2022 1st International Conference on Multidisciplinary Application of Information Technology

Modeling and Migration-based Control of Depopulation

Márton, Lőrinc

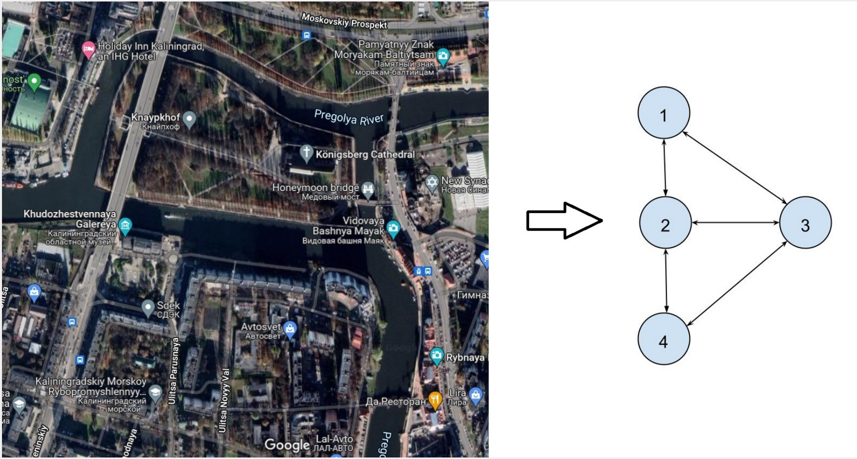
SAPIENTIA - Hungarian University of Transylvania, Romania
University of Pannonia, Hungary

Overview of the presentation

Dynamic Networks - Basic Notions

Networks

A system defined by interconnections (links) and subsystems (nodes) with similar proprieties.



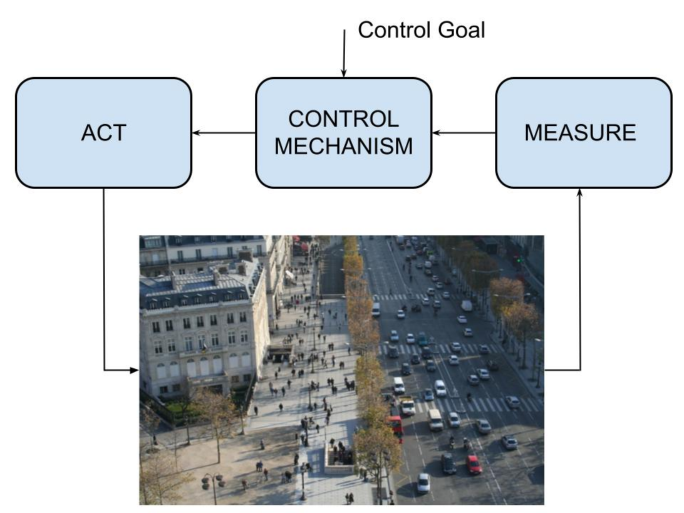
Migration networks

- *Subsystems*: Habitats
- *Interconnections*: Two subsystems are connected if migration is possible between them.

- A system which state rate of change is a function of the inputs and *current state*. An example of a mathematical model:

$$\frac{dN}{dt} = G(N, M), \quad N(0) = N_0 \geq 0$$

- N - local population size
- M - migrating population size
- $\frac{dN}{dt}$ - *population rate of change* - the change of the population (dN) over a time interval (dt)
- If the *growth function* $G(N, M)$ is positive $\rightarrow$ population increase.
- If the *growth function* $G(N, M)$ is negative $\rightarrow$ population decrease.


Control Goal
ACT
CONTROL
MECHANISM
MEASURE

Motivation of the Research Work

Depopulation - Romania

Technological Forecasting & Social Change 175 (2022) 121370

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Out-migration and social and technological marginalization in Romania. Regional disparities

Bianca Mitrică [a], Nicoleta Damian [b,*], Ines Grigorescu [b], Irena Mocanu [a], Monica Dumitraşcu [c], Mihaela Persu [a]

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A B S T R A C T

Migration is one of the drivers of population change in Europe. Out-migration has become a relatively new phenomenon for Romania, especially after the fall of communism and the accession to the European Union. According to EUROSTAT, Romania ranks fifth in the out-migration hierarchy at EU level. The present study aims to provide an insight on the influence of social and technological development level on the out-migration flows by computing and correlating the Social and Technological Disadvantage Index to Out-migration Rate. The study is conducted based on the statistical data available provided by the National Institute of Statistics and by the Romania's representative body of clusters. The study is carried out at the level of 42 Romanian counties (NUTS3 level) for the 2018 timeline. The main findings of the study are related to the fact that the high magnitude of out-migration pertain, on the one hand, to a low level of the social and technological degree (a group of counties from Southern Romania) and, on the other hand, to a high level (such as the case of several counties from Western or Central Romania, Bucharest Municipality and thereabouts). A distinct situation is that of the Eastern counties, which are no longer an area for high emigration, compared to the 2002–2007 period.

Aging - Romania

sustainability

MDPI

Article

Ageing Urban Population Prognostic between 2020 and 2050 in Transylvania Region (Romania)

Raisa Țăruș [1,*], Ștefan Dezsi [2,3] and Florin Pop [1]

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Abstract: Population ageing represents a dramatic scenario and a progressive process inducing major changes in the dynamics of the population and especially in the age structure. The ageing population process is a phenomenon relevant to define not only demographic but also social, cultural, and territorial transformations in relation to the urban settlements. In this article, we present a case study regarding the ageing process persistent in urban areas from the counties of the Transylvania region.

Depopulation - Spain

Europ. Countrys. · Vol. 11 · 2019 · No. 3 · p. 341-369
DOI: 10.2478/euco-2019-0021

sciendo

European Countryside MENDELU

DEPOPULATION PROCESSES IN EUROPEAN RURAL AREAS: A CASE STUDY OF CANTABRIA (SPAIN)

Carmen Delgado Viñas[1]

Depopulation - USA

Rural Sociology 84(1), 2019, pp. 3–27
DOI: 10.1111/ruso.12266

Rural Depopulation: Growth and Decline Processes over the Past Century*

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University of New Hampshire

Daniel T. Lichter
Departments of Policy Analysis and Management and Sociology
Cornell University

ABSTRACT This article highlights the rise and geographic spread of depopulation in rural America over the past century. "Depopulation" refers to chronic population losses that prevent counties from returning to an earlier period of peak population size. In this article, we identify 746 depopulating counties—mostly nonmetropolitan—representing 24 percent of all U.S. counties. More than 46 percent of remote rural counties are depopulating compared to 24 percent of the adjacent nonmetropolitan counties and just 6 percent of metropolitan counties. Rural county populations often peaked in size during the 1940s and 1950s, especially in the agricultural heartland. Depopulation today reflects a complex interplay of chronic net out-migration and natural decrease that is rooted in the past. Depopulation not only is a direct result of persistent out-migration but also reflects large second-order effects expressed in declining fertility and rising mortality (usually associated with population aging). Depopulation has become a signature demographic phenomenon in broad regions of rural America.

Depopulation - Indonesia

administrative sciences

MDPI

Article

Distance-Dependent Migration Intention of Villagers: Comparative Study of Peri-Urban and Remote Villages in Indonesia

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[4] Division of Environmental Science and Technology, Kyoto University, Kyoto 606-8502, Japan
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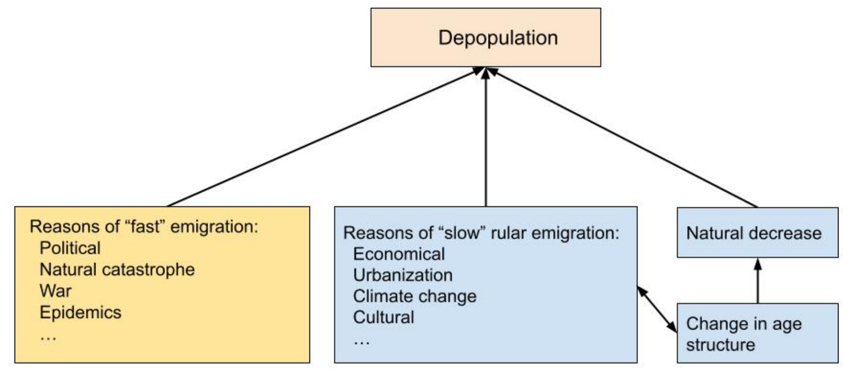
Abstract: Rural-to-urban migration disturbs essential factors of rural development, including labor forces, land ownership, and food production. To avoid late responses to emigration, scholars have begun investigating earlier stages of rural emigration. However, prior studies have focused on a single spatial entity only while also leaning toward trends in developed countries. Therefore, this study fills gaps by focusing on the differences in migration intention between villages in less developed settings. In observing the differences, this research takes peri-urban and remote villages as cases located at different distances from their nearest urban destination. This study treats migration intention as the

Some reasons of migration

Some reasons of migration

Some reasons of migration



Some consequences of emigration

- Loss of economic dynamism
- Basic service offers (health, education, retail, public transport) shrink.
- Crop abandonment
- Less social involvement
- *Quality of life decreases*

Some consequences of immigration

- Price increases
- Overpopulation
- More pollution
- *In the long run, the quality of life could decrease*

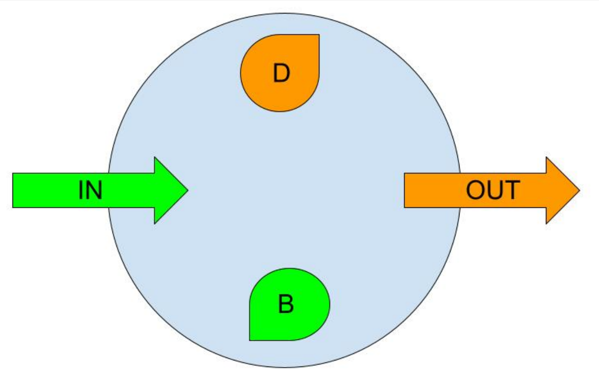
The goal of the research

- *Develop a population dynamics model that is able to catch both the depopulation phenomena and the migration processes.*

- *Develop a migration-based depopulation avoidance control.*

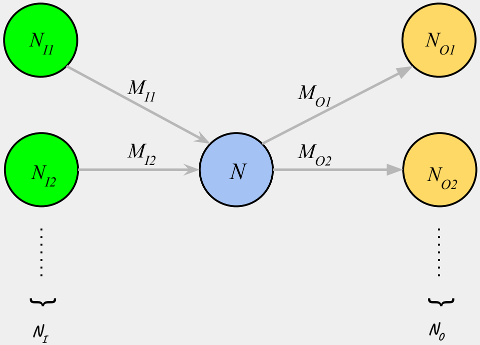
Depopulation Modeling

Population rate of change =
Birth rate - Death rate + Migration INflow rate - Migration OUTflow rate



Habitat subject to migration

$$\frac{dN}{dt} = G(N) + \sum_{j \in \mathcal{N}_I} \frac{dM_j}{dt} - \sum_{i \in \mathcal{N}_O} \frac{dM_i}{dt}, \quad N(0) = N_0 \geq 0.$$

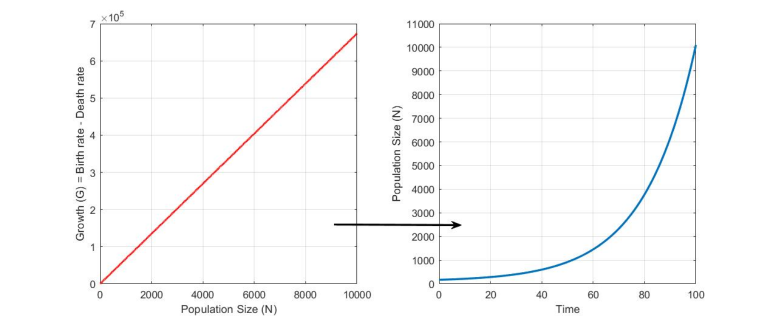


Classic growth rate model (without migration)

- Describes the exponential population growth:

$$G = r \cdot N,$$

- r is the Growth (Birth - Death) rate coefficient
- If the rate function is always strictly positive, the population of the habitat increases until the "end of time".

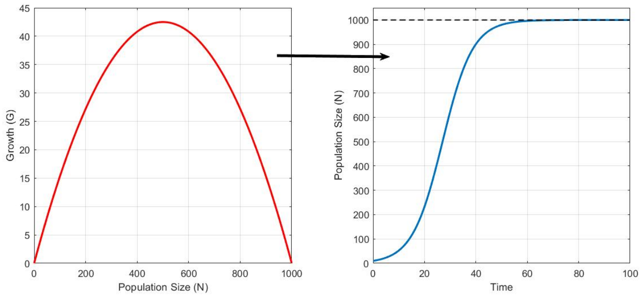


Logistic Growth Model (without migration)

- Describes the self-limiting growth of a biological population of a habitat:

$$G = r \cdot N \cdot \left(1 - \frac{N}{K}\right),$$

- K - carrying capacity of a habitat
- The rate function is always positive *but* if N reaches K the population increase stops.



- At high population size the carrying capacity remains important
- At low population size the aging could yield to depopulation
- The model should have different behavior at low population size and at high population size.

Definition for depopulation

- Johnson et al. - Rural Sociology (2019): "There is no consensus on what constitutes depopulation."

Definition for depopulation

- *Definition:* $N_C \in (0, K)$ is the *critical population size* if $N(t_0) < N_C$ implies that $\lim_{t \to \infty} N(t) = 0$ in case of vanishing immigration.

- *Definition*: A habitat is *subject to depopulation* if $N(t_0) < N_C$.

Habitat subject to depopulation

- Consider a general growth model:

$$\frac{dN}{dt} = \rho \cdot N \cdot r(N), \quad N(t_0) = N_0 \geq 0.$$

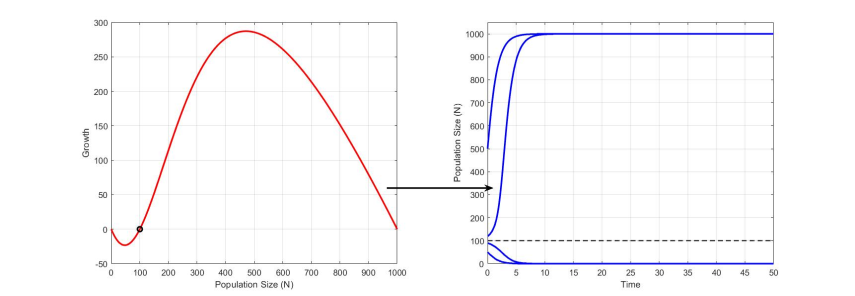
- $r(N)$ - per capita growth rate
- To capture the depopulation $r(N)$ should be chosen such that

$$r(N) < 0 \text{ if } 0 < N < N_C,$$
$$r(N) > 0 \text{ if } N_C < N < K$$

- N_C - Critical population size
- K - Carrying capacity
- The growth function:

$$G(N) = r \cdot N \cdot \left(\frac{2n_a \cdot N}{n_g^2 + N^2} - 1 \right)$$

- $n_a = (N_C + K)/2$ and $n_g = \sqrt{N_C K}$



Assumption: (Median age vs. critical population size) $N_C = N_C(a_m)$ where $N_C : (0, a_M) \to (0, N_M)$ is a strictly increasing and invertible function.

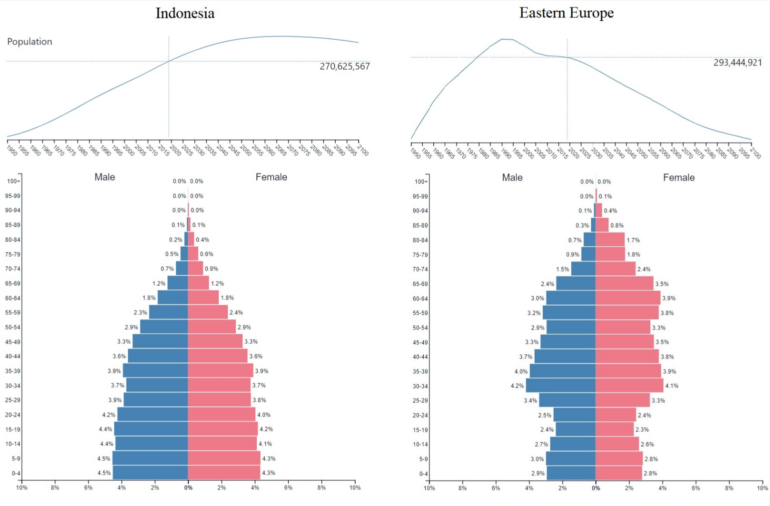
- McKendrick - Von Foerster model

$$n = n(a,t)$$
$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial a} + \mu(a,t)n(a,t) = 0$$

- The boundary conditions at $t = 0$ and $a = 0$ respectively are:

$$n(0,a) = n_0(a),$$
$$n(t,0) = \int_0^{a_M} b(a,t)n(t,a)da$$

Age pyramid and population dynamics



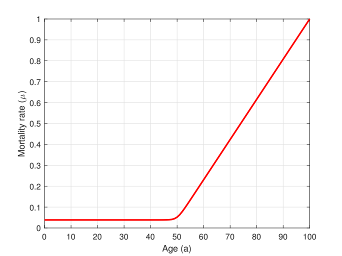
Source: https://www.populationpyramid.net/

- *Median age* (a_m):

$$\int_0^{a_m} n(t,a)da = \int_{a_m}^{a_M} n(t,a)da.$$

- If the mortality rate under the median age is almost constant ($\mu(a,t) = \mu_m(t), \text{ as } a(t) < a_m$)

$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial a} + \mu(a,t)n(a,t) = 0 \qquad \approx \qquad \frac{dN}{dt} = \rho N r(N)$$



Migration Modeling

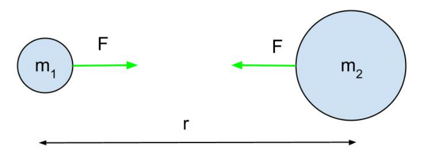
- The long term migration among two neighboring habitats with similar proprieties depends on the *population density difference* between them.

Human Migration

- Human migration involves the movement of people from one place to another with intentions of settling, permanently or temporarily, at a new location.
- *Spatial interaction*: habitats interact with each other in terms of the movement of people, services, energy, or information.

Gravity model of migration

- Inspired by the Newton's law of gravity ($F = g\frac{m_1 m_2}{r^2}$):



- Gravity model of migration rate:

$$\frac{dM_{12}}{dt} = \mu \frac{N_1^{\alpha} N_2^{\beta}}{r^{\eta}},$$

A generalized migration flow model

- Migration form habitat i to habitat j:

$$\frac{dM_{ij}}{dt} = \frac{1}{\gamma_{ij}} R_i(N_i) A_j(N_j)$$

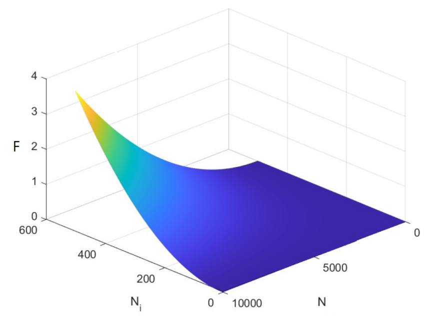
- γ_{ij} - cost from habitat i to habitat j
- $R_i(N_i)$ - repulsiveness of habitat i
- $A_j(N_j)$ - attractiveness of habitat j

Gravity model revisited

- The gravity model also falls into this category:

$$\gamma_j = d_{ij}^{\eta}/\mu_{ij}$$
$$R_i(N_i) = N_i^{\beta}$$
$$A_j(N_j) = N_j^{\alpha}$$

- The model predicts limitless migration inflow increase as the population sizes increase.



Improved migration flow model

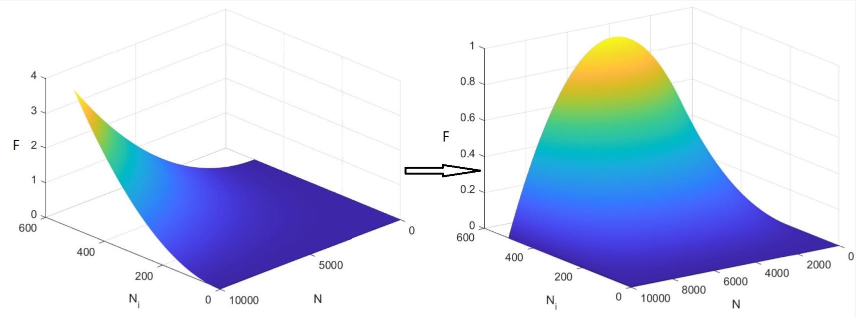
- It can be assumed that the possible emigrants are informed about the living condition in the destination habitat.
- We modify the attractiveness function such that the immigration stops when the destination habitat reaches its carrying capacity.
- This approach assumes that the potential migrants are aware about the living standards of the destinations.

$$A(K) = 0, \quad \frac{\partial A(K)}{\partial N} \leq 0.$$

Improved migration flow model

- A possible implementation of the attractiveness term:

$$A(N) = N(K - N), \qquad R_j(N_j) = N_j^2.$$



$$\frac{dN}{dt} = \underbrace{N\left(\rho r(N) + \sum_{j\in\mathcal{N}_I}\frac{1}{\gamma_j}R_j(N_j)A^{(1)}(N) - \sum_{i\in\mathcal{N}_O}\frac{1}{\gamma_i}A(N_i)R^{(1)}(N)\right)}_{r_M(N,t)}.$$

Migration Control

Non-controlled case

Journal of Rural Studies, Vol. 4, No. 1, pp. 21–34, 1988
Printed in Great Britain

0743–0167/88 $3.00 + 0.00
Pergamon Journals Ltd.

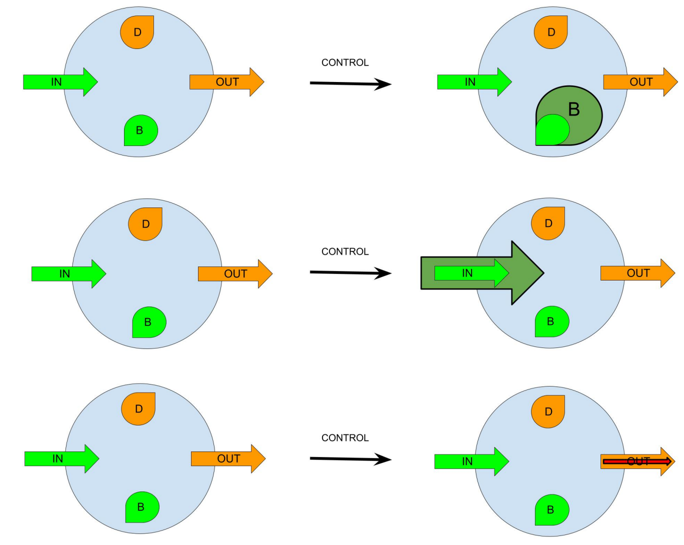
Planned Relocation of Severely Depopulated Rural Settlements: a Case Study from Japan

Edwina Palmer
Department of Asian Languages, University of Canterbury, Christchurch, New Zealand

Control Goal

- Avoid the depopulation of a habitat

Control possibilities



Internal growth control

English

euronews.

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HUNGARY

Hungary offers €30,000 to married couples who can produce three children

COMMENTS

By Emma Beswick • Updated: 31/07/2019

Inflow rate control

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Underpopulated Italian region offers visitors €25,000 to move in

Molise president finds novel way to breathe life into area as resident numbers dwindle

Lorenzo Tondo *in Palermo*

@lorenzo_tondo

Wed 11 Sep 2019 11.45 BST

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Spain

Spanish reality TV show takes on problem of rural depopulation

Forty contestants will compete to launch businesses from villages of fewer than 5,000 people

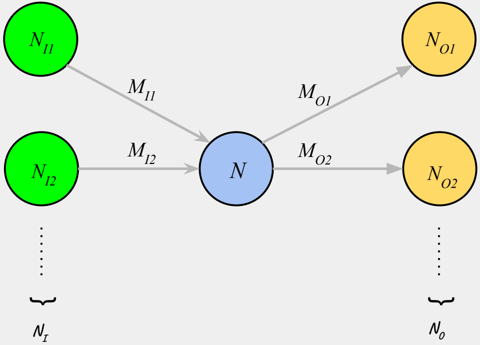
Ashifa Kassam *in Madrid*
@ashifa_k
Thu 5 Aug 2021 16.40 BST

Some control possibilities

- Diversification in economic sectors
- Technological improvements (good Internet connection bandwidth)
- Financial support

Habitat model with controlled migration

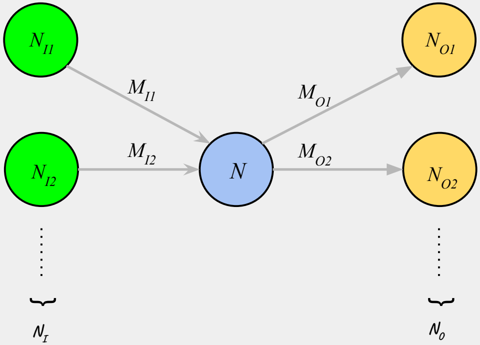
$$\frac{dN}{dt} = N\left(\rho r(N) + \sum_{j\in\mathcal{N}_I}\frac{1+u_{Ij}}{\gamma_j}R_j(N_j)A^{(1)}(N) - \sum_{i\in\mathcal{N}_O}\frac{1-u_{Oi}}{\gamma_i}A_i(N_i)R^{(1)}(N)\right)$$



Habitat model with controlled migration

$$\frac{dN}{dt} = N(r_M(N,t) + \mathbf{b}^T\mathbf{u}),$$

$$\text{where} \quad \mathbf{u} = (\ldots \ u_{Ij} \ \ldots \ \ldots \ u_{Oi} \ \ldots)^T$$



Control objective

- Design the control input vector $\mathbf{u}$ such that the population has a prescribed dynamics if $N \leq N_C$. The prescribed dynamics is defined by a per capita rate function $r_P(N, t)$.
- Let the prescribed population dynamics be:

$$\frac{dN}{dt} = r_P(N, t)N, \quad \text{if } N \leq N_C.$$

Control effort computation

- To each entry of the control vector a priority constants $(\alpha_i,\ \alpha_j)$ are associated as

$$
\begin{aligned}
&u_{Ij} \leftarrow \alpha_j \\
&u_{Oi} \leftarrow \alpha_i \\
&\sum_{j\in\mathcal{N}_I} \alpha_j + \sum_{i\in\mathcal{N}_O} \alpha_i = 1.
\end{aligned}
$$

- To compute the necessary control effort solve the equation:

$$
\begin{cases}
r_P(N,t) = r_M(N,t) + \mathbf{b}^T\mathbf{u} \quad \text{(if control is enabled)} \\
\frac{1}{\alpha_j}\frac{u_{Ij}-u_{Ij}^{(m)}}{u_{Ij}^{(M)}-u_{Ij}^{(m)}} = \ldots = \frac{1}{\alpha_i}\frac{u_{Oi}-u_{Oi}^{(m)}}{u_{Oi}^{(M)}-u_{Oi}^{(m)}}.
\end{cases}
$$

Control in the presence of uncertainties

- Generally, it cannot be assumed that all the parameters of the growth rate function and the migration rate functions are perfectly known.
- The cumulated effect of the uncertainties is introduced into the model as a bounded additive term (d):

$$\frac{dN}{dt} = N\left(r_M(N,t) + \mathbf{b}^T\mathbf{u} + d(N,t)\right).$$

- Assume that

$$d_m < d(N,t) < d_M$$

- Recall the design equation:

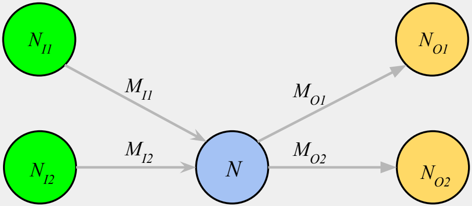
$$r_P(N,t) = r_M(N,t) + \mathbf{b}^T\mathbf{u}$$

- Choose the prescribed rate function as:

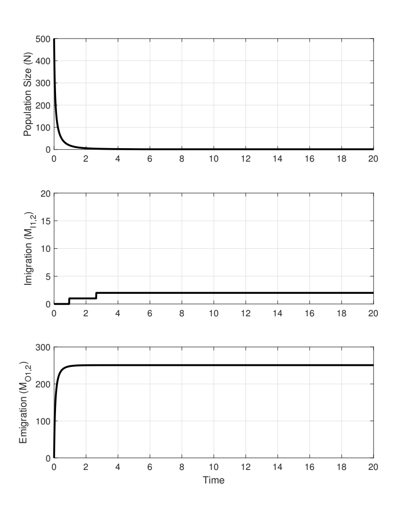
$$r_P(N,t) = K(N_P - N)$$

- Here $N_P > N_C$ is a prescribed population size.
- *If K_P is chosen such that $K(N_P - N_C) \geq |d_m|$ the control objective is achieved.*

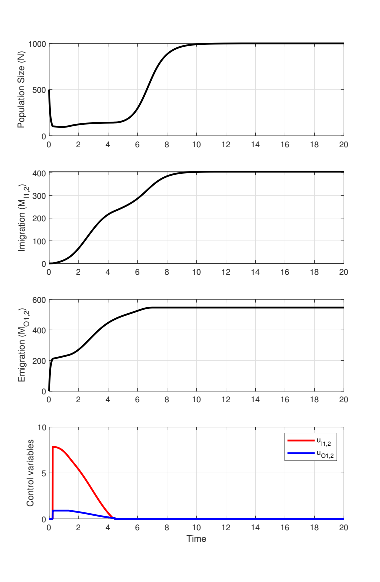
Simulation results



Simulation results - Non-controlled case



Simulation results - Controlled case



Conclusions

Conclusions

- Mathematical migration models: simplified descriptions of migration processes.
- They should reflect such aspects of migration that are important in the view of the targeted application.
- Based on the model the control parameters (control enable time, control effort) can be estimated.
- "There are no good models but some of them are useful."