A Framework for Discovering Health Disparities among Cohorts in an Influenza Epidemic

Lijing Wang*†, Jiangzhuo Chen†, Achla Marathe‡†

*Department of Computer Science, Virginia Tech, Falls Church, VA

†Network Dynamics and Simulation Science Laboratory, Biocomplexity Institute, Virginia Tech, Blacksburg, VA

‡Department of Agricultural and Applied Economics, Virginia Tech, Blacksburg, VA

VirginiaTech Biocomplexity Institute

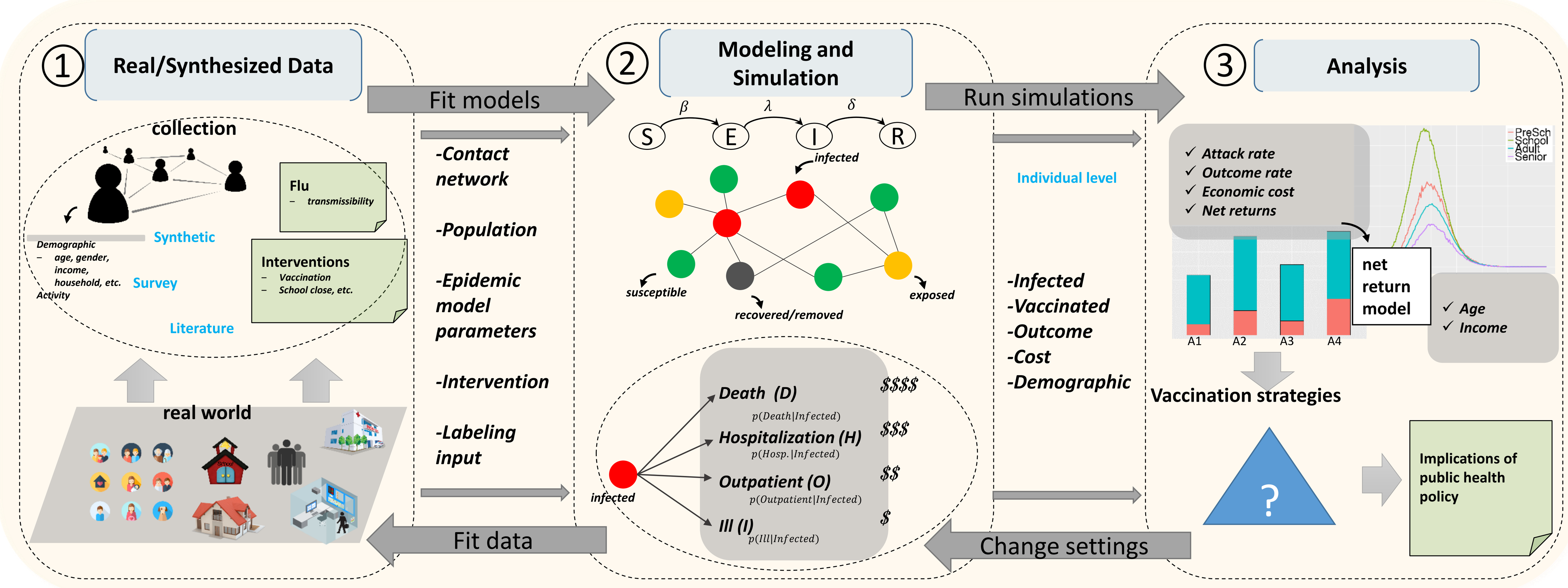
Introduction

This research provides a computational framework for studying health disparities among cohorts based on individual level features, such as age, gender, income, etc.

Contributions:

(i) We use an agent-based model to study health disparities among age and income-based groups during an influenza epidemic, in the Montgomery county of Southwest Virginia.

(ii) We design several vaccination prioritization strategies based on different objectives, and evaluate them. The findings have significant policy implications that may assist public health decision making in assigning limited pharmaceutical resources.



Method

Synthetic Social Contact Network

Montgomery county in Virginia: statistically equivalent to the real population of Montgomery County as given in the US census, when aggregated up to census block group level. Individuals in the synthetic population are endowed with the same social and demographic variables as available in the US Census.

Disease Model

EpiFast: a high-performance agent-based simulation model for ILI diseases.

Clinical Outcomes

Each infected person can have one of four clinical outcomes attributed to influenza infection: death, hospitalization, outpatient, ill but not seeking medical care. Economic cost is assigned to each infected person according to the outcome.

Two Scenarios

Base-case: No intervention is applied to contain the epidemic;

Intervention-case: A vaccine prioritization strategy is applied to targeted subpopulations (chosen by individuals' specific attributes) or a random order is followed (each person is equally likely to be chosen).

Net Return Model

net return = total cost in base case – total cost in intervention case (including vaccination cost)

Subpopulations based on AGE/INCOME

Age groups: 0-4 years old (preschool); 5-19 years old (school); 20-64 years old (adult); 65 years old and above (senior);

Income groups: \$0-\$18400 (1st Quartile); \$18400-\$41620 (2nd Quartile); \$41620-\$75000 (3rd Quartile); and above \$75000 (4th Quartile).

Simulations

Table 1: List of parameter values

Parameter	*Value*
Attack rate (AR)	40-60%
Transmission rate	calibrated to attack rate
Proportion of symptomatic	67%
Avg. incubation period	1.9 days
Avg. infectious period	4.1 days
Diagnosis rate	60%
Compliance to vaccination	25-50%
Efficacy of vaccine	90%

Results

➢ Health disparities among age groups

Observation 1: There are health disparities among age groups.

Observation 2: The school age people are much more vulnerable to influenza infections than other age groups.

Table 2: Disparities of attack rate among age groups: p-values

Attack rate by age group	preschool	school	adult	senior
preschool ($\overline{AR} = 44\%$)	-	0.0001***	0.0001***	0.0001***
school ($\overline{AR} = 70\%$)	-	-	0.0001***	0.0001***
adult ($\overline{AR} = 34\%$)	-	-	-	0.0001***
senior ($\overline{AR} = 22\%$)	-	-	-	-

$\overline{AR}$ is the average attack rate computed from 30 simulation replicates

$^{*}p < .05, ^{**}p < .01, ^{***}p < .001$

Observation 3: Death rates of age groups are significantly different from each other. Death rate of senior age group is significantly higher than other age groups.

Table 3: Disparities of death rate among age groups: p-values

Death rate by age group	preschool	school	adult	senior
preschool ($\overline{DR} = 0.035\%$)	-	0.0181*	0.0001***	0.0001***
school ($\overline{DR} = 0.046\%$)	-	-	0.0001***	0.0001***
adult ($\overline{DR} = 0.069\%$)	-	-	-	0.0001***
senior ($\overline{DR} = 0.296\%$)	-	-	-	-

$\overline{DR}$ is the average death rate computed from 30 simulation replicates

$^{*}p < .05, ^{**}p < .01, ^{***}p < .001$

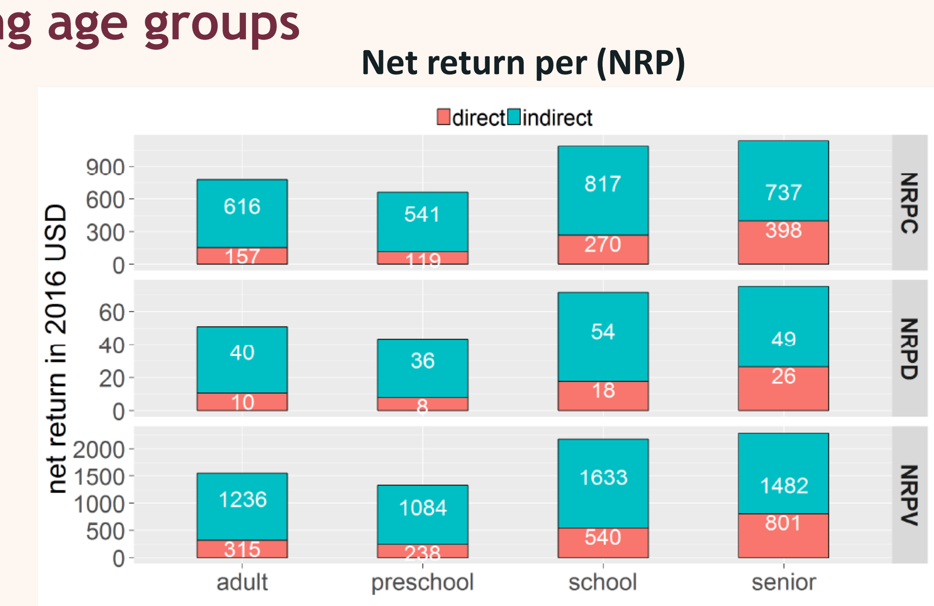
➢ Economic disparities among age groups

Observation 4: There are economic disparities among age groups.

Observation 5: Vaccination is economically more efficient in school age and senior groups than in preschool and adult groups.

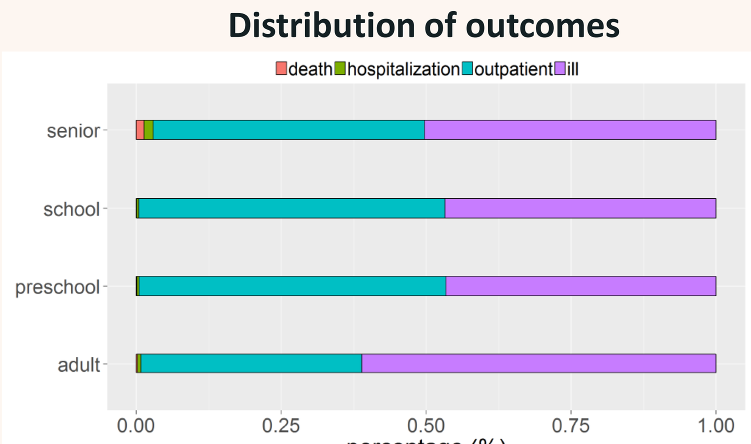
Observation 6: Indirect cost is much higher than direct cost.

Net return per (NRP)

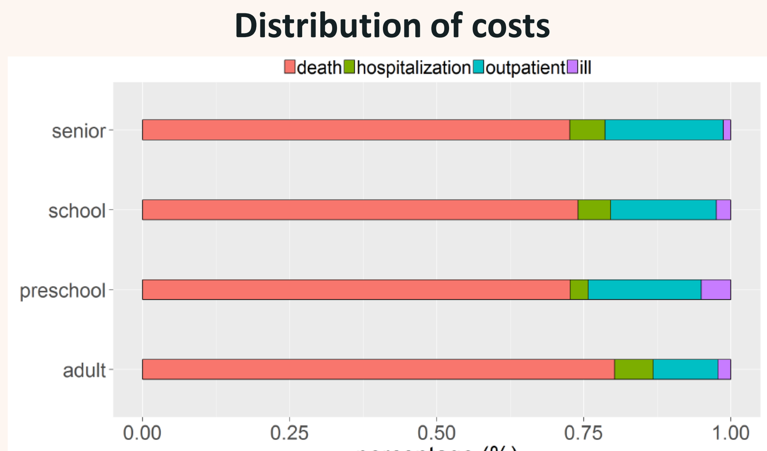


Observation 7: Death count is the smallest portion of total cases, while death cost is the largest portion of total cost.

Distribution of outcomes



Distribution of costs



➢ Health/economic disparities among income groups

The same analysis is applied to income groups and we observe similar health disparities among income groups. However, the death rates and net returns are not significantly different among income groups.

Policy Implications

Public health authorities often issue health directives to the population during an epidemic or a pandemic. In case of limited vaccines, some subpopulations are given higher priority, in order to optimize the efficiency of resources and to achieve specific objectives.

Table 4: Vaccination priorities for age-based groups

	criteria for prioritization				
priority	$\overline{DR}$	$\overline{DC}$	$\overline{NRPD}$	$\overline{TNR}$	$\overline{AR}$
1(top)	senior	adult	senior	adult	school
2	adult	senior	school	school	preschool
3	school	school	adult	senior	adult
4(bottom)	preschool	preschool	preschool	preschool	senior

$\overline{DR}$ - average death rate; $\overline{DC}$ - average death count; $\overline{NRPD}$ - average net return per dollar spent; $\overline{TNR}$ - average total net return; $\overline{AR}$ - average attack rate. $\overline{DR}$, $\overline{NRPD}$ and $\overline{AR}$ are normalized values that are comparable across subgroups.

Various objectives.

Vaccination priorities based on simulation results.

Limited resources: assume vaccines are only enough to cover 50% of the whole population, and all vaccines are accepted by the population.

Table 5: Vaccinated fraction of each age group under different vaccination strategies

subgroup (size)	S_{np}	S_{4321}	S_{3421}	S_{2134}	S_{4231}	S_{3241}
preschool (4617)	0.5	0	0	1	0	0
school (13310)	0.5	0	0	1	1	0
adult (52558)	0.5	0.6	0.74	0.4	0.35	0.74
senior (7335)	0.5	1	0	0	1	0

1-preschool, 2-school, 3-adult, 4-senior; S_{np} denotes strategy with no priority; S_{4321} denotes vaccinating seniors first, then adults, then school-aged and then preschoolers. Similarly strategies S_{3421}, S_{2134}, S_{4231}, S_{3241} follow priorities given by their subscripts. Note that S_{3421} and S_{3241} result in the same allocation because adult group has the first priority and it has more people than the size of the vaccine stockpile so no other age group could be vaccinated.

Optimal vaccination strategy minimizes death rate/count and maximizes economic returns for the whole population.

Table 6: Performance of different vaccination strategies

strategy	$\overline{DR}$(%)	$\overline{DC}$	$\overline{TNR}$(M\$)	$\overline{NRPD}$(\$)	$\overline{AR}$ (%)
S_{np}	0.0009	0.7	67.64	57.12	0.43
S_{4321}	0.0158	12	47.11	38.46	14.64
S_{3421}	0.0173	13	48.44	39.13	13.20
S_{2134}	**0.0006**	**0.5**	**68.15**	**59.69**	**0.29**
S_{4231}	0.0006	0.5	67.88	59.54	0.42
S_{3241}	0.0173	13	48.44	39.13	13.20

Low values of $\overline{DR}$(%), $\overline{DC}$, $\overline{AR}$ (%) are desirable and high values of $\overline{NRPD}$ (\$), $\overline{TNR}$ (million \$) are desirable. Values in bold are optimal.

School age group matters!

Implications

1. If vaccines are limited and a prioritization strategy is needed, then the school-age group should have a higher priority for minimizing attack rate and maximizing net returns.

2. Given that cost of death is high and seniors encounter higher death rates, a high priority to seniors will result in fewer deaths and high returns.

3. In a severe flu season with limited vaccines, random vaccination or no priority is more effective for preschoolers, adults, and seniors than for school-aged, due to the high connectivity of school aged children in the social contact network.

***Conclusions**: Death rate and economic return are impacted by vaccination priority. When prioritizing age groups, both attack rate and compliance rate should be considered carefully. Our research framework provides a general method to study health/economic disparities among subpopulations. Furthermore, it gives a methodology to explore and evaluate vaccination strategies in term of specific objectives by using simulations.*

References

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[2] C. Carias, C. Reed, I. K. Kim, I. M. Foppa, M. Biggerstaff, M. I. Meltzer, L. Finelli, and D. L. Swerdlow. Net costs due to seasonal influenza vaccination United States, 2005{2009. PLoS ONE, 10(7):1{15, 07 2015.