Bridging Epidemiology and Mobility: Creating a Policy-Aware Activity-Based Model for Epidemiological Studies

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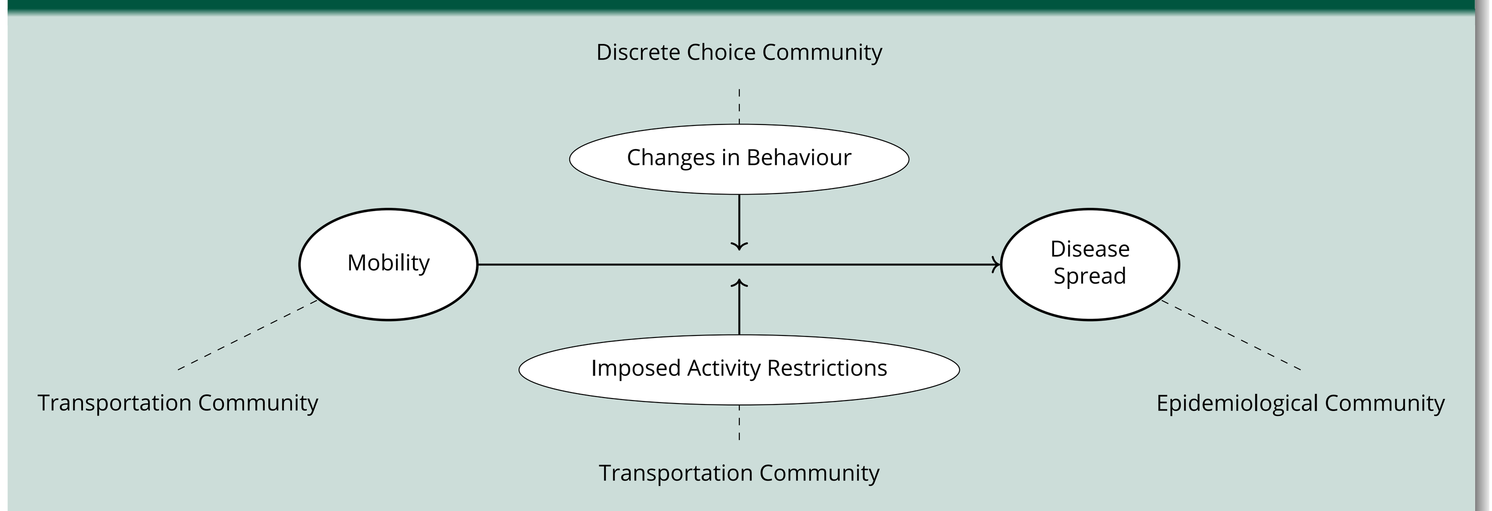
Introduction

How do we link these communities?



1. Activity-travel behaviour impacts disease spread.
2. Imposed activity restrictions change how people schedule their day.
3. Risk perception in performing activities changes how people schedule their day.

Description of the Data

A synthetic population provided by He et al. 2020:

i. **Information on individuals:** Age, Gender, Employment status, and Education level.

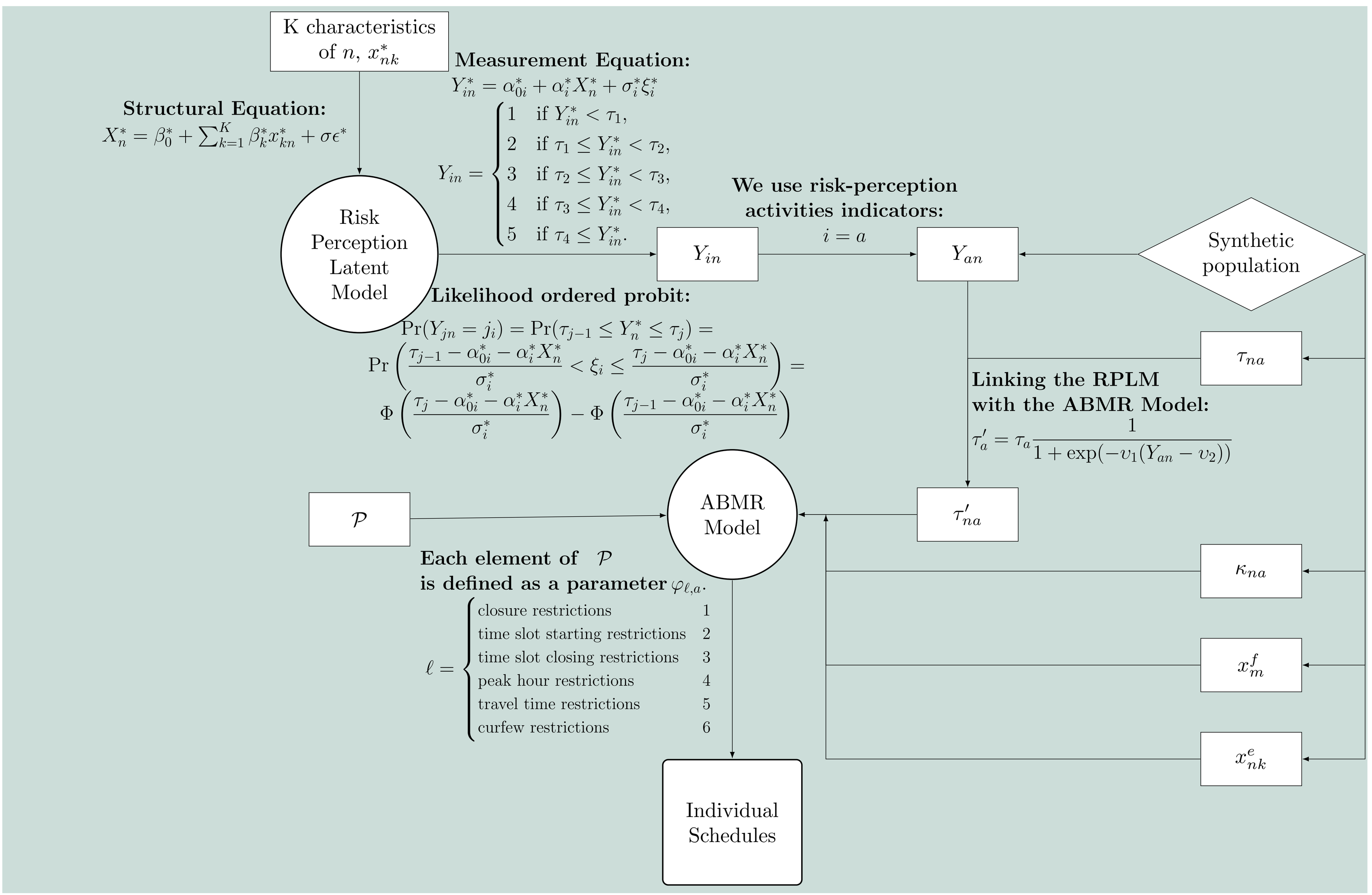
ii. **Geographic network data:** Coordinates assigned to nodes, and Specific activity types tagged to nodes (leisure, education, shop, work, home)

COVID Future Wave 1 Survey Data (see Salon et al. 2021)

i. **Attitudinal variables of individuals Y_{in}:** Reflecting risk perceptions and concerns regarding the pandemic.

ii. **Demographic information k of individuals n represented as x_{kn}:** Age, Gender, Education level, Region, and Race.

Methodology



ABRM Model

$$\max_{\omega,Z,x,\tau} \quad U_0 + \sum_{a=0}^{A} Z^0_a(\chi_a + V^1_a + V^2_a + \varphi_{5,a} V^3_{ab}) + \sum_{a=0}^{A}\sum_{b=0}^{A} Z_{ab} \cdot \theta_t \cdot \omega_{ab}$$

subject to:

$$
\begin{aligned}
&\sum_a \sum_b (Z^0_a \cdot x^2_a + Z_{ab} \cdot \omega_{ab}) = 24 && \\
&\omega_{\text{dawn}} = \omega_{\text{dusk}} = 1 && \\
&x^2_a \geq Z^0_a \cdot \tau^{\min}_a && \forall a \in \mathscr{A} \\
&x^2_a \leq Z^0_a \cdot T && \forall a \in \mathscr{A} \\
&Z_{ab} + Z_{ba} \leq 1 && \forall a, b \in \mathscr{A}, a \neq b \\
&Z_{a,\text{dawn}} = Z_{\text{dusk},a} = 0 && \forall a \in \mathscr{A} \\
&\sum_a Z_{ab} = Z^0_b && \forall b \in \mathscr{A}, b \neq \text{dawn} \\
&\sum_b Z_{ab} = Z^0_a && \forall a \in \mathscr{A}, a \neq \text{dusk} \\
&(Z_{ab} - 1) \cdot T \leq x^1_a + x^2_a + Z_{ab} \cdot \omega_{ab} - x^1_b && \forall a, b \in \mathscr{A}, a \neq b, \\
&(1 - Z_{ab}) \cdot T \geq x^1_a + x^2_a + Z_{ab} \cdot \omega_{ab} - x^1_b && \forall a, b \in \mathscr{A}, a \neq b \\
&x^1_a \geq \chi^-_a && \forall a \in \mathscr{A} \\
&x^1_a + x^2_a \leq \chi^+_a && \forall a \in \mathscr{A} \\
&\sum_{a \in \mathscr{F}_a} Z^0_a \leq 1 && \forall a \in \mathscr{A} \\
&\varphi_{1,a} Z^0_a = 0 && \forall \varphi_{1,a} \in \mathscr{P}, a \in \mathscr{A} \\
&\varphi_{2,a} x^1_a \geq \varphi_{2,a} t^1_\Theta && \forall \varphi_{2,a} \in \mathscr{P}, a \in \mathscr{A} \\
&\varphi_{3,a}(x^1_a + x^2_a) \geq \varphi_{3,a} t^2_\Theta && \forall \varphi_{3,a} \in \mathscr{P}, a \in \mathscr{A} \\
&\varphi_{4,a}(x^1_a + x^2_a) \leq \varphi_{4,a}(t^3_\Theta + 24 * (1 - Z_2)) && \forall \varphi_{4,a} \in \mathscr{P}, a \in \mathscr{A} \\
&\varphi_{4,a} x^1_a \geq \varphi_{4,a}(t^4_\Theta - 24 * (1 - Z_1)) && \forall \varphi_{4,a} \in \mathscr{P}, a \in \mathscr{A} \\
&\varphi_{4,a}(Z_1 + Z_2 - 1) \geq 0 && \forall a \in \mathscr{A} \\
&\varphi_{5,a}(Z_{ab} \cdot \omega_{ab}) \leq \varphi_{5,a} t^5_\Theta && \forall \varphi_{5,a} \in \mathscr{P}, a \in \mathscr{A} \\
&\varphi_{6,a} \tau_{\text{dawn}} \leq \varphi_{6,a} t^6_\Theta && \forall a \in \mathscr{A} \\
&\varphi_{6,a} x_{\text{dusk}} \geq \varphi_{6,a} t^7_\Theta && \forall a \in \mathscr{A}
\end{aligned}
$$

where:

$$
\begin{aligned}
V^1_a &= \theta^{\text{early}}_a \cdot \max(0, \kappa_a - x^1_a - \Delta^{\text{early}}_a) + \theta^{\text{late}}_a \cdot \max(0, x^1_a - \kappa_a - \Delta^{\text{late}}_a) \\
V^2_a &= \theta^{\text{short}}_a \cdot \max(0, \tau_a - x^2_a - \Delta^{\text{short}}_a) + \theta^{\text{long}}_a \cdot \max(0, x^2_a - \tau_a - \Delta^{\text{long}}_a) \\
V^3_{ab} &= \theta_t \cdot \omega_{ab}
\end{aligned}
$$

The framework is build upon Pougala, Hillel, and Bierlaire 2022.

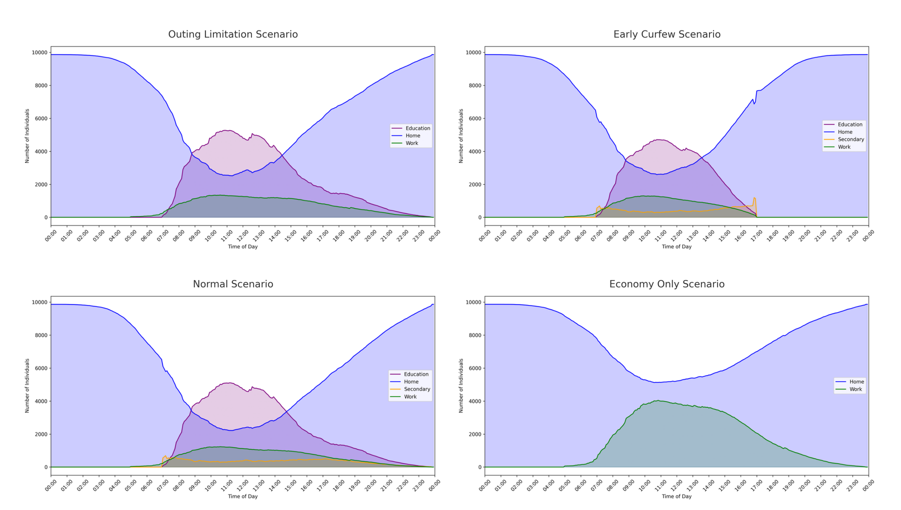
Case Study

We pick the scenario:

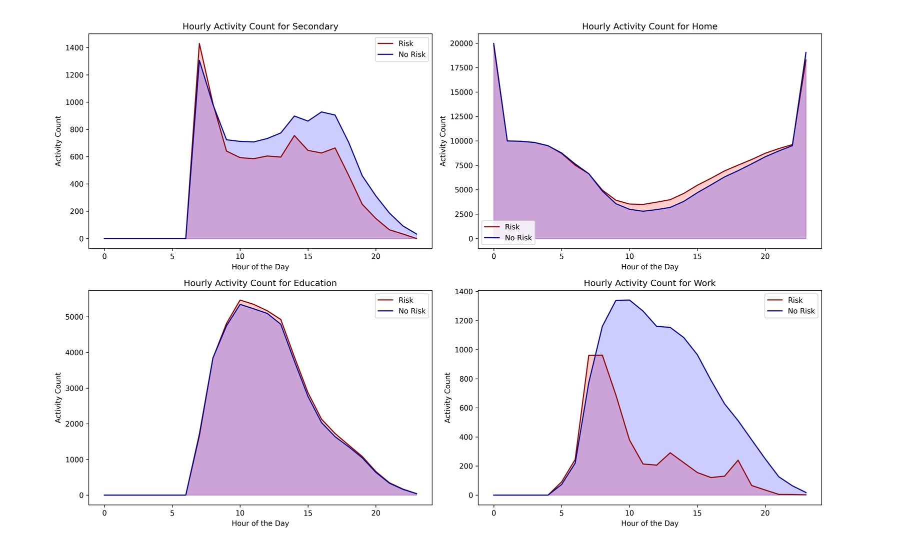
Tested Scenarios	Closure			Constraints
	Secondary	Education	Work	Curfew
No restrictions				
Outing limitations	x			
Early curfew				5pm
Economy preservation	x	x		
Work-education balance		x	x	

Results

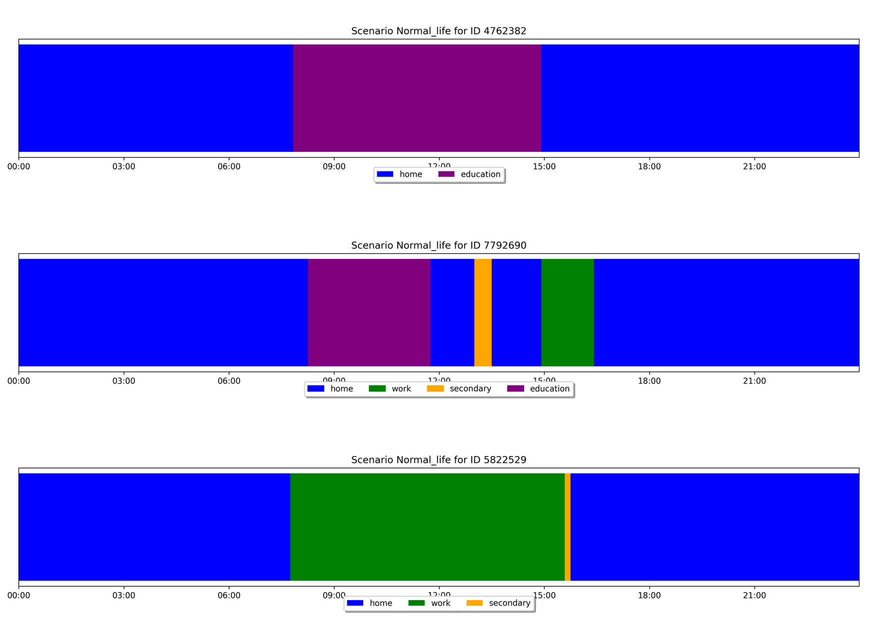
a. Aggregated Results: results across scenarios



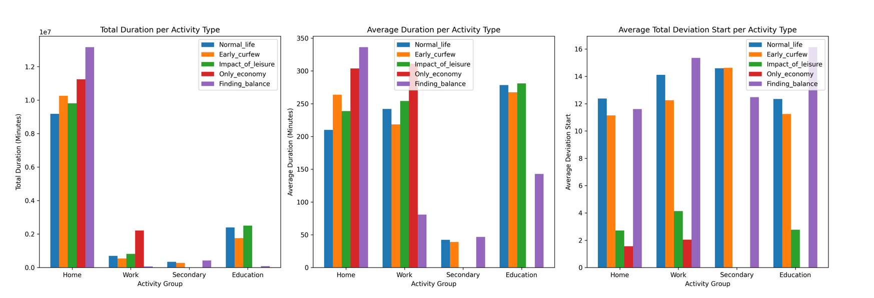
b. Aggregated results: insights on the RPLM



c. Disaggregated Results: results across individuals



d. Aggregated results: insights on activity durations



Observations

a. **Constraints work** as expected. b. The perception of **risk decreases activity participation**. c. The **schedules** seem **realistic**. d. We capture the **activity-swapping** phenomena.

Conclusion

Conclusion

i. Computationally efficient tool to model individual schedules for **epidemiological models**, capable of running 10,000 individuals with 5,000 facilities in 50 minutes.

ii. Able to capture the **'swapping-activities'** effect.

iii. Able to model government-**imposed mobility restrictions** and **self-imposed** changes due to perceived risks.

Future Work

i. Expand the sample to **300,000 individuals** and calibrate the latent model with more socioeconomic variables.

ii. Embed the activity-based model into an **epidemiological model** to optimize **policies**.

iii. **Validate** the model with **real data**.

References