, which is described further in Section 2.2.3. For each cell, convenience is a real number which thus equals the person's utility. Last but not least, another state variable is a list of the length of the number of the person's friends which contains the weights for the respective connections, the variable `friend weights`; these weights are positive real numbers.

Parameter	Domain	Description
`friends`	`person`^{k}	the person's list of k friends (other persons); the number k of friends per person is a simulation parameter
`cell`	`cell`	the person's location
Variable	**Domain**	**Description**
`mobility type`	$\{0,1\}$	the mobility type used
`utility`	$\mathbb{R}$	the utility experienced currently
`friend weights`	$\mathbb{R}^k$	the weights of the connections to the person's friends

Table 1: Parameters and variables of persons.

2.2.2 Cells

Cells in R-MoTMo are agents that represent locations, attributes of cells are listed in Table 2. Cells form a regular 2D grid, thus every cell has individual (x, y)-`coordinates`. Every person is connected to one and only one cell, and cells keep a list of `persons` that are connected to the cell. These persons are created during model setup (see Section 4.1.2) using the cell's attribute `population`, also denoted p_c, that is, the number of inhabitants. Variable attributes of cells come in pairs, with values for the two mobility types m: the `infrastructure` is a real number $B_{c,m}$ that characterise the infrastructure addend of equation (1) for each mobility type m in the cell, the `conveniences`, that is, real numbers that characterise the utilities from using either of the two mobility types in the cell, and the number of total `usage` $p_{c,m}$ of both types m at the cell; these user numbers are needed to calculate the conveniences of both mobility types at the cell (see Section 4.3.1 for details).

Parameter	Domain	Description
`coordinates`	$\mathbb{N}^2$	(x, y)-position of cell
`population`	$\mathbb{N}$	the number p_c of persons living at the location
`persons`	`person`^{p_c}	list of persons living in the cell
Variable	**Domain**	**Description**
`infrastructure`	$\mathbb{R}^2$	the local infrastructure parameters $B_{c,m}$ of both mobility types m in the cell (see also equation (1))
`conveniences`	$\mathbb{R}^2$	the local convenience of all mobility types
`usages`	$\mathbb{N}^2$	the local number of users per mobility types

Table 2: Parameters and variables of cells.

2.2.3 Mobility Types

There are two mobility types from which persons can choose, **Cars** and **Public Transport**. Both provide a certain convenience to their users. To represent many, not always tangible factors which can influence mobility decisions, such as access and availability, travel speed and ease, etc., convenience is modelled as a function over population density, i.e. the number of persons per cell. This convenience function has an exogenous part depending only on the mobility type, and an endogenous part, which means that this part is a function of the current total usage of the mobility type in the cell in which the convenience is currently considered.

In general, convenience functions are Gaussian functions of the population p_c per cell c, so the convenience depends on the cell c and the mobility type m. In R-MoTMo it varies over time and is given by

$$U_{c,m}(t) = A_{c,m}(t) \cdot (\frac{100}{\sqrt{2\pi}\sigma} \exp(-\frac{(p_c - \mu_m)^2}{2\sigma^2})) + B_{c,m}(t) \tag{1}$$

with p_{min} and p_{max} being the minimal and maximal population per cell in the chosen simulation setup, and 0 (car) and 1 (public transport) the available mobility types, μ_m and σ are given by

$$\sigma = \frac{1}{2}(p_{max} - p_{min}) \tag{2}$$

$$\mu_0 = p_{min} \tag{3}$$

$$\mu_1 = p_{max} \tag{4}$$

i.e. for cars the convenience has its maximum for the minimum of all population densities in the setup, and for public transport the convenience maximum is at the population density maximum.

The factor $A_{c,m}$ is a short-term "usage malus", representing the idea that the more persons a certain mobility type the less convenient it gets due to traffic jams or crowded trains/buses. It decreases from $A_{c,m} = 1$ (if nobody uses type m in cell c) to $A_{c,m} = 2/3$ (if all persons in cell c use type m); for the calculation of $A_{c,m}$ see (5) in Section 4.3.1.

The addend $B_{c,m}$ is a long-term "usage bonus", representing the idea that the more persons use a certain mobility type the more infrastructure is built up eventually and the more convenient the mobility type becomes in the long run. $B_{c,m} = 0$ in the beginning and then increases over time in all cells c and for all types m, as long as somebody chooses m in cell c. For the calculation of $B_{c,m}$ see (6) in Section 4.3.1.

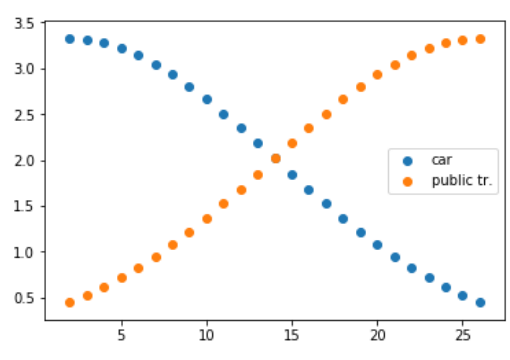


Figure 2: Conveniences of the two mobility types over the population p_c (for $A_{c,m}(t) = 1$ and $B_{c,m}(t) = 0$, i.e. the not cell-dependent "exogenous part" of the convenience functions).

The factor 100 just serves to bring conveniences to a handy numerical range. Figure 2 shows the exogenous part, i.e. the part of (1) that does not depend on usage of m in the respective cell c which is

$$\frac{100}{\sqrt{2\pi}\sigma} \exp(-\frac{(p - \mu_m)^2}{2\sigma^2})$$

over the population p per cell for both mobility types.

2.2.4 World

The entity to control and schedule the model runs is an object called world. Parameters and variables are given in Table 3. The attribute `parameters` contains the simulation parameters of the world, i.e. the parameters that determine a certain simulation scenario. They are listed in Table 4. The `population density` is a list that contains the number of persons per cell. Since in all the scenarios there are 36 cells, it has 36 entries. The sum of all entries in that list gives the total number of persons in the simulation; it is saved in the attribute `nPersons`. The list `cells` contains all the cell instances in the simulation, the list `persons` all the persons.

The variables of the world are the total `car usage`, the `mean utilities` of all persons, of car users, and of public transport users, the the `mean similarity`, that means the average number of a person's friends that use the same mobility type as the person.

Parameter	**Domain**	**Description**
`parameters`		dictionary of the simulation parameters (see Table 4)
`population`	$\mathbb{N}^{36}$	population distribution in the 36 cells
`cells`	$\texttt{cell}^{36}$	list of cells in the simulation
`persons`	$\texttt{person}^{N}$	list of persons in the simulation (N is sum of person numbers in `population`)
Variable	**Domain**	**Description**
`car usage`	$\mathbb{N}$	the current number of car users
`mean utilities`	$\mathbb{R}^3$	mean utilities for all persons, and per mobility type
`mean similarity`	$\mathbb{R}$	mean number of friends using the same mobility type as a person

Table 3: Parameters and variables of the world.

Name	**Domain**	**Description**
`time steps`	$\mathbb{N}$	the number of time steps
`density`	$\{1, 2, 3, 4\}$	chooses one of four different population maps
`initial choice`	$\{1, 2, 3\}$	chooses one of three sets of initial mobility choices
`number of friends`	$\mathbb{N}$	the number of friends each persons has
`friends locally`	{`True, False`}	chooses whether friends are chosen rather close to the person (True) or completely random (False)
`weight friends`	{`True, False`}	chooses whether friends connections are weighted
`convenience bonus`	{`True, False`}	chooses whether $B_{c,m}$ is calculated according to (6) (True) or $B_{c,m} = 0$ (False)
`convenience malus`	{`True, False`}	chooses whether $A_{c,m}$ is calculated according to (5) (True) or $A_{c,m} = 1$ (False)

Table 4: Simulation parameters (`parameters` attribute of the world object).

2.3 Process Overview and Scheduling

2.3.1 Simulation Setup

Upon initialisation of the model, the `world` object is created. During this setup, the following initialisation steps are taken in this order:

1. *Initialisation of cells*: Cells are set up, see Section 4.1.1 for details.
2. *Initialisation of persons*: Persons are set up, see Section 4.1.2 for details.
3. *Set initial mobility choices*: Persons' initial mobility types are set, see 4.1.3 for details.
4. *Generate social network*: Persons' networks of friends are created, see Section 4.1.4 for details.
5. *Finalize initialisation*: The data structures for saving the simulation output are created, see see Section 4.1.5 for details.

2.3.2 Proceeding in Time (Step Function)

In the model, time proceeds in discrete time steps. Every person reconsiders their mobility choices in every time step, so the real time equivalent of a time step is probably in the order of months or a few years but there is no explicit assumption in R-MoTMo.[1] In each time step, beginning with time $t = 0$ the **world's step function** is called. This function does the following:

1. If $t > 0$, for each person, if the person is copying a friend (see point 4c) the person's variable `mobility type` is updated accordingly.
2. For each cell, the **cell's step function** is called, which executes the following steps:
   (a) The number of current users of both mobility types in the cell is counted and the cell variable `usages` is updated accordingly.
   (b) The current conveniences in the cell of the two mobility types are calculated as described in Section 4.3.1 and the cell variables `infrastructure` and `conveniences` are updated accordingly.
   (c) Each cell's state variables are recorded.
3. For each person, the current utility of the person is determined, which equals the current convenience of the mobility type the person is using at the cell the person is located; the person's variable `utility` is updated accordingly.
4. For each person the **person's step function** is called, which executes the following steps:
   (a) The person updates the connections to the friends as described in Section 4.3.2, the person's variable `friend weights` is updated accordingly.
   (b) The persons chooses a friend from whom to imitate the mobility choice as described in Section 4.3.3.
   (c) The person actually copies the chosen friend's mobility choice if and only if the friend's current utility is larger than the own one. In this case, the mobility type to be copied is saved but the person's mobility type is not yet updated accordingly but only in the next iteration over all persons (see point 1).

[1] In MoTMo, a time step represents one month but there not all the persons reconsider their mobility choice in every step.

Further, the person's state variables are recorded.

5. Several global variables are recorded: mean utilities, mean utilities per used type, overall car usage and mean similarity, i.e. the mean number of friends that use the same mobility type as the person.

3 Design Concepts

3.1 Basic Principles

A fundamental principle in economics is **utility optimisation** meaning that individuals are assumed to take their consumption decisions maximising their utility subject to (budget) constraints. However, empirically this is often questionable; it is not always clear beforehand what "utility" may result from a certain consumption decision.

In R-MoTMo we decided to use utility maximisation as the objective of persons but we do not assume that they can calculate beforehand which utility results from a certain mobility choice. Rather, persons observe others in their social network and copy their choices if they seem to result in a high utility which can be seen as a form of **social learning**.

Individual choices for one or the other mobility type are assumed to influence the situation in which future decisions are taken. These **feedbacks** are, one the one hand, that local overall usage changes the local convenience of the mobility types; thus the a person's choice for one of the types depends on the action of the population in the past in the way that types' properties are changed by that; further, the way how social learning of persons is implemented means that the social network changes over time according to actions in the past.

3.2 Emergence

Persons learn over time which mobility type suits them better in their local circumstances. Whereas for very densely or scarsely populated cells this is given exogenously, for other areas persons coordinate on either of the two types which then makes it more useful for everybody.

3.3 Adaptation (Decision Making)

Persons in R-MoTMo take decisions about which of two mobility types to use with the goal to be as happy as possible (i.e. to maximise their utility). In particular, this is done by receiving information about how happy other persons in the social network are with their current mobility type and, if this seems promising, copying them.

3.4 Objectives

The objective of persons is to maximise their utility which equals the convenience they get from using one of the two available mobility types.

3.5 Learning

Persons learn what mobility decisions are best for them by copying other persons from their social network and evaluating the change in utility they achieve with it. The connection to the respective friend that has been copied is weakened if copying decreased the person's utility and becomes stronger if it increased the persons utility, as described in Section 4.3.2. Thus, over time the friends' network of a person is shaped due to learning.

3.6 Prediction

not applicable

3.7 Sensing

Persons in R-MoTMo know their own utility from their current mobility choice and the choices and respective utilities from all their friends (the persons in their social network). They have some information about how useful past information provided by their network has been, saved in the weights of the links in their network (as described in detail in Section 4.3.2).

3.8 Interaction

Interaction between agents in the model is the exchange of information. This takes place in the person's social network. In every time step, persons receive information about the utility of their friends and, if a friend is chosen to be copied, about the type this friend currently uses.

3.9 Stochasticity

In the model, stochastic processes play a role during simulation setup as well as during run time. During setup, for each person the social network is created either by choosing the given number of friends completely randomly from the other persons or by choosing persons located more closely with a higher probability (see Section 4.1.4 for details). Also the initial mobility choices of persons are chosen randomly with a probability of 0.5 for either mobility type; however, for that only three different sets of randomly chosen initial choices are available to choose from in order to make simulation runs more reproducible (see Section 4.1.3 for details).

During model run time, the order in which persons take their mobility decisions is random, and one stochastic process is called for every person in every time step: When a person decides which friend is a good candidate to copy the mobility choice from, this friend is determined with a probability distribution that depends on the utility of the friends and the connection strength (see Section 4.3.3).

3.10 Collectives

Collectives in the model are the friends networks of each person: In the beginning, each person is assigned a certain number of other persons that the person receives information about the utility of mobility choices from. How these networks are created is described in detail in Section 4.1.4, how they influence the person's decisions and thus the dynamics of the model and how they evolve over time in Sections 4.3.3 and 4.3.2. These network collectives do not have state variables of their own.

3.11 Observation

All the state variables of all cells and agents are recorded in every time step, as well as some global variables, such as mean utilities, mean utilities per used type, overall car usage and mean similarity, i.e. the mean number of friends that use the same mobility type as the person. All this data is available for further analysis after a simulation run.

4 Details

4.1 Initialisation

The initialisation of the model is done when the world object is created (see Section 2.3.1 for scheduling). In the following the different setup steps are described.

4.1.1 Initialisation of Cells

Cells are initialized in the following way: The population density map (simulation parameter ”density”, see also Section 4.2 for the choices available) is used to initialise 36 cells taking coordinates and population from the input density map. The initial infrastructure addend $B_{c,m}$ (see Section 2.2.3) is set to zero for all cells c and mobility types m.

4.1.2 Initialisation of Persons

For each cell, the designated number of persons is created and connected to the respective cell. The initial utility is set to 2.0 for all persons which is in the middle of the available utility range for $A_{c,m} = 1$ and $B_{c,m} = 0$ (see Section 2.2.3 and Figure 2). The initial mobility types for all persons are determined in the next step (see Section4.1.3).

4.1.3 Initial Mobility Choices

The initial mobility choices of persons are randomly chosen with a probability of 0.5 for each type. However, in order to make different runs more comparable, there are three fixed sets of such randomly chosen zeros and ones (of the size of the scenario with the maximum number of persons, if less persons are created the ones and zeros at the end of the list are not used); which of them is taken is determined by the simulation parameter ”initial choice” (Table 3).

4.1.4 Generation of the Social Networks

For each person, k friends are chosen in the beginning. Here, k is a simulation parameter, i.e. a parameter of the world object. There are two modes for creating the social network. If the simulation parameter `friends locally` is False, k friends are chosen completely randomly (equal probability without replacing) from the set of other persons.

If `friends locally` is True, friends are draw randomly, but not with equal probability; the probabilities for person i to be friends with person $j \neq i$, are determined in the following way:

1. Distance measures for all the other persons are determined as $d_{i,j} = 1/(dist_{j,i} + 0.1)$ with $dist_{i,j}$ being the Euclidean distance between the cells the persons i, j are located in (the $+0.1$ prevents dividing by zero for persons in the same cell).

2. These measures are normalised by $p_{i,j} = \frac{d_{i,j}}{\sum_j d_{i,j}}$.

3. For person i, the first friend, say j_1, is chosen randomly with probabilities $p_{i,j}$ for choosing person j. Then the remaining $p_{i,j}$ $(j \neq j_1)$ are renormalized and the next friend is chosen; this is repeated until person i has n friends.

As these processes do not mean that if j is a friend of i, i has to be a friend of j as well, friendship is not necessarily reciprocal and thus the respective social networks are directed graphs.

The connection weights $w_{i,j}$ a person i puts on the connections to friends are initialised with 1 for all friends j.

4.1.5 Finalize Initialisation

In the last part of the initialisation, the data structures for saving the the variables of all objects are created, and the constant parameters of all objects are saved.

4.2 Inputs

There are four different **population distributions** in R-MoTMo that can be used as the input population. They are shown in Figure 3. All maps consist of a square of 36 (6×6) cells on which – depending on the maps – between 330 and 480 persons are distributed. For all setups the maximum population density per cell is $p_{\max} = 26$ and the minimum is $p_{\min} = 2$. Apriori convenience functions for both mobility types are thus equal at cells with 14 inhabitants (see Section 2.2.3 and Figure 2 there); these cells are called indifferent. Cells with more than 14 inhabitants are called urban, those with less than 14 rural.

The four setups are designed to have either a mainly rural (map 2) or urban (map 3) setting, with a town/city in one corner of the map and a less populated area. Map 1 is a very balanced setup in the sense that there is an equal amount of 26 persons living in a maximally and minimally populated cells and the rest – the majority – of persons live in cells which are at the border of being rural or urban. Map 4 is similar and also a bit artificial; it is meant to study the impacts of abrupt population density changes.

4.3 Submodels

The three submodels described here are methods of either the `cell` or `person` objects. These objects are considered agents in the model because these subroutines represent a kind of internal information processing of the respective object.

4.3.1 Calculate Conveniences (Cell)

The convenience of mobility types, given in equation (1), has two elements that depend on the usage of the mobility type m in the cell c, $A_{c,m}$ and $B_{c,m}$. The rationale behind this is that – generally speaking – larger total usage of a mobility type makes it less convenient in the short term (because of traffic jams, crowded buses or trains etc.) but more convenient in the long run, if we assume that the infrastructure will be expanded etc. Thus we assume an immediate usage convenience malus, $A_{c,m}$, and a long term convenience bonus $B_{c,m}$, see (1). The mathematical representation of these assumptions in the model is

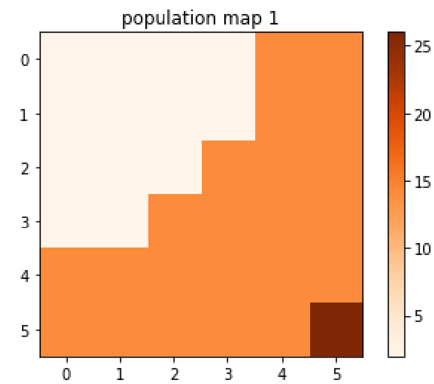
$$A_{c,m}(t) = 1 - \frac{1}{3} \cdot \frac{p_{c,m}(t)}{p_c} \tag{5}$$

$$B_{c,m}(t) = \frac{1}{3} \cdot \frac{p_{c,m}(t)}{p_c} + \frac{2}{3} \cdot B_{c,m}(t-1) \tag{6}$$

Here, p_c is the number of persons in cell c and $p_{c,m}(t)$ is the number of persons in cell c using mobility type m at time t. A only depends on the current amount of users in the cell, whereas B also depends on the developments in the past.

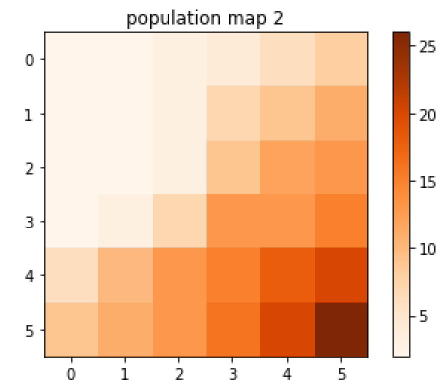
4.3.2 Weight Connections to Friends (Person)

In the beginning, all connections (links between persons and their friends) are equally weighted with 1. When the mobility choice of a friend is copied in time step t, in the next time step the



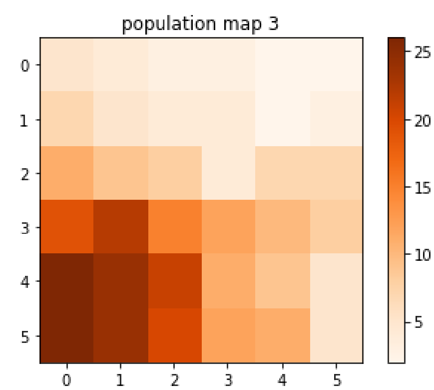
360 persons on 36 cells of which are

urban:	1 cell with 26 persons
rural:	13 cells with 26 persons
indifferent:	22 cells with 308 persons



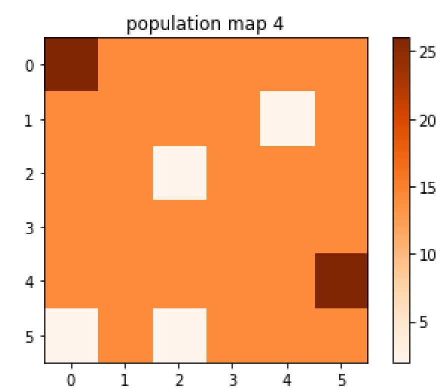
330 persons on 36 cells of which are

urban:	7 cells with 130 persons
rural:	29 cells with 200 persons
indifferent:	0 cells with 0 persons



370 persons on 36 cells of which are

urban:	9 cell with 197 persons
rural:	27 cells with 173 persons
indifferent:	0 cells with 0 persons



480 persons on 36 cells of which are

urban:	2 cells with 52 persons
rural:	4 cells with 8 persons
indifferent:	30 cells with 420 persons

Figure 3: The different population maps to choose from, for all maps the maximum population density per cell is 26 and the minimum is 2. Cells with more than 14 inhabitants are called urban, and cells with less than 14 rural. The rest of the cells in each maps are "indifferent" in the sense that neither of the two mobility types is more convenient apriori.

respective connection weight to this friend is updated. For this, the weight of the connection is multiplied by 1 plus the relative utility gain or loss archived by copying the friend's choice, i.e.

$$w_{i,j}(t+1) = w_{i,j}(t) \cdot \frac{u_i(t+1)}{u_i(t)} \tag{7}$$

with w being the weight of the connection to this friend and u the person's own utility. The rationale behind this is that if a person's utility is increased by copying somebody, it becomes more likely to copy this friend again and vice versa.

4.3.3 Imitate (Person)

In each time step, a friend is chosen randomly to copy the mobility choice from. The probability for choosing a specific friend is the normalized product of the friend's utility times the connection weight. That means

$$q_{ij}(t) = \frac{u_j(t) \cdot w_{ij}(t)}{\sum_{k \in F(i)} u_k(t) w_{ik}(t)} \tag{8}$$

is the probability to choose friend j, where $F(i)$ are the indices of friends of person i. After choosing a friend for imitation, the friend's mobility choice is actually copied if and only if the friend's utility is higher than the person's own utility. (This can also mean that the type that has been used already is copied in which case the mobility type is not really changed.)

References

[1] Sarah Wolf, Steffen Fürst, Andreas Geiges, Manfred Laublichler, Jahel Mielke, Gesine Steudle, Konstantin Winter, and Carlo Jaeger. The Decision Theatre Triangle for societal challenges – Insights from Decision Theatres on sustainable mobility and resulting research needs. *Global Climate Forum Working Paper*, 2, 2021.

[2] Manfred D. Laubichler and Jürgen Renn. Extended Evolution: A conceptual framework for integrating regulatory networks and niche construction. *Journal of Experimental Zoology (Part B: Molecular and Developmental Evolution)*, 324:565–577, 2015.