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AGENT-BASED SIMULATION AND OPTIMIZATION OF HOSPITAL UTILIZATION IN A REGIONAL NETWORK

Wei Wang, Jun Li, Yugang Jia, Marcelo Santos

Philips Research North America
2 Canal park, 3rd floor
Cambridge, 02141,MA,USA

ABSTRACT

Healthcare resources allocation is inherently difficult due to the prescriptive "what-if" nature of the question being asked. One kind of data driven method is building a statistical model for resource utilization and later leverage it for resource optimization. Another kind is agent based simulation, which is based on patient choice and service queue. In this paper, we applied both methods to an imaging device resource allocation problem with a public dataset from Parana, Brazil. Our results demonstrate that starting from diametric perspectives, the two approaches give consistent and interpretable results for finding the optimal allocation. Moreover, this can serve as the corroboration for the simulation model, which is notoriously difficult to validate.

1 INTRODUCTION

For many years, governments around the world have contended with the evolving challenge of managing the allocation of resources for health services. Improving the access to care is a high priority with objective to reduce travel time or patients waiting time with the same quality of care guaranteed.

In this case study, we took public MRI utilization dataset from Parana, Brazil as an example to demonstrate how can optimize MRI resource allocation and minimize patient outflow from a municipality to another.

The dataset consists of 0.1 million MRI exams from 399 municipalities in Parana. Based on facility and patient zip code, we can approximate travelling distance with Euclidian distance for each exam, shown in Figure 1.

	Patient Muni Code	Facility Muni Code	Travelling Distance
Exam 1	410480	410480	0
Exam 2	410690	410400	55
Exam 3	410830	410400	568
... ...	... ...	... ...	... ...

Figure 1 Parana MRI utilization data

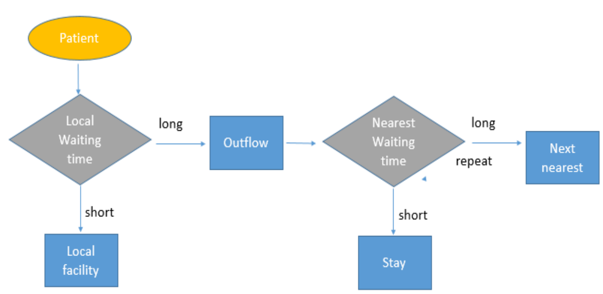

Figure 2 Patient Choice model

We also established a behavior model to guide our modelling and simulation, as shown in Figure 2. If the local waiting time is short, patient will prefer local facility. If it is long, patient will go out of current municipality and go to the nearest one. If the waiting time in this municipality is short, patient will stay. In other case the patient will go to the next nearest.

2 TOP-DOWN AGGREGATE-LEVEL-BASED OPTIMIZATION FRAMEWORK

The first step in this approach is to use logistic regression to model the patient outflow on municipality level. The predictors used are local demand (how many patient from this municipality have an MRI exam), local supply (how many MRI exams have been done by facilities in this municipality) and local demand to supply ratio. With 5-fold cross validation, the AUC (area under curve) for this model is 0.96 and the only significant predictor is municipality capacity.

The second step in this approach is to frame this resource allocation as an optimization problem, e.g. how we can allocate the resource to minimize patient outflow with the model established in the first step. This simple optimization problem can be solved with sequential quadratic programming and the result is quiet encouraging: Given a 10% capacity increase in total, the optimal allocation level, as established from our model, will decrease the patient outflow by 5% while the vanilla approach (increase capacity in each municipality by 10%) can only reduce the patient out-flow by 2.3%.

3 BOTTOM-UP AGENT-BASED SIMULATION MODEL

To set up the agent based simulation framework, patients' arrival rate and service rate are first defined as follows. Patients' arrival rate is proportional to municipality demand, that is, a newly simulated patient has higher probability of originating from a municipality with higher demand. High service rates indicate the queue will decrease rapidly . Service rate is proportional to municipality capacity.

Then a patient will be simulated according to demand distribution over municipality. The cost function of choosing a specific municipality is based on travel distance and waiting time. Since waiting time is not available, we use queue length instead. The final equation to calculate the cost is:

Cost = w*log(distance_to_municipality)+ queue_length_municipality.

While w is a parameter to be tuned via experiment. The patient will choose the municipality which minimize the cost function and join that queue.

The grid-search procedure is used to tune the parameter w with three criteria: outflow bias, municipality throughput difference and patient flow difference. Outflow bias is defined as computing the difference between simulated outflow and true outflow from each municipality. Municipality throughput difference is computed as difference between the simulated patient allocation vector and true patient allocation vector. Patient flow matrix is a 399-by-399 matrix while each entry is the number of patients travel from one municipality (row) to another municipality (column). Patient flow difference is computed as the difference between the patient flow matrix from simulation and that from true data. An interesting finding is that w, which can minimize outflow bias to zero, is also near optimal for other two parameters.

4 VALIDATION

Assuming a 10% increase of overall MRI capacity then both the optimization framework result (reduction on patient outflow) and the Agent based model give similar results. i.e. a reduction of 5 % outflow. This consistency gives the authors confidence in the validity of the results

REFERENCES

Panara MRI utilization dataset: http://datasus.saude.gov.br/informacoes-de-saude/tabnet

Knight, Vincent A., Janet E. Williams, and I. Reynolds. 2012. "Modelling patient choice in healthcare systems: development and application of a discrete event simulation with agent-based decision making." *Journal of Simulation*. 6(2): 92-102.