A new take on optimal vaccine prioritization: when age-based strategy is efficient? - Supplementary

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S.1 Detailed description of the SEIHARDS model

The population is modeled as a weighted graph $G(\mathcal{N}, \mathcal{L}, \Theta(\cdot), \Xi(\cdot,\cdot))$, where:

- $\mathcal{N} = \{\nu_1, \nu_2, ..., \nu_N\}$ is a nonempty set of elements known as vertices or nodes, each node representing an individual in the population;
- $\mathcal{L}$ is a set of ordered pairs from $\mathcal{N}$ called links or edges, representing contacts between two individuals;
- $\Theta(\nu) = (\alpha_\nu, \psi_\nu, \tau_\nu)$, where α_ν is the probability of ν becoming symptomatic if exposed to the virus, ψ_ν is their probability of being hospitalized if symptomatic, and τ_ν is their probability of dying if hospitalized;
- $\Xi(\nu, \mu)$ represents the daily contact time between the two linked individuals.

For the sake of notational convenience, we write $w_{\nu,\mu} = \Xi(\nu, \mu)$. In the case that the information of the daily contact time is not used, $w_{\nu,\mu}$ assumes only values 1 or 0, depending on whether those two individuals have contacts or not, respectively. Let us note that we assume that $\Theta(\nu)$ depends only on ν's age, but that is not necessary for the SEIHARDS model in its most general form.

The dynamics of the disease are modeled by a state vector $\vec{X}(t)$ that evolves with continuous time t and has N elements, one for each individual in the population. That is, $X_i(t)$ is the i-th element of the state vector associated with node $\nu_i \in \mathcal{N}$ and taking values in $\mathcal{D} = \{\mathbf{S}, \mathbf{E}, \mathbf{I}, \mathbf{H}, \mathbf{A}, \mathbf{R}, \mathbf{D}\}$. The semantics of these states are: **S**: susceptible; **E**: exposed; **I**: symptomatic; **H**: hospitalized; **A**: asymptomatic; **R**: recovered; **D**: dead.

Figure 1 in the main corpus of the paper and the corresponding discussion therein provide a brief description of the remaining semantics of the model. Mathematically, $\vec{X}(t)$ is modeled as a continuous-time Markov process. Let us denote by $p_i^\delta(t)$ the probability of ν_i being in state $\delta \in \mathcal{D}$ at time t. Then, the evolution of the disease can be described by the following differential equations:

$$\dot{p}_i^{\mathbf{S}}(t) = \gamma_{RS} \times p_i^{\mathbf{R}}(t) - \overline{\Lambda}_{\nu_i}(t) \times p_i^{\mathbf{S}}(t), \tag{1}$$

$$\dot{p}_i^{\mathbf{E}}(t) = \overline{\Lambda}_{\nu_i}(t) \times p_i^{\mathbf{S}}(t) - [\alpha_{\nu_i}\gamma_{EI} + (1-\alpha_{\nu_i})\gamma_{EA}] \times p_i^{\mathbf{E}}(t), \tag{2}$$

$$\dot{p}_i^{\mathbf{I}}(t) = \alpha_{\nu_i}\gamma_{EI} \times p_i^{\mathbf{E}}(t) - [\psi_{\nu_i}\gamma_{IR} + (1-\psi_{\nu_i})\gamma_{IH}] \times p_i^{\mathbf{I}}(t), \tag{3}$$

$$\dot{p}_i^{\mathbf{H}}(t) = \psi_{\nu_i}\gamma_{IH} \times p_i^{\mathbf{I}}(t) - [\tau_{\nu_i}\gamma_{HD} + (1-\tau_{\nu_i})\gamma_{HR}] \times p_i^{\mathbf{H}}(t), \tag{4}$$

$$\dot{p}_i^{\mathbf{A}}(t) = (1-\alpha_{\nu_i})\gamma_{EI} \times p_i^{\mathbf{E}}(t) - \gamma_{AR} \times p_i^{\mathbf{A}}(t), \tag{5}$$

$$\begin{aligned}\dot{p}_i^{\mathbf{R}}(t) = {} & \gamma_{AR} \times p_i^{\mathbf{A}}(t) + (1-\psi_{\nu_i})\gamma_{HR} \times p_i^{\mathbf{I}}(t) + (1-\tau_{\nu_i})\gamma_{AR} \times p_i^{\mathbf{H}}(t) \\ & - \gamma_{RS} \times p_i^{\mathbf{R}}(t),\end{aligned} \tag{6}$$

$$\dot{p}_i^{\mathbf{D}}(t) = \tau_{\nu_i}\gamma_{HD} \times p_i^{\mathbf{H}}(t). \tag{7}$$

Nonlinearity is introduced through the functions $\overline{\Lambda}_\nu$ defined as (see Eq. 1 in the paper):

$$\overline{\Lambda}_{\nu_i}(t) = \frac{1}{\langle k^w \rangle} \sum_{\nu_j \in \eta(\nu_i)} w_{\nu_j,\nu_i} \left[\epsilon_E p_j^{\mathbf{E}}(t) + \epsilon_A p_j^{\mathbf{A}}(t)\right], \tag{8}$$

where $\eta(\nu)$ is the set of neighbors of ν.

For any given network of contacts, we can solve those equations numerically. However, we proceed in a different manner, simulating individual realizations of the process $\vec{X}(t)$. Simulations are based on the fact that continuous-time Markov processes are associated with independent and exponentially distributed residence times [1] and hence can be simulated using Gillespie's algorithm [4].

S.2 Simulation parameters

Table S.1: Transition rates for the SEIHARDS model.

Parameter	Value [1/day]	Parameter	Value [1/day]
ϵ_E	$0.500^{(a)}$	γ_{AR}	$0.143^{(a)}$
ϵ_A	$0.410^{(b)}$	γ_{IR}	$0.143^{(a)}$
γ_{EI}	$0.196^{(a)}$	γ_{HR}	$0.083^{(c)}$
γ_{HD}	$0.073^{(c)}$	γ_{IH}	$0.144^{(c)}$
γ_{RS}	$0.025^{(d)}$		

Sources: $^{(a)}$ [2]; $^{(b)}$ [9]; $^{(c)}$ computed using openDataSUS [10]; $^{(d)}$ [8].

Table S.2: Age-dependent transition probabilities.

Param.	0 - 20	20 - 30	30 - 50	50 - 70	$\geq$ 70	
α_ν	29.100%	37.400%	41.680%	39.400%	31.30%	$^{(a)}$
ψ_ν	0.408%	1.040%	3.890%	9.980%	17.500%	$^{(b)}$
τ_ν	1.040%	1.330%	1.380%	7.600%	24.000%	$^{(c)}$
$\alpha_\nu \times \psi_\nu \times \tau_\nu$	0.012‰	0.052‰	0.224‰	2.988‰	13.146‰	

Sources: $^{(a)}$ [7]; $^{(b)}$ [3]; $^{(c)}$ computed using openDataSUS [10].

Table S.3: Post-vaccination parameter change.

Before vaccination	After vaccination
ϵ_E	$0.058 \times \epsilon_E$
ϵ_A	$0.058 \times \epsilon_A$
α_ν	$0.346 \times \alpha_\nu$
ψ_ν	$0.034 \times \psi_\nu$
τ_ν	$0.034 \times \tau_\nu$

Source: [6].

S.3 Pre-vaccination results

Networks with $N = 10000$ were generated as explained in the main text of the paper. We ran simulations for a total of 465 days, always starting with 10 randomly chosen nodes in the **E** state and all the remaining nodes in the **S** state. Figure S.1 shows the evolution as a mean of 400 simulations for the case of an unweighted network with $p = 0$ (mean clustering ~ 0.01), where p is the probability of connecting each pair of neighbors of every node in the network formation model of [5]. As can be observed, the fraction of susceptible individuals rapidly decreases up to the 25th day and then increases again until it reaches a stable value. The fraction of ill persons (in states **A** or **I**) increases until reaching a peak of $\sim 30\%$ of the total population. Finally, the fraction of recovered individuals increases up to 58% and then stabilizes at a smaller value. Most importantly, by the 100th day, all simulation values stabilize. Thus, this will be taken as the starting day for the vaccination campaign.

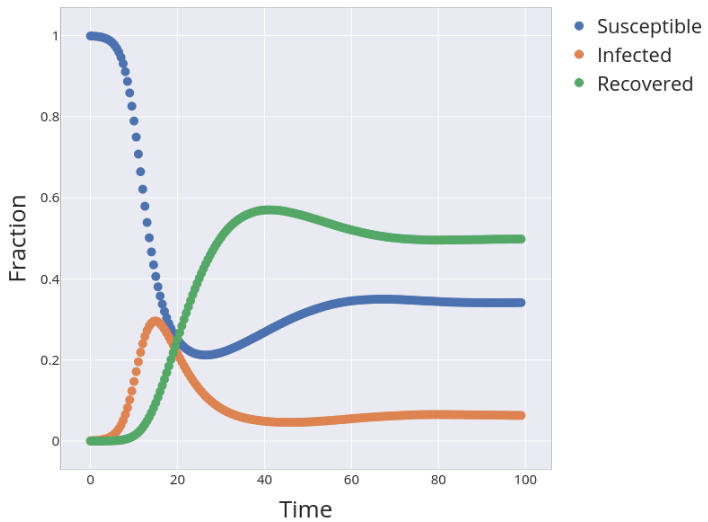

Figure S.1: Evolution of the disease spread before the vaccination campaign for an unweighted network with $N = 10000$ nodes and $p = 0$. Results, as fractions of the population, correspond to the mean of 400 realizations.

We first investigate how the clustering coefficient affects the evolution of the model. As displayed in Figure S.2, there are not very significant changes when p increases. However, it becomes apparent that the system takes more

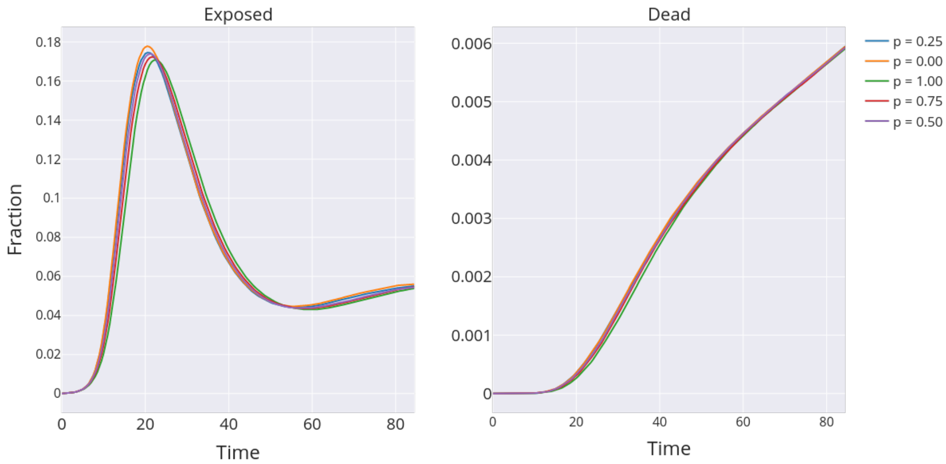

Figure S.2: Evolution of the number of exposed (left) and the number of deaths (right) for different values of p in an unweighted network.

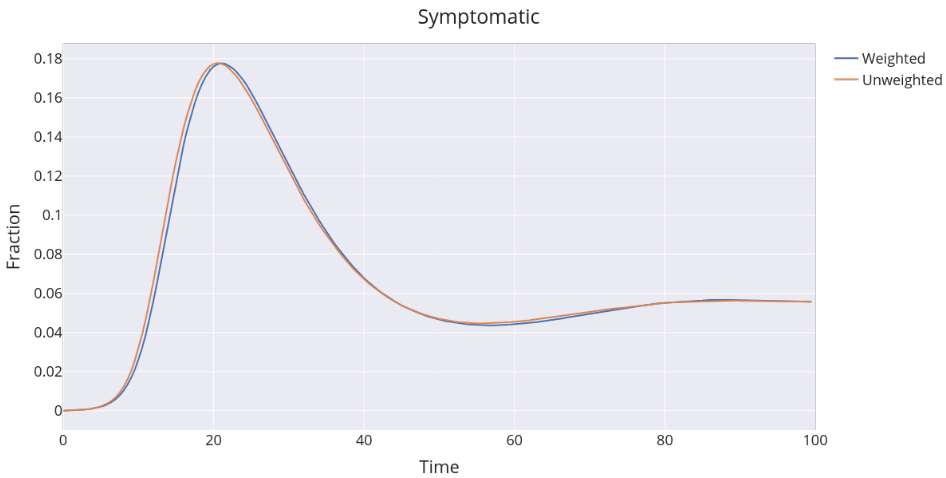

Figure S.3: Evolution of the number of symptomatic individuals for both a weighted and an unweighted network, generated using $p = 0$. As in this case of symptomatic vertices, very small differences are observed for nodes in other states.

time to stabilize and the number of deaths is slightly smaller.

We also compared the spread of COVID-19 in weighted and unweighted (weights set to one in the SEIHARDS model) networks. Figure S.3 shows that there are not very significant differences. Nonetheless, we evaluate prioritization strategies that consider the edge weights as they may be of relevance upon vaccination.

S.4 Results for all strategies

In order to evaluate the effectiveness of different prioritization strategies, we used three performance metrics: the total hospitalization time T_H, the fraction F_D of the population that dies as a consequence of the disease, and the fraction f_c of the population that needs to be vaccinated in order to extinguish the disease. In order to rank all strategies, and since the hospitalization time and the number of deaths depend on the fraction f of the population being vaccinated, we summarized these metrics by the area under the curves of $T_H(f)$ and $F_D(f)$, respectively, in the first two columns of the following tables.

Table S.4: Unweighted network with $p = 0.00$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.009	3648.921	0.420
AGR	0.012	4660.963	0.560
AGR1/2	0.014	5486.388	0.890
AGR1/3	0.014	5518.971	0.890
AGR1/4	0.014	5526.285	0.880
AGR1/5	0.014	5480.480	0.890
AGR2	0.011	4134.308	0.460
AGR3	0.010	3892.631	0.410
AGR4	0.010	3750.978	0.360
AGR5	0.009	3691.826	0.360
BE	0.010	3694.807	0.340
CL	0.010	3804.286	0.360
CC	0.013	4989.104	0.850
UT	0.009	3611.094	0.360
EC	0.012	4465.747	0.780
EI	0.010	3857.086	0.360
DE	0.009	3689.232	0.330
DD	0.012	4468.721	0.470
GR	0.010	4151.916	0.770

Strategy	F_D	T_H (days)	f_c
GR1/2	0.010	4322.697	0.930
GR1/3	0.010	4344.113	0.930
GR1/4	0.010	4330.174	0.930
GR1/5	0.010	4344.356	0.940
GR2	0.009	4127.597	0.730
GR3	0.009	4017.729	0.690
GR4	0.009	3912.571	0.630
GR5	0.009	3813.301	0.570
HH	0.010	3790.328	0.360
AG	0.010	4318.644	0.910
KC	0.011	4095.622	0.390
LA	0.011	4188.341	0.340
PR	0.009	3642.825	0.310
HP	0.011	4158.684	0.330
HA	0.016	5776.984	0.810
DP	0.011	4165.017	0.320
DA	0.016	5786.542	0.820
RN	0.013	5234.572	0.820

Table S.5: Unweighted network with $p = 0.25$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.009	3752.509	0.440
AGR	0.012	4551.090	0.540
AGR1/2	0.014	5400.810	0.910
AGR1/3	0.014	5393.984	0.910
AGR1/4	0.014	5418.711	0.910
AGR1/5	0.014	5398.208	0.900
AGR2	0.011	4089.688	0.460
AGR3	0.010	3911.676	0.410
AGR4	0.010	3788.980	0.390
AGR5	0.010	3709.050	0.360
BE	0.010	3713.028	0.340
CL	0.010	3885.150	0.400
CC	0.015	5824.486	0.860
UT	0.009	3696.094	0.360
EC	0.011	4307.000	0.770
EI	0.010	3888.261	0.390
DE	0.010	3728.585	0.320
DD	0.012	4604.976	0.460
GR	0.009	4087.133	0.770

Strategy	F_D	T_H (days)	f_c
GR1/2	0.010	4277.773	0.940
GR1/3	0.010	4254.297	0.940
GR1/4	0.010	4274.417	0.940
GR1/5	0.010	4281.586	0.940
GR2	0.009	4041.585	0.710
GR3	0.009	3969.950	0.670
GR4	0.009	3857.801	0.580
GR5	0.009	3785.124	0.520
HH	0.010	3874.235	0.390
AG	0.010	4276.754	0.910
KC	0.011	4073.086	0.400
LA	0.012	4293.609	0.360
PR	0.010	3690.279	0.320
HP	0.011	4228.272	0.330
HA	0.016	5795.855	0.820
DP	0.012	4233.150	0.320
DA	0.016	5776.343	0.800
RN	0.013	5137.396	0.820

Table S.6: Unweighted network with $p = 0.50$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.009	3734.118	0.400
AGR	0.012	4574.054	0.540
AGR1/2	0.014	5363.338	0.920
AGR1/3	0.014	5359.573	0.920
AGR1/4	0.014	5354.557	0.890
AGR1/5	0.013	5363.209	0.900
AGR2	0.011	4121.688	0.460
AGR3	0.010	3877.933	0.390
AGR4	0.010	3769.114	0.360
AGR5	0.009	3687.969	0.350
BE	0.010	3734.788	0.330
CL	0.010	3880.418	0.420
CC	0.015	5816.934	0.860
UT	0.009	3715.138	0.360
EC	0.011	4428.814	0.780
EI	0.010	3909.133	0.420
DE	0.010	3699.483	0.320
DD	0.012	4559.273	0.440
GR	0.009	4073.950	0.760

Strategy	F_D	T_H (days)	f_c
GR1/2	0.010	4238.606	0.940
GR1/3	0.010	4252.571	0.940
GR1/4	0.010	4254.322	0.930
GR1/5	0.010	4257.187	0.940
GR2	0.009	4007.549	0.700
GR3	0.009	3906.442	0.640
GR4	0.009	3828.507	0.570
GR5	0.009	3746.336	0.510
HH	0.010	3887.703	0.410
AG	0.010	4270.566	0.900
KC	0.011	4057.969	0.420
LA	0.011	4219.991	0.360
PR	0.010	3699.695	0.300
HP	0.011	4163.589	0.330
HA	0.015	5705.304	0.810
DP	0.011	4160.892	0.340
DA	0.015	5715.502	0.810
RN	0.013	5082.254	0.800

Table S.7: Unweighted network with $p = 0.75$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.009	3682.116	0.400
AGR	0.011	4501.113	0.520
AGR1/2	0.013	5293.818	0.880
AGR1/3	0.013	5317.795	0.890
AGR1/4	0.013	5304.354	0.900
AGR1/5	0.013	5292.868	0.900
AGR2	0.010	4063.869	0.460
AGR3	0.010	3843.892	0.390
AGR4	0.009	3703.839	0.350
AGR5	0.009	3634.113	0.350
BE	0.009	3677.205	0.330
CL	0.010	3914.390	0.460
CC	0.015	5785.574	0.870
UT	0.009	3670.361	0.350
EC	0.011	4421.317	0.760
EI	0.010	4003.871	0.460
DE	0.009	3665.494	0.320
DD	0.012	4560.863	0.430
GR	0.009	4088.880	0.750

Strategy	F_D	T_H (days)	f_c
GR1/2	0.010	4237.772	0.930
GR1/3	0.010	4239.523	0.930
GR1/4	0.010	4221.207	0.930
GR1/5	0.010	4237.295	0.930
GR2	0.009	3998.600	0.690
GR3	0.009	3896.531	0.620
GR4	0.009	3786.979	0.560
GR5	0.009	3704.953	0.500
HH	0.010	3894.006	0.430
AG	0.010	4214.700	0.900
KC	0.010	4041.844	0.430
LA	0.011	4195.887	0.340
PR	0.009	3649.881	0.290
HP	0.011	4138.824	0.310
HA	0.015	5659.372	0.800
DP	0.011	4115.198	0.310
DA	0.015	5674.675	0.780
RN	0.013	5041.591	0.790

Table S.8: Unweighted network with $p = 1.00$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.009	3650.372	0.390
AGR	0.011	4414.776	0.560
AGR1/2	0.013	5214.517	0.880
AGR1/3	0.013	5224.520	0.890
AGR1/4	0.013	5227.647	0.880
AGR1/5	0.013	5218.440	0.890
AGR2	0.010	4041.925	0.480
AGR3	0.010	3819.671	0.430
AGR4	0.009	3660.669	0.350
AGR5	0.009	3601.401	0.310
BE	0.009	3642.685	0.340
CL	0.010	3911.712	0.500
CC	0.015	5759.512	0.870
UT	0.009	3612.155	0.340
EC	0.011	4318.053	0.730
EI	0.011	4098.075	0.520
DE	0.009	3621.080	0.310
DD	0.012	4507.041	0.430
GR	0.009	4039.225	0.750

Strategy	F_D	T_H (days)	f_c
GR1/2	0.010	4193.864	0.920
GR1/3	0.010	4197.562	0.920
GR1/4	0.010	4206.681	0.930
GR1/5	0.010	4219.709	0.930
GR2	0.009	3985.370	0.680
GR3	0.009	3911.818	0.620
GR4	0.009	3766.894	0.530
GR5	0.009	3662.572	0.470
HH	0.010	3894.588	0.450
AG	0.010	4194.119	0.900
KC	0.010	4069.981	0.440
LA	0.011	4139.606	0.350
PR	0.009	3584.784	0.280
HP	0.011	4071.833	0.310
HA	0.015	5581.888	0.800
DP	0.011	4067.040	0.320
DA	0.015	5586.276	0.790
RN	0.013	5002.111	0.780

Table S.9: Weighted network with $p = 0.00$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.009	3424.777	0.350
AGR	0.013	4728.780	0.540
AGR1/2	0.015	5632.304	0.880
AGR1/3	0.015	5618.344	0.880
AGR1/4	0.015	5637.421	0.880
AGR1/5	0.015	5589.045	0.880
AGR2	0.011	4218.783	0.420
AGR3	0.011	4055.150	0.370
AGR4	0.009	3491.304	0.320
AGR5	0.009	3453.754	0.320
AWUT	0.011	4378.506	0.690
AWGR	0.013	4694.657	0.570
AWGR1/2	0.015	5602.037	0.880
AWGR1/3	0.015	5605.862	0.880
AWGR1/4	0.015	5605.817	0.880
AWGR1/5	0.015	5611.971	0.880
AWGR2	0.013	4665.625	0.560
AWGR3	0.013	4659.857	0.570
AWGR4	0.011	4229.514	0.590
AWGR5	0.011	4226.683	0.590

Strategy	F_D	T_H (days)	f_c
BE	0.009	3442.372	0.320
CL	0.009	3534.845	0.330
CC	0.012	4643.295	0.850
UT	0.009	3408.482	0.340
EC	0.011	4183.840	0.720
EI	0.009	3588.969	0.340
DE	0.009	3425.236	0.290
DD	0.011	4217.292	0.450
GR	0.009	4006.597	0.780
GR1/2	0.009	4146.734	0.930
GR1/3	0.009	4163.033	0.930
GR1/4	0.009	4171.172	0.940
GR1/5	0.009	4164.714	0.930
GR2	0.009	3951.019	0.730
GR3	0.009	3872.183	0.690
GR4	0.009	3747.785	0.620
GR5	0.009	3623.983	0.570

Strategy	F_D	T_H (days)	f_c
HH	0.009	3514.602	0.320
AG	0.009	4105.165	0.920
KC	0.010	3843.426	0.380
LA	0.011	3900.422	0.320
PR	0.009	3424.466	0.300
HP	0.010	3859.464	0.300
HA	0.015	5435.107	0.800
DP	0.010	3872.367	0.300
DA	0.015	5442.306	0.800
RN	0.013	4949.786	0.810
WBE	0.010	3894.029	0.500
WCL	0.010	4351.023	0.850
WUT	0.009	3657.961	0.560
WEI	0.010	3742.694	0.380
WGR	0.009	4063.808	0.840
WGR1/2	0.009	4148.560	0.930
WGR1/3	0.009	4169.494	0.930
WGR1/4	0.009	4173.168	0.930
WGR1/5	0.009	4165.897	0.930
WGR2	0.010	4087.971	0.780
WGR3	0.010	4180.706	0.730
WGR4	0.011	4190.044	0.680
WGR5	0.011	4238.067	0.650
WHH	0.011	4199.002	0.590
WLA	0.010	3852.314	0.280
WPR	0.009	3415.234	0.280

Table S.10: Weighted network with $p = 0.25$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.009	3455.633	0.380
AGR	0.013	4657.919	0.510
AGR1/2	0.015	5572.020	0.890
AGR1/3	0.015	5521.751	0.900
AGR1/4	0.015	5555.186	0.910
AGR1/5	0.015	5536.02	0.900
AGR2	0.011	4220.512	0.410
AGR3	0.011	4071.620	0.370
AGR4	0.009	3464.230	0.330
AGR5	0.009	3426.166	0.350
AWUT	0.011	4380.350	0.680
AWGR	0.012	4662.947	0.550
AWGR1/2	0.015	5543.060	0.910
AWGR1/3	0.015	5513.510	0.880
AWGR1/4	0.015	5526.690	0.910
AWGR1/5	0.015	5529.166	0.910
AWGR2	0.012	4646.729	0.570
AWGR3	0.013	4699.991	0.550
AWGR4	0.011	4106.059	0.580
AWGR5	0.011	4122.267	0.590

Strategy	F_D	T_H (days)	f_c
BE	0.009	3413.839	0.310
CL	0.009	3559.448	0.340
CC	0.014	5519.608	0.850
UT	0.009	3430.065	0.360
EC	0.010	3976.192	0.730
EI	0.009	3568.260	0.360
DE	0.009	3453.257	0.300
DD	0.012	4420.165	0.460
GR	0.009	3913.884	0.770
GR1/2	0.009	4096.159	0.940
GR1/3	0.009	4091.956	0.940
GR1/4	0.009	4082.347	0.950
GR1/5	0.009	4093.142	0.930
GR2	0.009	3852.63	0.730
GR3	0.009	3765.439	0.660
GR4	0.009	3638.568	0.600
GR5	0.008	3564.607	0.530

Strategy	F_D	T_H (days)	f_c
HH	0.009	3552.338	0.340
AG	0.009	4055.700	0.920
KC	0.010	3771.326	0.380
LA	0.011	4053.154	0.320
PR	0.009	3419.579	0.290
HP	0.011	3996.453	0.320
HA	0.015	5460.965	0.790
DP	0.011	3983.456	0.310
DA	0.015	5483.671	0.800
RN	0.012	4803.213	0.810
WBE	0.010	3786.165	0.490
WCL	0.010	4275.297	0.830
WUT	0.009	3652.804	0.570
WEI	0.010	3700.837	0.390
WGR	0.009	3943.281	0.810
WGR1/2	0.009	4094.425	0.940
WGR1/3	0.009	4061.437	0.930
WGR1/4	0.009	4087.847	0.940
WGR1/5	0.009	4081.640	0.940
WGR2	0.009	3957.741	0.770
WGR3	0.010	4043.713	0.720
WGR4	0.010	4110.649	0.660
WGR5	0.010	4122.584	0.640
WHH	0.010	4080.180	0.570
WLA	0.011	4019.485	0.310
WPR	0.009	3467.687	0.300

Table S.11: Weighted network with $p = 0.50$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.009	3440.745	0.380
AGR	0.012	4592.603	0.520
AGR1/2	0.015	5462.423	0.900
AGR1/3	0.015	5489.149	0.900
AGR1/4	0.015	5470.139	0.880
AGR1/5	0.015	5445.208	0.890
AGR2	0.011	4161.808	0.420
AGR3	0.011	4033.859	0.350
AGR4	0.009	3464.613	0.340
AGR5	0.009	3410.315	0.330
AWUT	0.011	4331.283	0.670
AWGR	0.012	4622.722	0.540
AWGR1/2	0.015	5454.667	0.910
AWGR1/3	0.015	5473.906	0.880
AWGR1/4	0.015	5469.175	0.880
AWGR1/5	0.015	5494.575	0.890
AWGR2	0.012	4630.694	0.540
AWGR3	0.012	4628.755	0.550
AWGR4	0.010	4082.748	0.580
AWGR5	0.010	4101.739	0.580

Strategy	F_D	T_H (days)	f_c
BE	0.009	3400.204	0.310
CL	0.009	3589.032	0.380
CC	0.014	5460.180	0.870
UT	0.009	3432.515	0.350
EC	0.011	4114.433	0.700
EI	0.009	3576.659	0.380
DE	0.009	3422.498	0.300
DD	0.012	4449.249	0.450
GR	0.009	3904.750	0.760
GR1/2	0.009	4045.355	0.940
GR1/3	0.009	4054.697	0.940
GR1/4	0.009	4045.532	0.950
GR1/5	0.009	4043.465	0.940
GR2	0.009	3841.269	0.710
GR3	0.009	3720.659	0.650
GR4	0.009	3641.965	0.570
GR5	0.008	3539.231	0.510

Strategy	F_D	T_H (days)	f_c
HH	0.009	3573.043	0.360
AG	0.009	4010.290	0.910
KC	0.010	3760.788	0.370
LA	0.011	3996.960	0.320
PR	0.009	3405.192	0.300
HP	0.011	3947.349	0.310
HA	0.015	5441.060	0.790
DP	0.011	3945.847	0.300
DA	0.015	5409.666	0.790
RN	0.012	4740.297	0.800
WBE	0.010	3751.958	0.480
WCL	0.010	4241.772	0.820
WUT	0.008	3619.796	0.540
WEI	0.010	3711.602	0.410
WGR	0.009	3914.916	0.800
WGR1/2	0.009	4036.869	0.930
WGR1/3	0.009	4058.844	0.940
WGR1/4	0.009	4046.758	0.940
WGR1/5	0.009	4048.120	0.940
WGR2	0.009	3916.507	0.770
WGR3	0.010	4054.052	0.720
WGR4	0.010	4053.718	0.660
WGR5	0.010	4072.912	0.640
WHH	0.010	4066.455	0.580
WLA	0.011	3964.738	0.290
WPR	0.009	3419.760	0.280

Table S.12: Weighted network with $p = 0.75$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.009	3406.291	0.370
AGR	0.012	4510.977	0.500
AGR1/2	0.014	5393.464	0.880
AGR1/3	0.014	5396.322	0.890
AGR1/4	0.015	5401.999	0.900
AGR1/5	0.014	5379.187	0.900
AGR2	0.011	4139.817	0.430
AGR3	0.011	3975.789	0.360
AGR4	0.009	3425.762	0.320
AGR5	0.009	3355.054	0.300
AWUT	0.011	4288.370	0.650
AWGR	0.012	4547.319	0.550
AWGR1/2	0.014	5374.054	0.860
AWGR1/3	0.014	5373.394	0.880
AWGR1/4	0.014	5360.752	0.890
AWGR1/5	0.014	5371.063	0.890
AWGR2	0.012	4551.284	0.530
AWGR3	0.012	4608.442	0.540
AWGR4	0.010	4038.795	0.560
AWGR5	0.010	4041.619	0.570

Strategy	F_D	T_H (days)	f_c
BE	0.009	3376.957	0.300
CL	0.009	3601.455	0.440
CC	0.014	5425.196	0.870
UT	0.008	3384.272	0.340
EC	0.011	4148.300	0.750
EI	0.009	3652.696	0.450
DE	0.009	3369.636	0.290
DD	0.012	4374.458	0.440
GR	0.009	3882.782	0.760
GR1/2	0.009	4040.024	0.930
GR1/3	0.009	4026.168	0.930
GR1/4	0.009	4032.729	0.940
GR1/5	0.009	4027.889	0.940
GR2	0.009	3807.227	0.710
GR3	0.009	3707.496	0.630
GR4	0.008	3605.936	0.540
GR5	0.008	3484.701	0.500

Strategy	F_D	T_H (days)	f_c
HH	0.009	3567.602	0.410
AG	0.009	3978.745	0.900
KC	0.010	3756.786	0.400
LA	0.011	3964.620	0.310
PR	0.009	3383.270	0.290
HP	0.011	3907.410	0.290
HA	0.014	5339.983	0.770
DP	0.011	3904.691	0.290
DA	0.014	5358.855	0.790
RN	0.012	4701.007	0.790
WBE	0.009	3720.087	0.450
WCL	0.010	4225.170	0.810
WUT	0.008	3604.701	0.540
WEI	0.010	3773.118	0.430
WGR	0.009	3896.158	0.790
WGR1/2	0.016	5923.093	0.930
WGR1/3	0.009	4020.735	0.920
WGR1/4	0.009	4023.032	0.930
WGR1/5	0.009	4043.593	0.940
WGR2	0.009	3912.140	0.750
WGR3	0.010	4019.730	0.700
WGR4	0.010	4032.136	0.640
WGR5	0.010	4035.849	0.600
WHH	0.010	4017.218	0.560
WLA	0.011	3924.010	0.280
WPR	0.009	3384.994	0.270

Table S.13: Weighted network with $p = 1.00$; lowest values in blue, highest in red.

Strategy	F_D	T_H (days)	f_c
AUT	0.008	3370.725	0.370
AGR	0.012	4459.305	0.500
AGR1/2	0.014	5272.003	0.860
AGR1/3	0.014	5269.998	0.850
AGR1/4	0.014	5272.118	0.860
AGR1/5	0.014	5267.036	0.850
AGR2	0.011	4070.886	0.480
AGR3	0.010	3903.074	0.380
AGR4	0.009	3386.251	0.320
AGR5	0.008	3329.700	0.290
AWUT	0.011	4226.580	0.640
AWGR	0.012	4473.489	0.550
AWGR1/2	0.014	5255.222	0.880
AWGR1/3	0.014	5260.268	0.880
AWGR1/4	0.014	5283.922	0.860
AWGR1/5	0.014	5256.038	0.870
AWGR2	0.012	4478.604	0.530
AWGR3	0.012	4542.163	0.550
AWGR4	0.010	4021.754	0.550
AWGR5	0.010	4007.248	0.560

Strategy	F_D	T_H (days)	f_c
BE	0.009	3345.877	0.310
CL	0.009	3596.557	0.500
CC	0.014	5412.409	0.860
UT	0.008	3349.457	0.320
EC	0.010	4001.191	0.730
EI	0.010	3781.089	0.490
DE	0.009	3357.337	0.280
DD	0.012	4345.141	0.430
GR	0.009	3847.166	0.750
GR1/2	0.009	3994.135	0.930
GR1/3	0.009	3989.692	0.930
GR1/4	0.009	4010.749	0.930
GR1/5	0.009	3977.147	0.930
GR2	0.009	3796.264	0.700
GR3	0.008	3696.406	0.620
GR4	0.008	3577.656	0.540
GR5	0.008	3473.688	0.470

Strategy	F_D	T_H (days)	f_c
HH	0.009	3552.474	0.460
AG	0.009	3943.418	0.900
KC	0.010	3750.344	0.420
LA	0.011	3903.973	0.320
PR	0.009	3334.411	0.270
HP	0.010	3852.392	0.290
HA	0.014	5265.469	0.780
DP	0.010	3880.232	0.290
DA	0.014	5288.059	0.780
RN	0.012	4663.076	0.770
WBE	0.009	3675.024	0.430
WCL	0.010	4169.536	0.810
WUT	0.008	3571.838	0.530
WEI	0.010	3791.627	0.490
WGR	0.009	3845.673	0.800
WGR1/2	0.009	4000.327	0.930
WGR1/3	0.009	3985.601	0.930
WGR1/4	0.009	3983.626	0.930
WGR1/5	0.009	3993.274	0.930
WGR2	0.009	3884.92	0.740
WGR3	0.010	3970.448	0.680
WGR4	0.010	4007.267	0.630
WGR5	0.010	4015.706	0.590
WHH	0.010	3998.115	0.590
WLA	0.010	3900.588	0.290
WPR	0.009	3332.773	0.270

S.5 List of acronyms

Table S.14: Strategies.

Acronym	Strategy
AG	Age
AGRs	Altruistic gravity with power s (see Eq. 3 in the manuscript)
AUT	Altruistic utility
AWGRs	Weighted altruistic gravity with power s (see Eq. 3 in the manuscript)
AWUT	Weighted altruistic utility
BE	Betweenness
CL	Closeness
DA	Probability of the node becoming asymptomatic and at least one neighbor dying
DD	Probability of death
DE	Node degree
DP	Probability of at least one neighbor dying
EC	Eccentricity
EI	Eigenvalue centrality
GRs	Egoistic gravity with power s (see Eq. 3 in the manuscript)
HA	Probability of the node becoming asymptomatic and at least one neighbor being hospitalized
HH	Harmonic centrality
HP	Probability of at least one neighbor being hospitalized
KC	k-core
LA	Laplacian centrality
PR	PageRank
RN	Random
UT	Egoistic utility
WBE	Weighted betweenness
WCL	Weighted closeness
WEI	Weighted eigenvalue centrality
WGRs	Weighted Egoistic gravity with power s (see Eq. 3 in the manuscript)
WHH	Weighted harmonic centrality
WLA	Weighted Laplacian centrality
WPR	Weighted PageRank
WUT	Weighted egoistic utility

Table S.15: Performance metrics.

Acronym	Metric
f_c	Fraction of the population that needs to be vaccinated in order to extinguish the disease
$F_D(f)$	Fraction of the population that dies when a fraction f is vaccinated
$T_H(f)$	Total hospitalization time when a fraction f is vaccinated

References

[1] Richard Durrett. *Essentials of stochastic processes.* Springer, 2012.

[2] Steffen E. Eikenberry, Marina Mancuso, Enahoro Iboi, Tin Phan, Keenan Eikenberry, Yang Kuang, Eric Kostelich, and Abba B. Gumel. To mask or not to mask: Modeling the potential for face mask use by the general public to curtail the COVID-19 pandemic. *Infectious Disease Modelling*, 5:293–308, 2020.

[3] Tarcísio M. Rocha Filho, José F. F. Mendes, Thiago B. Murari, Aloísio S. Nascimento Filho, Antônio J. A. Cordeiro, Walter M. Ramalho, Fúlvio A. Scorza, Antônio-Carlos G. Almeida, and Marcelo A. Moret. Optimization of COVID-19 vaccination and the role of individuals with a high number of contacts: A model based approach. *PLOS ONE*, 17(3):e0262433, Mar. 2022.

[4] Daniel T Gillespie. A general method for numerically simulating the stochastic time evolution of coupled chemical reactions. *Journal of Computational Physics*, 22(4):403–434, Dec. 1976.

[5] Miguel Gonçalves. Análise de estratégias de vacinação para COVID-19 baseada em redes complexas. Master's thesis, Universidade Federal do Ceará, Centro de Ciências, Departamento de Estatística e Matemática Aplicada, Programa de Pós-Graduação em Modelagem e Métodos Quantitativos, 2024.

[6] Eric J Haas, Frederick J Angulo, John M McLaughlin, Emilia Anis, Shepherd R Singer, Farid Khan, Nati Brooks, Meir Smaja, Gabriel Mircus, Kaijie Pan, Jo Southern, David L Swerdlow, Luis Jodar, Yeheskel Levy, and Sharon Alroy-Preis. Impact and effectiveness of mRNA BNT162b2 vaccine against SARS-CoV-2 infections and COVID-19 cases, hospitalisations, and deaths following a nationwide vaccination campaign in israel: an observational study using national surveillance data. *The Lancet*, 397(10287):1819–1829, May. 2021.

[7] Chan-Young Jung, Haeyong Park, Dong Wook Kim, Yoon Jung Choi, Seong Woo Kim, and Tae Ik Chang. Clinical characteristics of asymptomatic patients with COVID-19: A nationwide cohort study in south

korea. *International Journal of Infectious Diseases*, 99:266–268, Oct. 2020.

[8] Robert D. Kirkcaldy, Brian A. King, and John T. Brooks. COVID-19 and postinfection immunity. *JAMA*, 323(22):2245, Jun. 2020.

[9] Rodrigo Malagutti and Marcio Eisencraft. SEIHR epidemic model applied to the COVID-19 outbreak in São Paulo. Unpublished, Nov. 2021.

[10] Ministério da Saúde de Brasil. SRAG 2020 - banco de dados de síndrome respiratória aguda grave - incluindo dados da COVID-19. `https://opendatasus.saude.gov.br/dataset/srag-2020`, 2020. Accessed 05-12-2023.