# COVID-19

#### Proactive testing to mitigate spread

IPAM Workshop on Mathematical Models in Understanding COVID-19

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#### Disclosures

I have a paid consulting relationship with Color Genomics, and I will be talking about some of that work today. I have no financial interest in the production or sales COVID of tests or treatments.

I do have vested interests in going places, seeing people, working at the office, eating at restaurants, drinking at the bar, playing sports, hearing live music, sending my son to school, sending my daughter to college, visiting Europe, visiting anywhere else, and photographing birds that can't be bothered to visit Seattle.

## A vaccine is coming

#### But it won't be a panacea—if it comes at all.



# We need something else Something nimble.



## This is a talk about testing.



1. Individual diagnosis

Symptomatic patients, for treatment and peace of mind.

High sensitivity and specificity desired.



#### 2. Clearance

Verify that patients and practitioners are uninfected prior to performing a procedure.

#### Travel? Other activities?

High sensitivity needed. Specificity less essential.



#### 3. Surveillance

Public health officials want to track prevalence and trajectory of pandemic.

Can correct for lower sensitivity and (if common) lower specificity.



#### 4. Mitigation

Find non-symptomatic cases and isolate / trace as a means of disease control.

Volume is more important than sensitivity or specificity.



## Speed is critical in all cases.

#### 1. Individual health.

#### 2. Clearance

#### 3. Surveillance

Patients don't want to wait.

Treatments may depend on diagnosis. Tests should be point-ofcare to minimize chance of becoming infectious after sampling.

Heath officials need the latest information to make good decisions.

#### 4. Mitigation

Every day's delay is an extra day an infected person is walking around spreading disease.





A larger share Current of people are hospitalizations are swinging testing positive again, indicating back up too. more infections. 56k hospitalizations 8.5% positive May 1 Jul 19 Jul 19 May 1



#### The CDC Is Wrong

#### Testing is essential for colleges to reopen safely

By Carl T. Bergstrom July 14, 2020



#### The CDC guidelines state that:

Testing of all students, faculty and staff for Covid-19 before allowing campus entry (entry testing) has not been systematically studied. It is unknown if entry testing in IHEs provides any additional reduction in person-toperson transmission of the virus beyond what would be expected with implementation of other infection preventive measures (e.g., social distancing, cloth face covering, hand washing, enhanced cleaning and disinfection). Therefore, CDC does not recommend entry testing of all returning students, faculty, and staff.

## The aim of proactive (mitigation) testing: Reducing exposure-days





- C # infectious days
- *n* Testing periodicity
- *q* False negative rate
- *d* Delay for results

By what fraction does testing and isolation reduce exposure days relative to no testing at all?

# infectious days С Testing periodicity п False negative rate 9 Delay for results d

When testing periodicity is longer than infectious period, individuals will only be tested once while infectious.

bat + act a

Expecte exposu

ected true positive false negative not tested  
osure days  
$$E(C,\tau) = \int_{0}^{C-d} \frac{1}{n} \left( (1-q)(t+d) + qC \right) dt + \int_{C-d}^{n} \frac{1}{n} C dt$$

Simplifies to 
$$E(C,\tau) = C - \frac{(1-q)(C-d)^2}{2n}$$

*C* # infectious days*n* Testing periodicity*q* False negative rate*d* Delay for results

When testing periodicity is shorter than the infectious period, you get multiple chances to catch an infection.

After a bit of algebra, you can still get a nice expression for the expected exposure days.

$$E(C,\tau) = \left(\frac{n}{2} + d + \frac{nq}{1-q}\right) + q^{\bar{x}} \left(\frac{1}{2n} \left(qr^2 - (n-r)^2\right) - \frac{nq}{1-q}\right)$$

Where 
$$\bar{x} = \left\lfloor \frac{C-d}{n} \right\rfloor$$
 and  $r = C - d - n \bar{x}$ 

# But some symptomatic individuals can self-isolate. We need to account for this.



Compare infectious days with testing to infectious days without.

# $\phi = \frac{E \text{ with testing}}{E \text{ without testing}}$

# Compare infectious days with testing to infectious days without.



## Compare infectious days with testing to infectious days without.

$$\phi = \frac{\left(1 - (1 - u)v\right)E(C, \tau) + (1 - u)vE(y, \tau)}{\left(1 - (1 - u)v\right)C + (1 - u)vy}$$
Asymptomatic or don't isolate Self-isolate

Asymptomatic or don't isolate

#### Results

Delay = 0 days

	Р	0.1 robal	0.2 bility	0.3 of fal	0.4 se ne	0.5 gativ			
	30 -	2.21	2.25	2.28	2.31	2.34			
	21 -	2.09	2.14	2.18	2.23	2.27			
מאר	14 -	1.89	1.96	2.02	2.09	2.16			
ddad	10 -	1.64	1.74	1.83	1.93	2.02			
	7 -	1.29	1.43	1.56	1.69	1.83			
uays between tests)	6 -	1.15	1.29	1.44	1.58	1.73			
	5 -	0.99	1.14	1.29	1.45	1.61			
	4 -	0.82	0.96	1.11	1.28	1.45			
	3 -	0.62	0.75	0.89	1.05	1.24			
	2 -	0.42	0.51	0.62	0.76	0.93			
	1 -	0.21	0.26	0.32	0.40	0.51			

Delay = 1 days

	Р	robal	bility	of fal	se ne	gative
		01	02	0.3	04	0.5
	30 -	2.28	2.31	2.33	2.36	2.38
-	21 -	2.19	2.23	2.26	2.29	2.33
est fr	14 -	2.04	2.09	2.14	2.19	2.24
eque	10 -	1.85	1.93	2.00	2.07	2.14
ancy (	7 -	1.58	1.68	1.78	1.88	1.99
days	6 -	1.44	1.56	1.67	1.79	1.91
between tests)	5 -	1.30	1.42	1.55	1.68	1.81
	4 -	1.14	1.27	1.40	1.54	1.68
	3 -	0.96	1.07	1.20	1.34	1.50
	2 -	0.76	0.85	0.95	1.08	1.23
	1 -	0.55	0.60	0.66	0.74	0.84





Delay = 5 days



#### The real world is not so simple

Disease dynamics
Social network structure
Heterogeneity of disease trajectory, infectivity, etc.
Varying test sensitivity over time
Non-compliance with testing and isolation

## Ryan McGee's SEIRS+ framework

Open source python-based stochastic SEIRS model with multi-level network structure, network interventions (targeted testing, social distance, contact tracing, isolation, etc.)



https://github.com/ryansmcgee/seirsplus

## Stochastic disease dynamics



## Testing, tracing, and isolation



#### Multi-level network structure



## Individual heterogeneity



## Test sensitivity



Kucirka et al. 2020 Ann. Int. Med.



## Use case: workplace testing



Setting: workplaces of size 50-1000.

**Intervention:** self-administered workplace testing via nasal swab.

Network: single-layer FARZ network with 40% global transmission

Outcome measure: size of epidemic resulting from one introduction

https://www.color.com/covid-19-outbreak-model

#### Simulation trajectories





https://www.color.com/covid-19-outbreak-model



https://www.color.com/covid-19-outbreak-model

#### Most outbreaks fizzle





https://www.color.com/covid-19-outbreak-model

## Testing helps a lot





https://www.color.com/covid-19-outbreak-model

## Outbreak sizes





Fraction of introductions infecting >5% Mean fraction infected Daily Semiweekly Weekly No Testing Daily Semiweekly Weekly No Testing 100 40 75 30 Probability of Infection 50 16.5 34.6 25 10 19.1 3.8 1.3 7 Turn-around Time Turn-around Time

https://www.color.com/covid-19-outbreak-model

### Speed is of the essence





https://www.color.com/covid-19-outbreak-model

#### Use case: community test-trace-isolate

Setting: Community of 50,000

Intervention: test-trace-isolate

Network: multilayer FARZ with household, school, workplace structure.

Outcome measure: change in effective R value

## Test and isolate only

 $R_0 = 2.5$ TAT = 1 days

	50.00% -	1.23	1.21	1.18	1.20	1.20	1.22	1.17	1.21	1.15	1.15	1.17
per day	20.00% -	1.38	1.34	1.34	1.33	1.31	1.33	1.30	1.32	1.31	1.33	1.29
	10.00% -	1.43	1.42	1.40	1.41	1.40	1.37	1.40	1.35	1.37	1.36	1.36
	5.00% -	1.46	1.46	1.46	1.43	1.44	1.44	1.42	1.43	1.40	1.41	1.42
sted	2.00% -	1.50	1.47	1.49	1.49	1.47	1.45	1.44	1.46	1.46	1.47	1.45
pulation tes	1.00% -	1.48	1.50	1.47	1.47	1.45	1.47	1.48	1.46	1.46	1.47	1.49
	0.50% -	1.52	1.50	1.46	1.48	1.47	1.48	1.50	1.49	1.47	1.47	1.50
	0.20% -	1.50	1.51	1.52	1.50	1.52	1.50	50 1.50 1.51		1.51	1.49	1.48
of p	0.10% -	1.52	1.51	1.52	1.52	1.51	1.52	1.53	1.52	1.52	1.50	1.51
ent	0.05% -	1.52	1.54	1.53	1.52	1.55	1.51	1.52	1.52	1.52	1.51	1.52
perc	0.02% -	1.54	1.55	1.51	1.52	1.52	1.54	1.53	1.51	1.53	1.54	1.54
	0.01% -	1.52	1.52	1.51	1.51	1.53	1.53 1.55 1.51 1.52 1			1.50	1.54	1.52
	0.00% -	1.54	1.53	1.53	1.54	1.53	1.53	1.54	1.52	1.53	1.53	1.53
		0%		20%	, ,	40%		60%		80%	1	00%
	p	erce	nt of	con	tact	s tra	ced	for e	each	n pos	sitive	e case

 $R_0 = 2.5$ TAT = 2 days

	50.00% ·	1.35	1.35	1.34	1.34	1.33	1.29	1.32	1.33	1.31	1.27	1.32	
day	20.00% -	1.44	1.44	1.44	1.42	1.40	1.41	1.38	1.43	1.38	1.42	1.39	
	10.00% ·	1.49	1.47	1.44	1.44	1.45	1.45	1.43	1.43	1.44	1.42	1.43	
per	5.00% ·	1.46	1.48	1.49	1.46	1.48	1.46	1.47	1.44	1.46	1.45	1.47	
ted	2.00% ·	1.50	1.50	1.48	1.47	1.49	1.48	1.48	1.49	1.48	1.47	1.48	
pulation test	1.00% ·	1.51	1.50	1.50	1.49	1.48	1.47	1.49	1.48	1.50	1.51	1.48	
	0.50% ·	1.52	1.52	1.49	1.50	1.50	1.50	1.49	1.50	1.51	1.50	1.50	
	0.20% -	1.49	1.51	1.49	1.48	1.50	1.51	1.51	1.49	1.51	1.50	1.52	
of b	0.10% ·	1.51	1.50	1.51	1.52	1.51	1.53	1.51	1.52	1.51	1.53	1.51	
ent	0.05% -	1.52	1.52	1.52	1.51	1.53	1.52	1.52	1.53	1.54	1.51	1.53	
perc	0.02% ·	1.52	1.53	1.53	1.53	1.53	1.51	1.51	1.53	1.52	1.54	1.53	
	0.01% -	1.53	1.54	1.53	1.54	1.52	1.52	1.55	1.52	1.52	1.53	1.52	
	0.00% ·	1.50	1.51	1.53	1.50	1.53	1.52	1.53	1.51	1.52	1.52	1.53	
		0%		20%		40%	(	60%	)	80%	1	00%	
	р	erce	nt of	con	tact	s tra	ced	for e	each	n pos	sitive	case	Э

R<sub>0</sub> = 2.5 TAT = 3 days

	50.00% -	1.41	1.42	1.42	1.43	1.44	1.41	1.40	1.41	1.38	1.40	1.40
day	20.00% -	1.50	1.47	1.49	1.48	1.45	1.47	1.45	1.46	1.43	1.44	1.47
	10.00% -	1.49	1.50	1.48	1.50	1.47	1.49	1.46	1.47	1.49	1.46	1.47
per	5.00% -	1.51	1.50	1.50	1.47	1.49	1.50	1.47	1.49	1.48	1.48	1.51
ted	2.00% -	1.50	1.51	1.48	1.51	1.49	1.51	1.49	1.51	1.49	1.50	1.52
ו tes	1.00% -	1.50	1.51	1.50	1.51	1.52	1.53	1.49	1.50	1.50	1.52	1.53
pulation	0.50% -	1.52	1.51	1.51	1.51	1.50	1.50	1.51	1.51	1.50	1.51	1.52
	0.20% -	1.52	1.49	1.51	1.52	1.50	1.52	1.51	1.51	1.54	1.54	1.49
of po	0.10% -	1.51	1.52	1.51	1.51	1.51	1.52	1.51	1.52	1.52	1.50	1.53
ent	0.05% -	1.52	1.52	1.51	1.51	1.53	1.51	1.54	1.51	1.54	1.53	1.52
perc	0.02% -	1.52	1.52	1.54	1.51	1.53	1.53	1.52	1.53	1.54	1.53	1.52
	0.01% -	1.54	1.52	1.52	1.51	1.50	1.50	1.53	1.52	1.52	1.51	1.55
	0.00% -	1.52	1.53	1.53	1.51	1.54	1.53	1.53	1.54	1.53	1.53	1.54
		0%		20%	, ,	40%		60%	)	80%	1	00%
	pe	erce	nt of	con	tact	s tra	ced	for e	each	n pos	sitive	e case

#### Test, trace, and isolate Households of positive tests are isolated. Contacts traced in two days, and isolated along with household.

 $R_0 = 2.5$ TAT = 1 days



Traced Households

Isolate Positive &

$$R_0 = 2.5$$
  
TAT = 2 days

50.00% -1.24 1.02 0.95 0.92 0.94 0.92 0.90 0.90 0.90 0.91 0.89 20.00% -1 .32 1.16 1.04 0.97 0.95 0.94 0.93 0.92 0.92 0.91 0.94 day 10.00% -1.41 1.28 1.13 1.03 1.02 0.97 0.95 0.93 0.93 0.94 0.95 per 5.00% -.40 1.31 1.21 1.16 1.11 1.03 0.97 0.97 0.97 0.95 0.94 percent of population tested 2.00% -1.47 1.40 1.24 1.22 1.16 1.08 1.04 0.98 0.98 0.96 0.97 1.00% -1.46 1.36 1.28 1.21 1.19 1.11 1.04 1.02 1.01 1.00 0.97 0.50% -1.45 1.39 1.29 1.24 1.20 1.12 1.08 1.05 1.06 1.03 0.99 0.20% -1.48 1.40 1.34 1.26 1.21 1.19 1.14 1.08 1.05 1.04 1.03 0.10% -1.49 1.44 1.36 1.32 1.24 1.19 1.15 1.10 1.14 1.06 1.06 0.05% -1.51 1.47 1.45 1.40 1.35 1.31 1.27 1.24 1.26 1.20 1.16 0.02% -1.51 1.51 1.49 1.48 1.47 1.46 1.42 1.41 1.40 1.40 1.41 0.01% -1.54 1.52 1.50 1.49 1.50 1.50 1.48 1.50 1.47 1.46 1.46 0.00% - 1.53<u>55 1.5</u>2 1.53 1.52 1.52 1.54 40% 60% 80% 100% percent of contacts traced for each positive case R<sub>0</sub> = 2.5 TAT = 3 days



## Comparing with the analytic approximation

	Delay = 0 days	Delay = 1 days	Delay = 2 days	Delay = 3 days	Delay = 5 days
	1.0 - 0.19 0.23 0.29 0.36 0.46	1.0 - 0.50 0.55 0.60 0.67 0.77	1.0 - 0.82 0.86 0.91 0.98 1.07	1.0 - 1.13 1.16 1.21 1.27 1.35	<b>1.0 - 1.41 1.58 1.67 1.74 1.81</b>
	2.0 - 0.38 0.46 0.57 0.69 0.85	2.0 - 0.69 0.77 0.87 0.98 1.12	2.0 - 1.00 1.07 1.16 1.26 1.38	2.0 - 1.29 1.36 1.44 1.52 1.62	2.0 - 1.68 1.80 1.87 1.93 1.99
	3.0 - 0.57 0.68 0.81 0.96 1.12	3.0 - 0.87 0.98 1.09 1.22 1.36	3.0 - 1.17 1.26 1.36 1.47 1.58	3.0 - 1.44 1.52 1.60 1.69 1.78	<b>3.0</b> - 1.84 1.93 1.98 2.03 2.07
	<b>4.0 - 0.74 0.87 1.01 1.16 1.32</b>	4.0 - 1.04 1.15 1.27 1.40 1.53	<b>4.0 - 1.32 1.41 1.51 1.61 1.72</b>	<b>4.0 - 1.57 1.65 1.73 1.80 1.88</b>	<b>4.0 -</b> 1.95 2.02 2.06 2.09 2.12
$(1-(1-u)v)E(C,\tau)+(1-u)vE(y,\tau)$	5.0 - 0.90 1.04 1.18 1.32 1.47	5.0 - 1.18 1.30 1.41 1.53 1.65	<u>5.0 - 1.45</u> 1.54 1.63 1.72 1.81	<b>5.0 -</b> 1.69 1.76 1.82 1.89 1.95	4 5.0 - 2.06 2.09 2.11 2.13 2.16
$\phi = $	6.0 - 1.05 1.18 1.31 1.44 1.58	6.0 - 1.31 1.42 1.52 1.63 1.74	6.0 - 1.57 1.64 1.72 1.80 1.88	6.0 - 1.79 1.84 1.90 1.95 2.01	6.0 - 2.10 2.12 2.14 2.16 2.18
Asymptomatic or don't isolate Self-isolate	2 7.0 - 1.18 1.30 1.42 1.54 1.66	2 7.0 - 1.44 1.53 1.62 1.72 1.81	2 7.0 - 1.67 1.74 1.80 1.87 1.94	2 7.0 - 1.86 1.91 1.95 2.00 2.04	2.12 2.14 2.16 2.17 2.19
	00 - 1.50 1.58 1.67 1.76 1.84	<b>10.0 -</b> 1.69 1.75 1.82 1.88 1.95	<b>9</b> <b>10.0 -</b> 1.85 1.90 1.94 1.99 2.04	0 10.0 - 1.98 2.02 2.05 2.08 2.11	9 10.0 - 2.17 2.18 2.19 2.20 2.22
	5 14.0 - 1.72 1.78 1.84 1.90 1.97	5 14.0 - 1.86 1.90 1.95 2.00 2.04	₩ 5 14.0 - 1.97 2.00 2.04 2.07 2.11	₩ 5 14.0 - 2.07 2.09 2.11 2.14 2.16	u= to 14.0 - 2.20 2.21 2.22 2.22 2.23
	21.0 - 1.90 1.95 1.99 2.03 2.07	21.0 - 2.00 2.03 2.06 2.09 2.12	21.0 - 2.07 2.10 2.12 2.14 2.16	21.0 - 2.14 2.15 2.17 2.18 2.20	21.0 - 2.22 2.23 2.24 2.24 2.25
	<b>30.0 -</b> 2.02 2.04 2.07 2.10 2.13	<b>30.0 -</b> 2.08 2.10 2.12 2.14 2.17	30.0 - 2.13 2.15 2.16 2.18 2.20	30.0 - 2.18 2.19 2.20 2.21 2.22	30.0 - 2.24 2.24 2.25 2.25 2.26
	0.1 0.2 0.3 0.4 0.5 Probability of false negative	0.1 0.2 0.3 0.4 0.5 Probability of false negative	0.1 0.2 0.3 0.4 0.5 Probability of false negative	0.1 0.2 0.3 0.4 0.5 Probability of false negative	0.1 0.2 0.3 0.4 0.5 Probability of false negative
	Delay = 0 days	Delay = 1 days	Delay = 2 days	Delay = 3 days	Delay = 5 days
	Delay = 0 days	Delay = 1 days	Delay = 2 days	Delay = 3 days	Delay = 5 days
Age Group	Delay = 0 days 1 - 0.73 0.78 0.82 0.80 0.87 2 - 0.81 0.86 0.88 0.94 1.01	Delay = 1 days 1 - 0.88 0.92 0.94 0.97 0.97 2 - 0.98 1.00 1.05 1.09 1.15	Delay = 2 days 1 - 1.06 1.04 1.11 1.10 1.16 2 - 1.10 1.15 1.21 1.24 1.32	Delay = 3 days 1 - 1.17 1.20 1.24 1.27 1.30 2 - 1.28 1.28 1.36 1.37 1.40	Delay = 5 days 1 - 1.44 1.45 1.49 1.45 1.52 2 - 1.50 1.48 1.51 1.53 1.55
Age Group Layers	$Delay = 0 days$ $1 - 0.73  0.78  0.82  0.80  0.87$ $2 - 0.81  0.86  0.88  0.94  1.01$ $\left(\frac{99}{88}\right) 3 - 0.89  0.93  1.00  1.09  1.16$	$Delay = 1 days$ $1 - 0.88 0.92 0.94 0.97 0.97$ $2 - 0.98 1.00 1.05 1.09 1.15$ $\left[\frac{99}{89} 3 - 1.04 1.10 1.16 1.22 1.29\right]$	$Delay = 2 \text{ days}$ $1 - 1.06  1.04  1.11  1.10  1.16$ $2 - 1.10  1.15  1.21  1.24  1.32$ $\left( \frac{55}{50}  3 - 1.19  1.23  1.30  1.35  1.40 \right)$	$Delay = 3 days$ $1 - 1.17  1.20  1.24  1.27  1.30$ $2 - 1.28  1.28  1.36  1.37  1.40$ $\left(\frac{55}{89}  3 - 1.34  1.37  1.41  1.46  1.49$	$Delay = 5 days$ $1 - 1.44  1.45  1.49  1.45  1.52$ $2 - 1.50  1.48  1.51  1.53  1.55$ $\left(\frac{5}{90} - 3 - 1.52  1.53  1.55  1.58  1.59\right)$
Age Group Layers 0-9 Households	1       -       0.73       0.78       0.82       0.80       0.87         2       -       0.81       0.86       0.88       0.94       1.01         3       -       0.89       0.93       1.00       1.09       1.16         5       5       -       0.95       1.03       1.08       1.16       1.24	Delay = 1 days         1 - 0.88       0.92       0.94       0.97       0.97         2 - 0.98       1.00       1.05       1.09       1.15         3 - 1.04       1.10       1.16       1.22       1.29         5       4 - 1.13       1.17       1.22       1.30       1.36	Delay = 2 days         1 - 1.06       1.04       1.11       1.10       1.16         2 - 1.10       1.15       1.21       1.24       1.32         3 - 1.19       1.23       1.30       1.35       1.40         9       4 - 1.28       1.32       1.35       1.42       1.46	Delay = 3 days         1 -       1.17       1.20       1.24       1.27       1.30         2 -       1.28       1.28       1.36       1.37       1.40         \$	1       1.44       1.45       1.49       1.45       1.52         2       1.50       1.48       1.51       1.53       1.55         3       -       1.52       1.53       1.55       1.58       1.59         9       4       -       1.55       1.54       1.58       1.58       1.61
Age Group Layers 0-9 10-19 Households	Delay = 0 days         1 - 0.73       0.78       0.82       0.80       0.87         2 - 0.81       0.86       0.88       0.94       1.01         3 - 0.89       0.93       1.00       1.09       1.16         4 - 0.95       1.03       1.08       1.16       1.24         5 - 1.03       1.08       1.17       1.25       1.33	Delay = 1 days         1 - 0.88       0.92       0.94       0.97       0.97         2 - 0.98       1.00       1.05       1.09       1.15         3 - 1.04       1.10       1.16       1.22       1.29         4 - 1.13       1.17       1.22       1.30       1.36         5 - 1.20       1.26       1.32       1.36       1.45	Delay = 2 days         1 -       1.06       1.04       1.11       1.10       1.16         2 -       1.10       1.15       1.21       1.24       1.32         3 -       1.19       1.23       1.30       1.35       1.40         4 -       1.28       1.32       1.35       1.42       1.46         5 -       1.36       1.36       1.41       1.47       1.49	Delay = 3 days         1 - 1.17       1.20       1.24       1.27       1.30         2 - 1.28       1.28       1.36       1.37       1.40         3 - 1.34       1.37       1.41       1.46       1.49         4 - 1.38       1.43       1.47       1.48       1.53         6       5 - 1.43       1.45       1.48       1.55       1.55	Delay = 5 days         1 -       1.44       1.45       1.49       1.45       1.52         2 -       1.50       1.48       1.51       1.53       1.55         3 -       1.52       1.53       1.55       1.58       1.58       1.59         4 -       1.55       1.54       1.58       1.58       1.58       1.61         5 -       1.58       1.58       1.58       1.62       1.63
Age Group Layers 0 - 9 Households	Delay = 0 days         1       0.73       0.78       0.82       0.80       0.87         2       0.81       0.86       0.88       0.94       1.01         3       0.89       0.93       1.00       1.09       1.16         4       0.95       1.03       1.08       1.16       1.24         5       1.03       1.08       1.17       1.25       1.33	Delay = 1 days           1         0.88         0.92         0.94         0.97         0.97           2         0.98         1.00         1.05         1.09         1.15           3         -         1.04         1.10         1.16         1.22         1.20           4         -         1.13         1.17         1.22         1.30         1.36           5         -         1.20         1.32         1.36         1.45           6         -         1.26         1.33         1.36         1.42	Delay = 2 days           1 - 1.06         1.04         1.11         1.10         1.16           2 - 1.10         1.15         1.21         1.24         1.32           3 - 1.19         1.23         1.30         1.35         1.40           4 - 1.28         1.32         1.35         1.42         1.49           5 - 1.35         1.36         1.41         1.47         1.49           6 - 1.36         1.42         1.45         1.50         1.54	Delay = 3 days           1 -         1.17         1.20         1.24         1.27         1.30           2 -         1.28         1.28         1.36         1.37         1.40           3 -         1.34         1.37         1.41         1.46         1.49           4 -         1.38         1.43         1.47         1.48         1.53           5 -         1.43         1.45         1.48         1.55         1.55           6 -         1.48         1.51         1.53         1.57         1.57	Delay = 5 days           1         1.44         1.45         1.49         1.45         1.52           2         1.50         1.48         1.51         1.53         1.55           3         1.52         1.53         1.55         1.58         1.58         1.59           4         1.55         1.54         1.58         1.58         1.58         1.61           5         1.58         1.58         1.58         1.62         1.63           %p         6         1.57         1.58         1.60         1.63         1.63
Age Group Layers 0-9 10-19 20-59	Delay = 0 days         1 - 0.73       0.78       0.82       0.80       0.87         2 - 0.81       0.86       0.88       0.94       1.01         3 - 0.89       0.93       1.00       1.08       1.16         4 - 0.95       1.03       1.08       1.01       1.24         5 - 1.03       1.08       1.17       1.25       1.33         6 - 1.10       1.16       1.25       1.30       1.38         7 - 1.15       1.23       1.29       1.36       1.44	Delay = 1 days         1 - 0.88       0.92       0.94       0.97       0.97         2 - 0.98       1.00       1.05       1.09       1.15         3 - 1.04       1.10       1.16       1.22       1.29         4 - 1.13       1.17       1.22       1.30       1.45         5 - 1.20       1.26       1.32       1.42       1.46         6 - 1.26       1.33       1.36       1.42       1.45	Delay = 2 days         1 -       1.06       1.04       1.11       1.10       1.16         2 -       1.01       1.15       1.21       1.24       1.32         3 -       1.19       1.23       1.30       1.35       1.40         4 -       1.28       1.32       1.35       1.42       1.46         5 -       1.36       1.41       1.47       1.49         6 -       1.36       1.42       1.45       1.50       1.54         6 -       7 -       1.40       1.43       1.49       1.53       1.56	Delay = 3 days         1 = 1.17       1.20       1.24       1.27       1.30         2 = 1.28       1.28       1.36       1.37       1.40         2 = 1.28       1.28       1.36       1.37       1.40         3 = 1.34       1.37       1.41       1.46       1.49         4 = 1.38       1.43       1.47       1.48       1.53         5 = 1.43       1.45       1.48       1.55       1.57         6 = 1.48       1.51       1.53       1.57       1.57         6 = 7       1.51       1.54       1.59       1.59	Delay = 5 days           1 -         1.44         1.45         1.49         1.45         1.52           2 -         1.50         1.48         1.51         1.53         1.55           3 -         1.52         1.53         1.55         1.58         1.59           4 -         1.55         1.54         1.58         1.58         1.61           5 -         1.58         1.58         1.62         1.63           6 -         1.57         1.58         1.60         1.63           60         7 -         1.61         1.57         1.62         1.64
Age Group Layers 0-9 Households 20-59 20-59	Delay = 0 days         1       0.73       0.78       0.82       0.80       0.87         2       0.81       0.86       0.88       0.94       1.01         3       0.89       0.93       1.00       1.09       1.16         4       0.95       1.03       1.08       1.16       1.24         5       0.13       1.08       1.17       1.25       1.38         6       1.10       1.16       1.25       1.34       1.34         10       1.26       1.31       1.39       1.45       1.44	Delay = 1 days         1       0.88       0.92       0.94       0.97       0.97         2       0.98       1.00       1.05       1.09       1.15         3       0       1.01       1.16       1.22       1.29         4       0       1.17       1.22       1.30       1.36         5       0       1.26       1.32       1.36       1.42         6       0       1.26       1.33       1.42       1.45         6       0       1.33       1.36       1.42       1.45         6       0       1.33       1.36       1.42       1.51         6       0       1.33       1.36       1.42       1.51         6       0       1.33       1.36       1.42       1.51	Delay = 2 days         1       1.06       1.04       1.11       1.10       1.16         2       1.10       1.15       1.21       1.24       1.32         3       1.10       1.23       1.30       1.36       1.40         4       1.28       1.32       1.35       1.40       1.46         5       1.35       1.36       1.41       1.47       1.49         66       1.36       1.42       1.43       1.45       1.46         7       1.36       1.42       1.43       1.49       1.54         10       1.47       1.51       1.52       1.58       1.56	Delay = 3 days         1       1.17       1.20       1.24       1.27       1.30         2       1.28       1.28       1.36       1.37       1.40         3       -       1.34       1.37       1.41       1.46       1.49         4       -       1.38       1.43       1.41       1.46       1.53         6       -       1.43       1.45       1.48       1.55       1.57         6       -       1.51       1.54       1.59       1.59         60       -       1.51       1.54       1.59       1.59         60       -       1.57       1.56       1.58       1.61	Delay = 5 days         1 -       1.44       1.45       1.49       1.45       1.50         2 -       1.50       1.48       1.51       1.53       1.55         3 -       1.52       1.53       1.55       1.58       1.58       1.59         4 -       1.55       1.54       1.58       1.58       1.61       1.63         5 -       1.58       1.58       1.58       1.62       1.63         6 -       1.57       1.58       1.60       1.63       1.63         6 -       1.57       1.58       1.62       1.64       1.63       1.63         6 -       1.57       1.58       1.60       1.63       1.63       1.64         6 -       1.61       1.57       1.62       1.62       1.64
Age Group Layers 0 - 9 10 - 19 20 - 59 60+	Delay = 0 days         1 - 0.73       0.78       0.82       0.80       0.87         2 - 0.81       0.86       0.88       0.94       1.01         3 - 0.89       0.93       1.00       1.02       1.16         4 - 0.95       1.03       1.08       1.16       1.24         5 - 1.03       1.08       1.17       1.25       1.33         6 - 1.10       1.66       1.25       1.30       1.34         10 - 1.26       1.31       1.39       1.45       1.48         14 - 1.41       1.45       1.47       1.53       1.57	Delay = 1 days         1 - 0.88       0.92       0.94       0.97       0.97         2 - 0.98       1.00       1.05       1.09       1.15         3 - 1.04       1.10       1.16       1.22       1.29         4 - 1.13       1.17       1.22       1.30       1.36         5 - 1.20       1.26       1.32       1.36       1.45         6 - 1.26       1.33       1.36       1.42       1.51         10 - 1.39       1.44       1.47       1.49       1.55         14 - 1.50       1.52       1.55       1.57       1.60	Delay = 2 days         1 -       1.06       1.04       1.11       1.10       1.16         2 -       1.00       1.05       1.21       1.24       1.32         3 -       1.10       1.23       1.30       1.35       1.40         4 -       1.28       1.32       1.35       1.42       1.49         6 -       1.36       1.42       1.45       1.50       1.54         10 -       1.40       1.43       1.49       1.53       1.56         10 -       1.47       1.51       1.52       1.57       1.58         14 -       1.52       1.58       1.60       1.62	Delay = 3 days         1 =       1.17       1.20       1.24       1.27       1.30         2 =       1.28       1.28       1.36       1.37       1.40         2 =       1.28       1.28       1.36       1.37       1.40         3 =       1.34       1.37       1.41       1.46       1.49         4 =       1.38       1.43       1.47       1.48       1.53         6 =       1.48       1.51       1.53       1.57       1.57         6 =       1.48       1.51       1.54       1.59       1.59         10 =       1.57       1.56       1.58       1.62       1.61         14 =       1.58       1.59       1.60       1.64       1.64	1       1.44       1.45       1.49       1.45       1.49       1.45       1.45         2       -       1.50       1.48       1.51       1.53       1.52         3       -       1.52       1.53       1.55       1.58       1.59         4       -       1.55       1.54       1.58       1.58       1.61         5       -       1.57       1.58       1.58       1.62       1.63         6       -       1.57       1.58       1.62       1.63       1.63         10       -       1.64       1.63       1.63       1.65       1.64         10       -       1.65       1.65       1.66       1.66       1.66
Age Group 0-9 10-19 20-59 60-	Delay = 0 days         1       0.73       0.78       0.82       0.80       0.87         2       0.81       0.86       0.88       0.94       1.01         3       0.89       0.93       1.00       1.09       1.16         4       0.95       1.03       1.08       1.16       1.24         5       0.10       1.16       1.17       1.25       1.30         6       1.10       1.16       1.29       1.36       1.41         10       1.16       1.21       1.29       1.41       1.45       1.47       1.53       1.57         14       1.41       1.45       1.47       1.53       1.57       1.53       1.57         21       1.35       1.37       1.42       1.45       1.45       1.45	Delay = 1 days         1       0.88       0.92       0.94       0.97       0.97         2       0.98       1.00       1.05       1.09       1.15         3       0       1.00       1.05       1.09       1.26         4       1.10       1.17       1.22       1.30       1.36         5       0       1.26       1.33       1.36       1.42       1.46         7       1.33       1.36       1.42       1.45       1.51       1.57       1.56         10       1.39       1.44       1.47       1.49       1.55       1.57       1.60         14       1.50       1.52       1.55       1.57       1.60         21       1.57       1.56       1.60       1.61       1.63	Delay = 2 days         1 - 1.06       1.04       1.11       1.00       1.16         2 - 1.00       1.05       1.21       1.24       1.32         3 - 1.10       1.23       1.30       1.35       1.40         4 - 1.28       1.32       1.35       1.40       1.46         5 - 1.35       1.36       1.41       1.47       1.49         6 - 1.36       1.42       1.42       1.42       1.49         10 - 7       1.40       1.43       1.49       1.54         14 - 1.52       1.56       1.58       1.60       1.62         14 - 1.52       1.56       1.58       1.60       1.62         14 - 1.52       1.56       1.58       1.60       1.62         14 - 1.4       1.52       1.58       1.60       1.52         14 - 1.52       1.56       1.58       1.60       1.52         14 - 1.52       1.56       1.58       1.60       1.62	Delay = 3 days         1       1.17       1.20       1.24       1.27       1.30         2       1.28       1.28       1.36       1.37       1.40         2       1.28       1.28       1.36       1.37       1.40         3       -       1.34       1.37       1.41       1.46       1.49         4       -       1.38       1.43       1.47       1.48       1.53         6       -       1.48       1.51       1.54       1.55       1.57         7       -       1.51       1.54       1.59       1.59       1.59         10       -       1.57       1.56       1.68       1.60       1.61       1.61         14       -       1.58       1.59       1.60       1.61       1.61	Delay = 5 days         1 -       1.44       1.45       1.49       1.45       1.49         2 -       1.50       1.48       1.51       1.53       1.55         3 -       1.52       1.53       1.55       1.58       1.59         4 -       1.55       1.54       1.58       1.58       1.61         5 -       1.58       1.58       1.58       1.63       1.63         6 -       1.57       1.58       1.60       1.63       1.63         10 -       1.61       1.57       1.62       1.64       1.63         10 -       1.64       1.63       1.65       1.65       1.66       1.66         10 -       1.64       1.65       1.65       1.66       1.66       1.66         21 -       1.67       1.69       1.69       1.69       1.69       1.69
Age Group 0-9 10-19 20-59 60+	Delay = 0 days         1       0.73       0.78       0.82       0.80       0.87         2       0.81       0.86       0.88       0.94       1.01         3       0.89       0.93       1.00       1.02       1.16         4       0.95       1.03       1.08       1.16       1.26         5       1.03       1.08       1.17       1.25       1.33         6       1.10       1.66       1.25       1.30       1.34         10       1.26       1.31       1.29       1.34       1.44         10       1.26       1.31       1.39       1.45       1.48         10       1.26       1.31       1.39       1.45       1.48         10       1.26       1.31       1.49       1.45       1.45         14       1.41       1.45       1.47       1.45       1.56         21       1.35       1.37       1.42       1.45       1.56         30       1.70       1.70       1.70       1.70       1.69       1.69	Delay = 1 days         1 - 0.88       0.92       0.94       0.97       0.97         2 - 0.98       1.00       1.05       1.09       1.15         3 - 1.04       1.10       1.16       1.22       1.29         4 - 1.13       1.77       1.22       1.30       1.36         5 - 1.20       1.26       1.33       1.36       1.42       1.46         6 - 1.26       1.33       1.36       1.42       1.51       1.51         10 - 1.39       1.44       1.47       1.49       1.55         14 - 1.50       1.52       1.55       1.50       1.60         21 - 1.57       1.56       1.60       1.61       1.63         30 - 1.69       1.70       1.70       1.71       1.69	Delay = 2 days         1 -       1.06       1.04       1.11       1.10       1.16         2 -       1.00       1.05       1.21       1.24       1.32         3 -       1.10       1.23       1.30       1.35       1.40         4 -       1.28       1.32       1.35       1.42       1.49         6 -       1.35       1.36       1.41       1.49       1.49         6 -       1.35       1.36       1.41       1.49       1.49         6 -       1.35       1.36       1.41       1.49       1.49         10 -       1.47       1.51       1.52       1.57       1.58         10 -       1.47       1.51       1.52       1.57       1.58         14 -       1.52       1.58       1.60       1.62       1.61         21 -       1.62       1.63       1.64       1.65       1.66         30 -       1.69       1.68       1.68       1.71       1.70	Delay = 3 days           1         1.17         1.20         1.24         1.27         1.30           2         1.28         1.28         1.36         1.37         1.40           3         1.28         1.37         1.41         1.46         1.49           4         1.38         1.43         1.47         1.48         1.53           6         1.48         1.45         1.48         1.53         1.57           6         1.48         1.51         1.54         1.57         1.57           10         1.57         1.55         1.54         1.62         1.51           14         1.58         1.56         1.60         1.64         1.64           21         1.68         1.66         1.67         1.68         1.69	Delay = 5 days1 -1.441.451.491.451.522 -1.501.481.511.531.553 -1.521.531.551.581.594 -1.551.541.581.581.615 -1.581.581.581.621.636 -1.571.581.601.631.6310 -1.641.631.631.651.6621 -1.671.691.691.691.6930 -1.701.691.681.701.68

## Comparing with the analytic approximation

Delay = 5 days

4 1.93 1.98 2.03 2.0 5 2.02 2.06 2.09 2.1

06 2.09 2.11 2.13 2.1

17 2.18 2.19 2.20 2.22

20 2.21 2.22 2.22 2.23

21.0 - 222 223 224 224 225 30.0 - 224 224 225 225 226 0.1 0.2 0.3 0.4 0.5 Probability of false negative Delay = 5 days 1 - 1.44 145 149 145 152

> 2 - 1.50 1.48 1.51 1.53 1.55 3 - 1.52 1.53 1.55 1.58 1.59

4 - 1.55 1.54 1.58 1.58 1.61

5 - 1.58 1.58 1.58 1.62 1.63

6 - 1.57 1.58 1.60 1.63 1.63

7 - 1.61 1.57 1.62 1.62 1.64 10 - 1.64 1.63 1.63 1.65 1.67 14 - 1.65 1.65 1.65 1.66 1.66

0.1 0.2 0.3 0.4 0.5 Probability of false negative

1 - 1.27 1.31 1.26 1.29 1.36 2 - 1.31 1.33 1.33 1.33 1.42 3 - 1.34 1.37 1.34 1.39 1.43 4 - 1.39 1.37 1.39 1.43 1.47

5 - 1.42 1.43 1.43 1.45 1.45 6 - 1.40 1.39 1.43 1.46 1.48 7 - 1.45 1.47 1.48 1.47 1.50 10 - 1.48 1.47 1.50 1.47 1.51 14 - 1.50 1.48 1.50 1.51 1.53

21 - 1.54 1.54 1.56 1.57 1.56

30 - 1.54 1.52 1.55 1.53 1.55

0.1 0.2 0.3 0.4 0.5 Probability of false negative

21 -

30 -

2.0 -

4.0 -

6.0 -

10.0 -

5 14.0 -

		De	lay	= 0	da	ys		D	elay	= 1	da	ys				De	lay	= 2	da	ys			De	alay	= 3	da	ays
1	.0 -	0.19	0.23	0.29	0.36	0.46		1.0 - 0.50	0.55	0.60	0.67	0.77		1.	0 - 0	0.82	0.86	0.91	0.98	1.07		1.0 -	1.13	1.16	1.21	1.27	1.3
2	.0 -	0.38	0.46	0.57	0.69	0.85		2.0 - 0.69	0.77	0.87	0.98	1.12		2.	0 -	1.00	1.07	1.16	1.26	1.38		2.0 -	1.29	1.36	1.44	1.52	1.6
3	.0 -	0.57	0.68	0.81	0.96	1.12	asts)	3.0 - 0.87	0.98	1.09	1.22	1.36	asts)	3.	0 -	1.17	1.26	1.36	1.47	1.58	asts)	3.0 -	1.44	1.52	1.60		
4	.0 -	0.74	0.87	1.01	1.16	1.32	sen ti	4.0 - 1.04	1.15	1.27	1.40	1.53	sen ti	4.	0 -	1.32	1.41	1.51	1.61	1.72	cen to	4.0 -	1.57	1.65			
5	.0 -	0.90	1.04	1.18	1.32	1.47	oetwic	5.0 - 1.18	1.30	1.41	1.53	1.65	betwe	5.	0 -	1.45	1.54	1.63		1.81	Detwe	5.0 -					
6	.0 -	1.05	1.18	1.31	1.44	1.58	ays l	6.0 - 1.31	1.42	1.52	1.63	1.74	ays	6.	0 -	1.57	1.64			1.88	ays t	6.0 -					
7	.0 -	1.18	1.30	1.42	1.54	1.66	cy (d	7.0 - 1.44	1.53	1.62		1.81	cy (d	7.	0 -	1.67				1.94	cy (d	7.0 -					
10	.0 -	1.50	1.58	1.67		1.84	uenb	10.0 - 1.65	1.75			1.95	uenb	10.	0 -					2:04	duen	10.0 -	1.98			2.08	
4	.0 -					1.97	st fre	4.0 - 1.86				2.04	st fre	14.	0 -					2.11	st fre	14.0 -	2.07			2.14	
1	.0 -					2.07	Te	21.0 - 2.00				2.12	Te	21.	0 -					2.16	Te	21.0 -	2.14			2.18	
0	.0 -			2.07		2.13	3	30.0 - 2.08		2.12		2.17		30.	0 -	2.13				2.20		30.0 -	2.18	2.19		2.21	
	P	0.1 robat	0.2 bility o	0.3 of fals	0.4 se ne	0.5 gative		0.1 Proba	0.2 ability o	0.3 If fals	0.4 se ne	0.5 gative			Pr	0.1 obab	0.2 ility	0.3 of fal	0.4 se ne	0.5 gative		P	0.1 robab	0.2 pillity o	0.3 of fal	0.4 se n	0. ega
		De	elay	= 0	) da	ys		D	elay	= 1	da	ys				De	elay	= 2	2 da	ys			De	elay	= 3	3 da	ay
	1.	0.73	0.78	0.82	0.80	0.87		1 - 0.88	8 0.92	0.94	0.97	0.97			1 -	1.06	1.04	1.11	1.10	1.16		1 -	1.17	1.20	1.24	1/21	104
	2.	0.81	0.86	0.88	0.94	1.01		2 - 0.98	3 1.00	1.05	1.09	1.15			2 -	1.10	1.15	1.21	1.24	1.32		2	1.28	1.28	1.36	1.37	1 1
	3 -	0.89	0.93	1.00	1.09	1.16	ests)	3 - 1.04	1.10	1,16	1.22	1.29		ests)	3 -	1.19	1.23	1.30	1.35	1.40	3	1999 3	1.34	1.37	1,41	1.4	5 1.
	4 -	0.95	1.03	1.08	1.16	1.24	sen t	4 - 1.1	3 1.17	1.22	1.30	1.36		sen to	4 -	1.28	1.32	1.35	1.42	1.46		4	1.38	1.43	1.47	1.48	3 1.
	5 -	1.03	1.08	1.17	1.25	1.33	betw	5 - 1.2	1.26	1.32	1.36	1.45		betwi	5 -	1.35	1.36	1.41	1.47	1.49		Mia 5	1.43	1.45	1.48	1,50	5 1,
	6 -	1,10	1.16	1.25	1.30	1.38	lavs	6 - 1.2	5 1.33	1.36	1.42	1.46		lays	6 -	1.36	1.42	1.45	1.50	1.54		skip 6	1.48	1.51	1.53	1.5	1
	7.	1.15	1.23	1.29	1.36	1.44	lov (c	7 - 1.3	3 1.36	1.42	1.45	1.51		) And	7 -	1.40	1.43	1.49	1.53	1.56		5 7	1.51	1.51	1.54	1.55	1. 13
	10 -	1.26	1.31	1.39	1.45	1.48	auei	10 - 1.3	9 1.44	1,47	1,49	1.55		ianbe	0 -	1,47	1.51	1.52	1.57	1.58		10	1.57	1.56	1.58	1,63	2 10
	14 -	1.41	1.45	1.47	1.53	1.57	st fre	14 - 1.50	1.52	1.55	1.57	1.60		est fre	4 -	1.52	1.56	1,58	1,60	1.62		i 7 14 -	1.58	1.59	1.60	1.65	2 13
	21 -	1.35	1.37	1.42	1.45	1.56	1	21 - 1.5	1.56	1.60	1.61	1.63		1 2	1-	1.62	1.63	1.64	1.65	1.66	3	21	1 68	1.66		1.63	. 1
	30 -	1.70	1.70			1.69		30 - 1.6				1 69		9	10 -					1.70		30	1.68				
		0.1	0.2	0.3	0.4	0.5		0.1	0.2	0.3	0.4	0.5			1	0.1	0.2	0.3	0.4	0.5			0.1	0.2	0,3	0.4	0
	P	robal	bility o	of fails	se ne	gative		Prob	ability o	of fails	se ne	egative			Pr	obal	oility	of fa	lse ne	egative		F	robal	bility	of fal	lse r	iega
	1-	0.67	0.66	86.0	0.75	0.71		1 - 0.80	0.79	0.84	0.85	0.90			1 -	0.93	0.94	0.98	1.03	1.02		1	1.08	1.10	1,10	1.13	1
	2 .	0.69	0.76	0.77	0.85	0.94	685	2 - 0.87	0.90	0.97	0.97	1.05		See S	2 -	1.05	1.07	1.04	1.08	1.16		2	1.11	1.19	1.22	1.10	1.1
	3 -	0.78	0.83	0.93	0.92	1.06	ests)	3 - 0.93	0.99	1.06	1.09	1.17		ests)	3 -	1.09	1.13	1.17	1.20	1.24		19150 3	1.18	1.25	1.26	1.2	1
4	1 -	0.85	0.94	1.00	1.06	1.14	ten te	4 - 1.0	2 1.03	1.10	1.18	1.19		een ti	4 -	1.13	1.16	1.19	1.24	1.32	1	4	1.25	1.28	1.28	1.36	1 1
	5 -	0.92	1.00	1.05	1.09	1.17	betwe	5 - 1.0	8 1.12	1.19	1.24	1.27		betwi	5 -	1.17	1.23	1.28	1.29	1.37		5	1.24	1.25	1.35	1.34	1.1.
	6 -	0.98	1.04	1.07	1.17	1.20	avs	6 - 1.1	3 1.18	1.21	1.26	1.28		ays	6 -	1.26	1.25	1.28	1.31	1.36		SÁP 6	1.31	1.34	1.35	1.3	1 1
	7.	1.05	1.07	1.16	1.21	1.26	lcv (d	7 - 1.1	1.20	1.24	1.28	1.38		hcy (c	7 -	1.24	1.29	1.31	1.32	1.41		5 7	1.34	1.39	1.35	1.4	1 1
	10 -	1.13	1.16	1.21	1.28	1.33	duen	10 - 1.2	1.29	1.32	1.32	1.39		anba	0 -	1.28	1.33	1.42	1.40	1.43		10 ·	1.40	1.41	1.42	1.48	5 1
14	ļ	1.23	1.33	1.32	1.37	1.39	st fre	14 - 1.3	1.36	1.42	1.42	1.44		t fre	4 -	1.40	1.45	1.43	1.44	1.46		5 14 ·	1.45	1.42	1.45	1.48	8 12
2	1.	1.30	1.32	1.32	1.33	1.43	Te	21 - 1.3	2 1.38	1.37	1.46	1,44		Te	1-	1.45	1.42	1.48	1.53	1.51	,	21	1.52	1.51	1.52	1.50	3 1;
	30 -	1.52	1.56	1.53	1.54	1.53		30 - 1.5	1.56	1,56	1.55	1.55		3	10 -	1.53	1.50	1.56	1.53	1.55		30	1.54	1,53	1.54	1.5	1 1
		0.1	0.2	0.3	0.4	0.5		0.1	0.2	0.3	0.4	0.5			1000	0.1	0.2	0.3	0.4	0.5			0.1	0.2	0.3	0.4	0
	F	robal	oility o	of fals	se ne	gative	1	Prob	ability of	of fals	se ne	gative			Pr	obat	oility	of fai	se ne	gative		F	robal	bility	of fal	lse r	lega

 $R_0 CV = 0.2$ 

 $R_0 CV = 2.0$ 





### Pooled testing stretches capacity.



Using standard testing it would take 25 tests to determine which of these 25 people are infected with Covid.

## Pooled testing stretches capacity.



## **•** • • • •

5 individual tests

Pooling stretches test capacity but requires re-testing stored samples from batches that test positive.

5 pooled tests

## Pooled testing stretches capacity.



Double-pooling stretches test capacity without having to go back and re-test

#### Take-home messages

Proactive testing can help control the epidemic...

...but the speed of turnaround is essential.

Simple models give decent approximations and allow quick exploration of speed / sensitivity / volume / cost tradeoffs.

Network structure and heterogeneity matter—especially for rapid spread.

#### CARL Theodore Bergstrom



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## Carl T. Bergstrom

Modeling the flow of information through biological and social systems.

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