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Childbirth Mobilities: A Geo-Spatial Simulation Approach

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Abstract. While the literature has identified some predictors to childbirth hospital selection such as distance to facilities, ranking of hospitals and word-of-mouth, there is a lack of knowledge on how they interact. This contribution aims at filling this gap leveraging agent-based modeling as a method of collective artificial intelligence, modeling the decisional process of expectant women and social influence mechanisms. We initialize our model with a synthetic population extracted from integrated geo-data from the Tuscany region in Italy. We identify what combination of distance to hospital, opinion ranking and modes of social influence can replicate data and to what extent.

Keywords. childbirth mobilities, agent-based simulation, hospital choice, social network, social influence

1. Introduction

Selecting a maternity hospital for childbirth is a significant decision for expectant parents. It is critical for the public sector to understand how these decisions are shaped and how they can generate uneven demand across the territory. A wide range of factors can influence the hospital choice: the most important identified in the literature are distance to the facility [1], their ranking [2] and word-of-mouth [3], such as seeking recommendations from the own social networks or elsewhere. The main challenge to understand the phenomenon is to address the interaction of those predictors within a dynamic process of communication, and how individual decisions translate into collective mobilities observed. This paper aims to fill this gap, proposing a geo-spatial agent-based model for childbirth hospital selection. The method leverages artificial intelligence to model virtual agents able to elaborate information and interact with other agents and their environment, adapting to achieve a goal. It thus can best fit the study of the social dynamics linking the individual behavior to collective aggregated phenomena, not scalable to the agency of isolated individuals [4]. We simulate the decisional process of agents integrating the predictors of distance to facilities and ranking, together with communication processes of social influence between agents. Our work represents a methodological innovation in two ways. First, we show how agent-based modeling as a

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form of collective artificial intelligence can be used to investigate the link between the individual behavior of citizens and collective patterns in healthcare demand. Second, we provide a framework for integrating aggregated and separate healthcare data into synthetic populations that represent individual-level characteristics and are spatially mapped onto the territory.

2. Model description

We initialized the artificial society to mimic the Tuscany region in Italy, with attributes of expectant population from aggregated empirical data referred to the year 2023, mapping the synthetic population extracted to a shapefile of municipalities. We disaggregated the data collected from regional healthcare registry [5] and mapped each woman to their childbirth hospital and to their municipality residency, so to reproduce the empirical mobilities we aimed at. Another set of data was the hospitals' national performance ranking, i.e. PNE (Programma Nazionale Esiti) [6]. We used a travel time matrix for the distances between municipalities, downloaded from the national statistics bureau (ISTAT) [7].[2]

The model comprises 20,177 women resident in 273 municipalities, and 24 hospitals allocated in the region. Figure 1 shows the flow of the model. At time 0 of the simulation, women are provided with an opinion for each hospital in the range -1 and +1 drawn from a random distribution. At each time step, one woman is set to the status pregnant and is called to select one hospital. Social influence is modeled through two channels: selective information seeking and continuous communication. The first occurs within the selection decision, where the pregnant woman selects randomly 50 other women closer in space from whom to seek advice, we will refer to this group as *friends*. One woman can select only one hospital, while the communication process is continuous. After the hospital has been selected, the woman's opinion is aligned to the hospital's PNE actual ranking, drawing from a normal distribution centered on the PNE record (clamped range -1 +1, sd 0.25), and communicated to other women in their municipality. The latter can thus potentially update their personal opinion of that hospital. Updating one's opinion via this channel has a direct implication for the receiver when she still has to select a hospital, and an indirect implication for other women when the receiver is selected as a friend by another pregnant woman and reports her updated opinion. We describe in detail these two steps and their interdependencies.

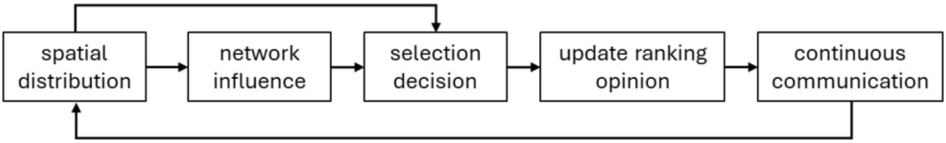

Figure 1. Flowchart of the model.

The selection process is modeled according to a random utility discrete choice model [8], which defines a utility attributed to each hospital, and the selection of the best choice based on weights attributed to the separate dimensions of distance to the hospital and

[2] The model is developed in NetLogo and available at https://github.com/RoccoPaolillo/childbirthnet/tree/MIE together with data wrangling.

ranking of hospital (opinion), allowing for some stochasticity through the inclusion of a random term. Utility attributed to each hospital is modeled as:

$$U = -\beta_{distance}(distance) + \beta_{ranking}\left(OwnOpinion + \theta\left(\left(\frac{op+oa+\cdots}{p+a+\cdots}\right) - OwnOpinion\right)\right) + \varepsilon \quad (1)$$

- $-\beta_{distance}$: weight of distance from the agent to the hospital, it is negative since closer hospitals have higher utility
- $(distance)$: travel distance from the agent to hospital, normalized distance [0,1] to align with the scale of ranking
- $\beta_{ranking}$: weight given to the ranking of the hospital, as own opinion or influenced by *friends*
- $(OwnOpinion)$: weight of own personal ranking opinion
- $\theta\left(\left(\frac{op+oa+\cdots}{p+a+\cdots}\right) - OwnOpinion\right)$: social multiplier of influence of *friends*
- ε: random term

The social multiplier comprises the weighted average of opinion of *friends* for the hospital ranging from -1 to 1, with a different weight given if the friend has had a direct experience of childbirth in the facility (p[0,1]) or the opinion is derived from continuous communication, with a weight complementary to *p* (*a*[0,1] = 1-*p*). θ[0,1] represents a convergence factor towards the weighted average of *friends*, with $\theta = 0$ meaning only $OwnOpinion$ is taken into consideration, and $\theta = 1$ meaning the $OwnOpinion$ of the agent is completely aligned to the weighted average of *friends*. Utilities attributed to hospitals are used to sort the best hospital *h* in a set of hospitals *k* via a random-wheel probability selection using the softmax function:

$$P = \frac{e^{(U_h - \max U_k)}}{\sum_{k=n}^{n} e^{(U_h - \max U_k)}} \quad (2)$$

After a hospital is selected, the *pregnant* woman closes her cycle, thereby initiating the cycle of a new *pregnant* woman. Parallel to the selection process, every 80 cycles the continuous communication occurs, where women who gave birth communicate the updated opinion out of the own experience to the 1% of their municipality. The receiver exposed to the communication updates the *OwnOpinion* following the Deffuant-Weisbuch model [9]:

$$o_t^i = o_{t-1}^i + \mu(o_{t-1}^a - o_{t-1}^i) \quad (3)$$

- o_t^i: opinion of agent *i* at time *t*
- o_{t-1}^i: opinion of agent *i* at time *t-1*
- o_{t-1}^a: opinion of agent *a* who initiates the communication at time *t-1*
- μ[0,1]: parameter of convergence; with $\mu = 0$ equal to not update, $\mu = 1$ equal to complete alignment to the opinion of agent *a*

The model implies that the communication occurs when the distance between opinions falls within a latitude of acceptance (ε). We set so that all receivers accepted the communication and converged with parameter $\mu = 0.5$.

3. Preliminary results

Figure 2 compares the empirical mobilities, aggregated by ranking of hospitals, to results of the simulations. We focus on the interaction between the strengths of preferences described in Eq. (1). In panel A, we first focus on the independent effect of distance, on which we prioritize due to its importance in healthcare literature. With minimal weight of distance ($\beta_{distance} - 1$), results are close to random distribution, as demonstrated by hospitals selection counts not differing between ranking categories and wider average distance, due to random selection from agents in the population. With the increase in the weight of distance to $\beta_{distance} - 5$, simulation results approximate the empirical distribution but not differentiating between ranking categories. In panel B, the match with empirical data is improved by including the interaction with same high level of $\beta_{ranking}$ 5. Note that the same level of $\beta_{ranking}$ 5 does not produce similar results with lower level of $\beta_{distance} - 1$. Despite being preliminary and necessitating further testing, these observations can provide some information on the phenomenon. Taking as a benchmark the ability of simulations to replicate empirical mobilities, one conclusion is that distance plays a more central role, with women preferring to give birth at the closer facility. Ranking of hospitals still matters, but it is the interaction between predictors that better replicates empirical data in panel B, covering the difference left by the effect of distance in panel A. In terms of mechanism diffusion, the selection of hospitals based on the distance seems to condition what are the hospitals agents are more likely to update to coherent PNE ranking, and to then spread in their communities, so to increase the likelihood of selection for next expectant women. Panel C tends to confirm this conclusion, showing the effect of the activation of social multiplier to 1. When pregnant women are influenced exclusively by women who gave birth (*w* exp 1), the selection of top PNE ranking hospitals is overestimated in the simulation results while the selection of low PNE ranking hospitals is underestimated. This outcome is attenuated when opinions based on experience and continuous communication have equal weight (*w* exp 0.5). This difference might be due to constant exposure to actual PNE values from women who gave birth in the first condition.

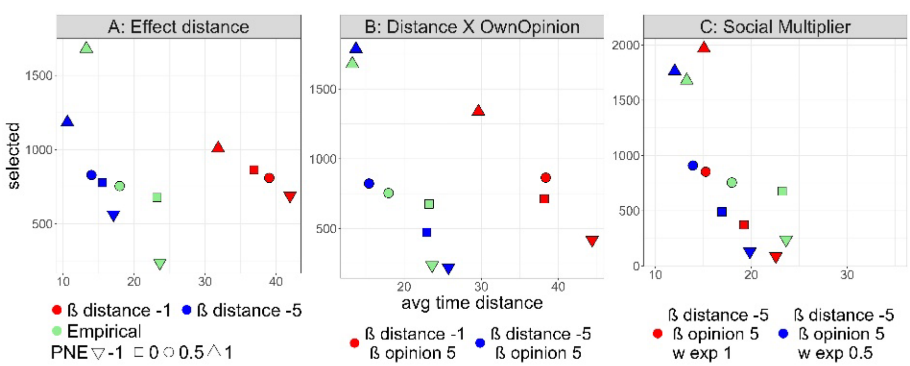

Figure 2. Simulations results. The x-axis for each panel reports the average time distance to the ranking cluster, while the y-axis the selection count. Color label Empirical and PNE legend refers to all three panels.

4. Conclusions

We presented the preliminary results of a geo-spatial agent-based model to simulate the processes underlying the selection of childbirth hospitals in the region Tuscany, Italy. We focused on distance to facilities and ranking of hospitals as main predictors known in the literature, showing the contribution of the method to simulate their interactions in the decisional process of virtual agents and mechanisms of social influence. Our results show that preference for reduced distance itself can approximate the empirical distribution, which doesn't apply to the effect of ranking. However, when the strength of ranking equals the strength of distance, their interaction improves the match with empirical data. We acknowledge some limits to our preliminary study. Further sensitivity analysis is needed to identify the persistence of the outcomes we identify for other weights of predictors and their interaction, together with robustness checks. The lack of substantial differences between conditions in panel C needs further investigation to disentangle more deeply the interaction between continuous communication and the selection decision instance. Beyond this specific case study, the method we implemented can shed light on how the predictors of healthcare decisions interact within social processes. This can be an innovative tool to investigate how individual decisions link to health demand over the territory, mapping and integrating geo-spatial information with hypothetical or data-driven scenarios, which can be extended to various medical domains.

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