Preliminary Notes on Using Genetic Algorithms to Optimize Vaccine Distribution

July 20, 2021

Abstract

We generate vaccination strategies, by people groups and time, with the goal of reducing the number of symptomatic infected people. Deceased persons come from that condition. The results are promising, have a look to Table 19.

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8.1.3 Vaccinated people still spreading the infection

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1 The tools and the goal

The tools in use are NetLogo, to build the model, and BehaviorSearch, to run Genetic Algorithms.

Model information is online at [https://terna.to.it/simul/SIsaR.html](https://terna.to.it/simul/SIsaR.html) and in a short paper (Pescarmona et al., 2020).

We are considering epidemic trends in an area with the Piedmont region’s characteristics; the calendar of the non-pharmaceutical measures of containment is updated until day 350, Jan. 18th, 2021. **TO BE UPDATED.**

The goal of the simulation of the vaccination campaigns is to find vaccination sequences by people groups to reduce the number of symptomatic infected people. Deceased persons come from that condition.

Click hereafter for an introduction both to Genetic Algorithms and the related Holland’s schema theorem.

2 The sequence of the contagions in a simulated epidemic

The critical point that makes helpful the production of an agent-based model of the SARS-CoV-2 epidemic is the possibility of creating a tool that allows analyzing the contagions’ sequences in the simulated epidemics and identifying the places where they occur.

![Figure 1: The initial contagion events in a simulation](image-url)
We represent each infecting agent as a horizontal segment with a vertical connection to another agent receiving the infection. We represent the second agent via a further segment at an upper level. With colors, line thickness, and styles, we display multiple data.

As an example, look at Fig. 1: we start with two agents coming from the outside, with black color code (external place); the first one is regular, as reported by the thickness of the segment, starting at day 0 and finishing at day 22; it is asymptomatic (dashed line) and infects five agents; the second one, robust, as reported by the thickness of the segment, starting at day 0 and finishing at day 15, is asymptomatic (dashed line) and infects no one; the first of the five infected agents received the infection at home (cyan color) and turns to be asymptomatic after a few days of incubation (dotted line), and so on.

Solid lines identify symptomatic infected agents; dashed lines refer to asymptomatic infected agents. Colors: brown relates to workplaces, orange to nursing homes, yellow to schools; pink to hospitals; cyan to houses, gray to open spaces. Thick or extra-thick lines refer to fragile or extra-fragile agents, respectively. Lines with regular thickness identify regular people and thin ones identify robust (young) persons.

3 Applying Genetic Algorithms (GA)

3.1 Population groups

We take into consideration seven groups in order of decreasing fragility if we also take into account the exposure to contagion:

- $g_1$ extra fragile people with three components;
  - (a) due to intrinsic characteristics: people in nursing homes;
  - (b) due to risk exposure:
    - i. nursing homes operators;
    - ii. healthcare operators;
- $g_2$ teachers;
- $g_3$ workers with medical fragility;
- $g_4$ regular workers;
- $g_5$ fragile people without special characteristics;
- $g_6$ regular people, not young, not worker, and not teacher;
- $g_7$ young people excluding special activity cases (a limited number in $g_1$).

3.2 Vaccination quantities

For each group, we have to fix five daily vaccination quotas over different periods. We have two base proposals: (a) the “plain” one is in Table 1 and the “wise” one in Table 2.

The quotas apply to each group’s number of components to determine the number of vaccination for that group on that day. **We start from the first group, which**
absorbs its quantity; if in that day there are residual vaccine doses, we move to
the second group and so on. A wholly vaccinated group is no more considered.
The numbers of people in each group are those of the model at [https://terna.to.
it/simul/SisaR.html](https://terna.to.it/simul/SisaR.html) and are related to Piedmont. The daily vaccinations quantities are
similar to those of Piedmont, reduced by 50% to take into account the second dose.
How we reason?

- Considering the *plain* option adopted in Table 1 and remembering that the time-
  sequence in daily actions is the winner, we will primarily vaccinate the left column
groups to move gradually to other columns: ($g_1$) extra fragile people, ($g_2$) teachers,
($g_3$) fragile workers, ($g_4$) regular workers, ($g_5$) fragile people, ($g_6$) regular people,
($g_7$) young people.

<table>
<thead>
<tr>
<th>From day of vaccines (000)</th>
<th>Q. of vaccines</th>
<th>$g_1$</th>
<th>$g_2$</th>
<th>$g_3$</th>
<th>$g_4$</th>
<th>$g_5$</th>
<th>$g_6$</th>
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<tr>
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<tr>
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</tr>
</tbody>
</table>

Table 1: From the day of the first column, considering the quantity of the second column
(000), the vaccination of each group follows the quota of the related columns

- Considering the *wise* option adopted in Table 2 and remembering that the time-
  sequence in daily actions is the winner, we will primarily vaccinate the left column
groups to move gradually to other columns, but postponing group $g_4$ (regular work-
ers), $g_6$ (regular people), and $g_7$ (young people).
### Table 2: From the day of the first column, considering the quantity of the second column (1000), the vaccination of each group follows the quota of the related columns

<table>
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<tr>
<th>From day</th>
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<th>g2</th>
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<th>g4</th>
<th>g5</th>
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<td>0.1</td>
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</tr>
<tr>
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<td>738</td>
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<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

In the internal calendar of the model, day 373 is Feb. 12th, 2021, which is effectively the starting point of the vaccinations in the region; the endpoint, day 738, is Feb. 10th, 2022, two years after the conventional starting point of the epidemic in this model.

## 4 Vaccination experiments

We run the simulations of the epidemic in Piedmont in batches of ten thousand executions. The batches are different as initial hypotheses. Considering the adoption of the government non-pharmaceutical measures, we search for realizations of sequences similar to the actual events occurred in Piedmont.

In Fig. 2, we have the time series of the first part of Piedmont’s actual epidemic, with some crucial points. The blue line represents the cumulative number of infected persons. Initially, only symptomatic cases were accounted, but after the 2020 Summer, with the adoption of more generalized tests, also asymptomatic patients are included. The model instead has two categories of positive agents. (In Fig. 3 the time series cover whole the period.)

Following the dynamic of the data in Fig. 2 we search within the simulation batch for cases with both:

(i) numbers of infected persons quite similar at \( cp_2 \) and at \( cp_3 \); besides, numbers not too different from those of the figure;

(ii) the number of infected persons at \( cp_4 \) has to be significantly greater than those at the previous check point.

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1. At [https://terna.to.it/simul/TernaCCA20210329.pdf](https://terna.to.it/simul/TernaCCA20210329.pdf) some examples.
2. With \( cp \) we indicate the internal check points of the simulation program. In Fig. 2 we also report the number of days from the beginning of the epidemic for each check point.
In a lot of cases, epidemics satisfying condition (i) fail to match condition (ii); both the situations happen only in less than the 1.5% of the instances in the batch of ten thousand epidemic.\textsuperscript{3} We can conclude that the second wave registered in Piedmont after the Summer stability is due to new infected agents coming from outside and restarting the contagion process, as in the batch represented in the slides at the given address.

![Figure 2: Time series of the actual epidemic in Piedmont with some crucial points](image)

Other critical points in our analysis are the day on which the vaccination campaign starts, 373 of the simulation (Feb. 12\textsuperscript{th}, 2021), and the day of the effectiveness of the initial vaccinations, 40 days later, day 413 (Mar. 22\textsuperscript{nd}, 2021). At those dates, within the simulations, we can find either the presence of many infected agents or of few ones, as effectively was the situation in Piedmont.\textsuperscript{4}

\textsuperscript{3}Again, see [https://terna.to.it/simul/TernaCCA20210329.pdf](https://terna.to.it/simul/TernaCCA20210329.pdf).

\textsuperscript{4}We simulate the vaccination campaigns with the GAs BehaviorSearch program, with a maximum step number of 865, related to the actual duration of case I. In the case of "y" use, the simulation never ends; when applying the GAs quotas ex-post, the simulation stops when no more infected people exist. In any case, if necessary, we have a hard finish button.
Figure 3: Time series of the actual epidemic updated to the beginning of May

5 Experiment I, with few infected agents at the vaccination starting point

This experiment’s main plot is in Fig. 4 where we read on $x$ axis the time and on the $y$ axis the number of infected people of any kind. Considering the thickness of the snake (or tape) developing in the figure, we also read the number of agents infected at a given date, with the thickness determining the slope of the cumulative dynamic of infected persons.

The hole in the series identifies the period in which the epidemic was extinct, to restart with the arrival of infected persons from outside.
The following sequences start from day 413, Mar. 22nd, when the effectiveness of the initial vaccinations—if any—begins, after 40 days from initial vaccinations.

5.1 Planned vaccination campaigns in Experiment I

5.1.1 Vaccinated persons by group using “plain” or “wise” quotas

Applying the “plain” quotas of Table 1 to the group composition of Experiment I, as in Table 3, the effects on the numbers of vaccinated people in each group are in Fig. 5.
Figure 5: Experiment I, “plain” vaccination sequence; on the y axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

Applying the “wise” quotas of Table 2 to the group composition of Experiment I, as in Table 3, the effects on the numbers of vaccinated people in each group are in Fig. 6.
Figure 6: Experiment I, “wise” vaccination sequence; on the $y$ axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

5.1.2 No vaccination

Figure 7: The sequence of contagions in Experiment I, after day 413: no vaccination campaign
5.1.3 Vaccinated people still spreading the infection

Figure 8: The sequence of contagions in Experiment I, after day 413: “plain” vaccination campaign, with vaccinated people still spreading the infection

Figure 9: The sequence of contagions in Experiment I, after day 413: “wise” vaccination campaign, with vaccinated people still spreading the infection
5.1.4 Vaccinated people not spreading the infection

Figure 10: The sequence of contagions in Experiment I, after day 413: “plain” vaccination campaign, with vaccinated people not spreading the infection.

Figure 11: The sequence of contagions in Experiment I, after day 413: “wise” vaccination campaign, with vaccinated people not spreading the infection.
5.1.5 Vaccinated people 50% spreading the infection

Figure 12: The sequence of contagions in Experiment I, after day 413: “plain” vaccination campaign, with vaccinated people spreading the infection in the 50% of cases

Figure 13: The sequence of contagions in Experiment I, after day 413: “wise” vaccination campaign, with vaccinated people spreading the infection in the 50% of cases
5.2 Experiment I, following GAs suggestions

<table>
<thead>
<tr>
<th></th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
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<td>Susc. when vacc. starts</td>
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<td>162</td>
<td>1234</td>
<td>1032</td>
<td>245</td>
<td>891</td>
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</tbody>
</table>

Table 3: Experiment I: susceptible persons at the beginning of the simulation and when the vaccination campaign starts, day 373, Feb. 12\textsuperscript{th}, 2021

5.2.1 Vaccinated people still spreading the infection

Figure 14: The sequence of contagions in Experiment I, after day 413: GAs vaccination campaign, with vaccinated people still spreading the infection: best GAs strategy
Table 4: GAs best strategy in experiment I, with vaccinated people still spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns.

Applying the quotas of Table 4 to the group composition of Experiment I, as in Table 3, the effects on the numbers of vaccinated people in each group are in Fig. 15.

Some of the coefficients in Table 4 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.
5.2.2 Vaccinated people not spreading the infection

Figure 16: The sequence of contagions in Experiment I, after day 413: GAs vaccination campaign, with \textit{vaccinated people not spreading the infection: best GAs strategy}

<table>
<thead>
<tr>
<th>From day</th>
<th>Q. of vaccines (000)</th>
<th>(g1)</th>
<th>(g2)</th>
<th>(g3)</th>
<th>(g4)</th>
<th>(g5)</th>
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<tr>
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<td>0.79</td>
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</tr>
</tbody>
</table>

Table 5: GAs best strategy in experiment I, with \textit{vaccinated people not spreading the infection}: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns.

Applying the quotas of Table 5 to the group composition of Experiment I, as in Table 3, the effects on the numbers of vaccinated people in each group are in Fig. [17]
Figure 17: Experiment I, GA 0 vaccination sequence; on the $y$ axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

Some of the coefficients in Table 5 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.
5.2.3 Vaccinated people 50% spreading the infection

Figure 18: The sequence of contagions in Experiment I, after day 413: GAs vaccination campaign, with vaccinated people 50% spreading the infection: best GAs strategy

<table>
<thead>
<tr>
<th>From day</th>
<th>Q. of vaccines (000)</th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
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</table>

Table 6: GAs best strategy in experiment I, with vaccinated people 50% spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns

Applying the quotas of Table[6] to the group composition of Experiment II, as in Table[3] the effects on the numbers of vaccinated people in each group are in Fig.[19]
Some of the coefficients in Table 6 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.

5.3 A very short comment on Experiment I

The advantage of the GAs strategy is relevant in the case of the vaccinated people still spreading the infection, comparing both with “plain” or “wise” strategies. Note: we have, in this case, a pretty limited number of infected people at the date of both the initial vaccination and the validity of the initial vaccinations. The limited number of agents at the vaccination starting point can explain the presence of worse results in “wise” strategy adoption, due to the prevalence of particular sequences.

The main attention of the GAs is initially related to $g_4$, and $g_6$ groups (regular workers and regular persons). Maybe, they are composed of highly circulating persons. In the third sub-case (Table 6), also $g_2$ (teachers) and $g_7$ (young persons, but as residual intervention and discontinuously) groups are relevant.

Figure 19: Experiment I, GA 0.5 vaccination sequence; on the $y$ axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)
6 Experiment II, with many infected agents at the vaccination starting point

This experiment’s main plot is in Fig. 20, where we read on the x axis the time and on the y axis the number of infected people of any kind. Considering the thickness of the snake (or tape) developing in the figure, we also read the number of agents infected at a given date, with the thickness determining the slope of the cumulative dynamic of infected persons.

The hole in the series identifies the period in which the epidemic was extinct, to restart with the arrival of infected persons from outside.

Figure 20: The sequence of contagions in Experiment II, without vaccinations; crucial dates: blue line for the starting point of the vaccination campaign and red line for the start of the effectiveness of the initial vaccinations

The following sequences start from day 413, Mar. 22nd, when the effectiveness of the initial vaccinations—if any—begins, after 40 days from initial vaccinations.

6.1 Planned vaccination campaigns in experiment II

6.1.1 Vaccinated persons by group using “plain” or “wise” quotas

Applying the “plain” quotas of Table 1 to the group composition of Experiment II, as in Table 7, the effects on the numbers of vaccinated people in each group are in Fig. 21.
Applying the “wise” quotas of Table 2 to the group composition of Experiment II, as in Table 7, the effects on the numbers of vaccinated people in each group are in Fig. 22.
Figure 22: Experiment II, “wise” vaccination sequence; on the $y$ axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

6.1.2 No vaccination

Figure 23: The sequence of contagions in Experiment II, after day 413: no vaccination campaign
6.1.3 Vaccinated people still spreading the infection

Figure 24: The sequence of contagions in Experiment II, after day 413: “plain” vaccination campaign, with vaccinated people still spreading the infection

Figure 25: The sequence of contagions in Experiment II, after day 413: “wise” vaccination campaign, with vaccinated people still spreading the infection
6.1.4 Vaccinated people not spreading the infection

Figure 26: The sequence of contagions in Experiment II, after day 413: “plain” vaccination campaign, with vaccinated people not spreading the infection

Figure 27: The sequence of contagions in Experiment II, after day 413: “wise” vaccination campaign, with vaccinated people not spreading the infection
6.1.5 Vaccinated people 50% spreading the infection

Figure 28: The sequence of contagions in Experiment II, after day 413: “plain” vaccination campaign, with vaccinated people spreading the infection in the 50% of cases

Figure 29: The sequence of contagions in Experiment II, after day 413: “wise” vaccination campaign, with vaccinated people spreading the infection in the 50% of cases
6.2 Experiment II, following GAs suggestions

<table>
<thead>
<tr>
<th></th>
<th>$g1$</th>
<th>$g2$</th>
<th>$g3$</th>
<th>$g4$</th>
<th>$g5$</th>
<th>$g6$</th>
<th>$g7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susc. at $t = 0$</td>
<td>116</td>
<td>108</td>
<td>244</td>
<td>1530</td>
<td>1216</td>
<td>250</td>
<td>886</td>
</tr>
<tr>
<td>Susc. when vacc. starts</td>
<td>92</td>
<td>105</td>
<td>170</td>
<td>1300</td>
<td>1104</td>
<td>245</td>
<td>878</td>
</tr>
</tbody>
</table>

Table 7: Experiment II: susceptible persons at the beginning of the simulation and when the vaccination campaign starts, day 373, Feb. 12th, 2021

6.2.1 Vaccinated people still spreading the infection

Figure 30: The sequence of contagions in Experiment II, after day 413: GAs vaccination campaign, with vaccinated people still spreading the infection: best GAs strategy
From day Q. of vaccines
g1 g2 g3 g4 g5 g6 g7
373 5 0.03 0 0.97 0.75 0.89 0.59 0.9
433 10 0.97 0.97 0.45 0.78 0.22 0.82 0.8
493 10 0.35 0.37 0.07 0.63 0.04 0.41 0.03
553 10 0.45 0 0.9 0.29 0.01 0.07 0.12
613 20 0.31 0.22 0.35 0.41 0.52 0.22 0.68
738 end

Table 8: GAs best strategy in experiment II, with vaccinated people still spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns.

Applying the quotas of Table 8 to the group composition of Experiment II, as in Table 7, the effects on the numbers of vaccinated people in each group are in Fig. 31.

Some of the coefficients in Table 8 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.

Figure 31: Experiment II, GA 1 vaccination sequence; on the y axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)
6.2.2 Vaccinated people not spreading the infection

Figure 32: The sequence of contagions in Experiment II, after day 413: GAs vaccination campaign, with vaccinated people not spreading the infection: best GAs strategy

<table>
<thead>
<tr>
<th>From day</th>
<th>Q. of vaccines (000)</th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
</tr>
</thead>
<tbody>
<tr>
<td>373</td>
<td>5</td>
<td>0.01</td>
<td>0.26</td>
<td>0.73</td>
<td>0.38</td>
<td>0.78</td>
<td>0.85</td>
<td></td>
</tr>
<tr>
<td>433</td>
<td>10</td>
<td>0.4</td>
<td>0</td>
<td>0.35</td>
<td>0</td>
<td>0.86</td>
<td>0.21</td>
<td>0.64</td>
</tr>
<tr>
<td>493</td>
<td>10</td>
<td>0.97</td>
<td>0.67</td>
<td>0.6</td>
<td>0.06</td>
<td>0.71</td>
<td>0.15</td>
<td>0.38</td>
</tr>
<tr>
<td>553</td>
<td>10</td>
<td>0.43</td>
<td>0.06</td>
<td>0.86</td>
<td>0.9</td>
<td>0.78</td>
<td>0.34</td>
<td>0.17</td>
</tr>
<tr>
<td>613</td>
<td>20</td>
<td>0.77</td>
<td>0.67</td>
<td>0.83</td>
<td>0.36</td>
<td>0.37</td>
<td>0.79</td>
<td>0.78</td>
</tr>
<tr>
<td>738</td>
<td>end</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9: GAs best strategy in experiment II, with vaccinated people not spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns

Applying the quotas of Table 9 to the group composition of Experiment II, as in Table 7, the effects on the numbers of vaccinated people in each group are in Fig. 33.
Figure 33: Experiment II, GA 0 vaccination sequence; on the $y$ axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

Some of the coefficients in Table 9 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.
6.2.3 Vaccinated people 50% spreading the infection

Figure 34: The sequence of contagions in Experiment II, after day 413: GAs vaccination campaign, with vaccinated people 50% spreading the infection: best GAs strategy

<table>
<thead>
<tr>
<th>From day vaccines (000)</th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
</tr>
</thead>
<tbody>
<tr>
<td>373</td>
<td>5</td>
<td>0.01</td>
<td>0.41</td>
<td>0.67</td>
<td>0.67</td>
<td>0.07</td>
<td>0.32</td>
</tr>
<tr>
<td>433</td>
<td>10</td>
<td>0.03</td>
<td>0.48</td>
<td>0.35</td>
<td>0.52</td>
<td>0.21</td>
<td>0.15</td>
</tr>
<tr>
<td>493</td>
<td>10</td>
<td>0.44</td>
<td>0.97</td>
<td>0.63</td>
<td>0.75</td>
<td>0.09</td>
<td>0.22</td>
</tr>
<tr>
<td>553</td>
<td>10</td>
<td>0.47</td>
<td>0.02</td>
<td>0.79</td>
<td>0.62</td>
<td>0.52</td>
<td>0.56</td>
</tr>
<tr>
<td>613</td>
<td>20</td>
<td>0.54</td>
<td>0.67</td>
<td>0.83</td>
<td>0.26</td>
<td>0.64</td>
<td>0.35</td>
</tr>
<tr>
<td>738</td>
<td>end</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 10: GAs best strategy in experiment II, with vaccinated people 50% spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns.

Applying the quotas of Table 10 to the group composition of Experiment II, as in Table 7, the effects on the numbers of vaccinated people in each group are in Fig. 35.
Some of the coefficients in Table [10] are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.

6.3 A very short comment on Experiment II

The advantage of the GAs strategy is relevant in all the cases. Note: a significant difference from experiment I is the large number of infected people at the date of both the initial vaccination and the validity of the initial vaccinations. “Wise” strategy is a bit better than “plain” strategy.

The main attention of the GAs in the three cases seems related to $g_3$, $g_4$, and $g_5$ groups, i.e., fragile workers, workers, fragile people. Again, they are composed—at least partially—of highly circulating persons.

7 Experiment III, with few infected agents at the vaccination starting point

This experiment’s main plot is in Fig. [36] where we read on the x axis the time and on the y axis the number of infected people of any kind. Considering the thickness of the snake (or tape) developing in the figure, we also read the number of agents infected at a
given date, with the thickness determining the slope of the cumulative dynamic of infected persons.

The hole in the series identifies the period in which the epidemic was extinct, to restart with the arrival of infected persons from outside.

Figure 36: The sequence of contagions in Experiment III, without vaccinations; crucial dates: blue line for the starting point of the vaccination campaign and red line for the start of the effectiveness of the initial vaccinations.

The following sequences start from day 413, Mar. 22nd, when the effectiveness of the initial vaccinations—if any—begins, after 40 days from initial vaccinations.

7.1 Planned vaccination campaigns in experiment III

7.1.1 Vaccinated persons by group using “plain” or “wise” quotas

Applying the “plain” quotas of Table 1 to the group composition of Experiment III, as in Table 11, the effects on the numbers of vaccinated people in each group are in Fig. 37.
Figure 37: Experiment III, “plain” vaccination sequence; on the y axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

Applying the “wise” quotas of Table 2 to the group composition of Experiment III, as in Table 11, the effects on the numbers of vaccinated people in each group are in Fig. 38
Figure 38: Experiment III, “wise” vaccination sequence; on the $y$ axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

7.1.2 No vaccination

Figure 39: The sequence of contagions in Experiment III, after day 413: no vaccination campaign
7.1.3 Vaccinated people still spreading the infection

Figure 40: The sequence of contagions in Experiment III, after day 413: “plain” vaccination campaign, with vaccinated people still spreading the infection

Figure 41: The sequence of contagions in Experiment III, after day 413: “wise” vaccination campaign, with vaccinated people still spreading the infection
7.1.4 Vaccinated people not spreading the infection

Figure 42: The sequence of contagions in Experiment III, after day 413: “plain” vaccination campaign, with vaccinated people not spreading the infection

Figure 43: The sequence of contagions in Experiment III, after day 413: “wise” vaccination campaign, with vaccinated people not spreading the infection
7.1.5 Vaccinated people 50% spreading the infection

Figure 44: The sequence of contagions in Experiment III, after day 413: “plain” vaccination campaign, with vaccinated people spreading the infection in the 50% of cases

Figure 45: The sequence of contagions in Experiment III, after day 413: “wise” vaccination campaign, with vaccinated people spreading the infection in the 50% of cases
7.2 Experiment III, following GAs suggestions

<table>
<thead>
<tr>
<th></th>
<th>$g_1$</th>
<th>$g_2$</th>
<th>$g_3$</th>
<th>$g_4$</th>
<th>$g_5$</th>
<th>$g_6$</th>
<th>$g_7$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susc. at $t=0$</td>
<td>129</td>
<td>56</td>
<td>243</td>
<td>1541</td>
<td>1197</td>
<td>252</td>
<td>932</td>
</tr>
<tr>
<td>Susc. when vacc. starts</td>
<td>81</td>
<td>50</td>
<td>196</td>
<td>1364</td>
<td>1052</td>
<td>238</td>
<td>918</td>
</tr>
</tbody>
</table>

Table 11: Experiment III: susceptible persons at the beginning of the simulation and when the vaccination campaign starts, day 373, Feb. 12$^{th}$, 2021

7.2.1 Vaccinated people still spreading the infection

Figure 46: The sequence of contagions in Experiment III, after day 413: GAs vaccination campaign, with vaccinated people still spreading the infection: best GAs strategy
Table 12: GAs best strategy in experiment III, with vaccinated people still spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns.

Applying the quotas of Table 12 to the group composition of Experiment III, as in Table 11, the effects on the numbers of vaccinated people in each group are in Fig. 47.

Some of the coefficients in Table 12 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.
7.2.2 Vaccinated people not spreading the infection

Figure 48: The sequence of contagions in Experiment II, after day 413: GAs vaccination campaign, with vaccinated people not spreading the infection: best GAs strategy

<table>
<thead>
<tr>
<th>From day</th>
<th>Q. of vaccines (000)</th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
</tr>
</thead>
<tbody>
<tr>
<td>373</td>
<td>5</td>
<td>0.5</td>
<td>0.04</td>
<td>0.71</td>
<td>0.78</td>
<td>0.58</td>
<td>0.45</td>
<td>0.71</td>
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<tr>
<td>433</td>
<td>10</td>
<td>0.45</td>
<td>0.04</td>
<td>0.72</td>
<td>0</td>
<td>0.36</td>
<td>0.18</td>
<td>0.46</td>
</tr>
<tr>
<td>493</td>
<td>10</td>
<td>0.6</td>
<td>0.24</td>
<td>0.92</td>
<td>0.82</td>
<td>1</td>
<td>0.04</td>
<td>0.82</td>
</tr>
<tr>
<td>553</td>
<td>10</td>
<td>0.46</td>
<td>0.12</td>
<td>0.65</td>
<td>0.67</td>
<td>0.43</td>
<td>0.63</td>
<td>0.49</td>
</tr>
<tr>
<td>613</td>
<td>20</td>
<td>0.6</td>
<td>0.3</td>
<td>0.39</td>
<td>0.43</td>
<td>1</td>
<td>0.71</td>
<td>0.29</td>
</tr>
<tr>
<td>738</td>
<td>end</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13: GAs best strategy in experiment III, with vaccinated people not spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns

Applying the quotas of Table 13 to the group composition of Experiment III, as in Table 11 the effects on the numbers of vaccinated people in each group are in Fig. 49
Figure 49: Experiment III, GA 0 vaccination sequence; on the $y$ axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

Some of the coefficients in Table 13 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.
7.2.3 Vaccinated people 50% spreading the infection

Figure 50: The sequence of contagions in Experiment III, after day 413: GAs vaccination campaign, with vaccinated people 50% spreading the infection: best GAs strategy

<table>
<thead>
<tr>
<th>From day</th>
<th>Q. of vaccines (000)</th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
</tr>
</thead>
<tbody>
<tr>
<td>373</td>
<td>5</td>
<td>0.92</td>
<td>0.04</td>
<td>0.56</td>
<td>0.55</td>
<td>0.7</td>
<td>0.67</td>
<td>0.58</td>
</tr>
<tr>
<td>433</td>
<td>10</td>
<td>0.62</td>
<td>0.3</td>
<td>0.74</td>
<td>0.57</td>
<td>0.75</td>
<td>0.26</td>
<td>0.88</td>
</tr>
<tr>
<td>493</td>
<td>10</td>
<td>0.19</td>
<td>0.82</td>
<td>0.25</td>
<td>0.94</td>
<td>0.16</td>
<td>0.79</td>
<td>0.56</td>
</tr>
<tr>
<td>553</td>
<td>10</td>
<td>0.16</td>
<td>0.22</td>
<td>0.09</td>
<td>0.9</td>
<td>0.2</td>
<td>0.29</td>
<td>0.92</td>
</tr>
<tr>
<td>613</td>
<td>20</td>
<td>0.07</td>
<td>0.41</td>
<td>0.83</td>
<td>0.6</td>
<td>0.56</td>
<td>0.82</td>
<td>0.25</td>
</tr>
<tr>
<td>738</td>
<td>end</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 14: GAs best strategy in experiment III, with vaccinated people 50% spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns

Applying the quotas of Table 14 to the group composition of Experiment III, as in Table 11 the effects on the numbers of vaccinated people in each group are in Fig. 51.
Some of the coefficients in Table 14 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.

7.3 A very short comment on Experiment III

The advantage of the GAs strategy is relevant in the case of the vaccinated people still spreading the infection if we compare it with “plain” plain strategy; referring to the “wise” one, the advantage is quite limited. Note: we have, in this case, a pretty limited number of infected people at the date of both the initial vaccination and the validity of the initial vaccinations. As a consequence, if vaccinated people do not spread the infection or spread it in a limited way, all the vaccination strategies have the same relevant effect.

The main attention of the GAs in the case 7.2.1 is related to fragile workers and people.

8 Experiment IV, with many infected agents at the vaccination starting point

This experiment’s main plot is in Fig. 52 where we read on x axis the time and on the the y axis the number of infected people of any kind. Considering the thickness of the snake (or tape) developing in the figure, we also read the number of agents infected at a
given date, with the thickness determining the slope of the cumulative dynamic of infected persons.

The hole in the series identifies the period in which the epidemic was extinct, to restart with the arrival of infected persons from outside.

Figure 52: The sequence of contagions in Experiment IV, without vaccinations; crucial dates: blue line for the starting point of the vaccination campaign and red line for the start of the effectiveness of the initial vaccinations.

The following sequences start from day 413, Mar. 22nd, when the effectiveness of the initial vaccinations—if any—begins, after 40 days from initial vaccinations.

8.1 Planned vaccination campaigns in experiment IV

8.1.1 Vaccinated persons by group using “plain” or “wise” quotas

Applying the “plain” quotas of Table 1 to the group composition of Experiment IV, as in Table 15, the effects on the numbers of vaccinated people in each group are in Fig. 53.
Figure 53: Experiment IV, “plain” vaccination sequence; on the $y$ axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

Applying the “wise” quotas of Table 2 to the group composition of Experiment IV, as in Table 15 the effects on the numbers of vaccinated people in each group are in Fig. 54.
Figure 54: Experiment IV, “wise” vaccination sequence; on the $y$ axis the number of vaccinated subjects of each group (if vaccination is complete, the line is horizontal)

8.1.2 No vaccination

Figure 55: The sequence of contagions in Experiment IV, after day 413: no vaccination campaign

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8.1.3 Vaccinated people still spreading the infection

Figure 56: The sequence of contagions in Experiment IV, after day 413: “plain” vaccination campaign, with vaccinated people still spreading the infection

Figure 57: The sequence of contagions in Experiment IV, after day 413: “wise” vaccination campaign, with vaccinated people still spreading the infection
8.1.4 Vaccinated people not spreading the infection

Figure 58: The sequence of contagions in Experiment IV, after day 413: “plain” vaccination campaign, with vaccinated people not spreading the infection

Figure 59: The sequence of contagions in Experiment IV, after day 413: “wise” vaccination campaign, with vaccinated people not spreading the infection
8.1.5 Vaccinated people 50% spreading the infection

Figure 60: The sequence of contagions in Experiment IV, after day 413: “plain” vaccination campaign, with vaccinated people spreading the infection in the 50% of cases

Figure 61: The sequence of contagions in Experiment IV, after day 413: “wise” vaccination campaign, with vaccinated people spreading the infection in the 50% of cases
8.2 Experiment IV, following GAs suggestions

<table>
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<tr>
<th></th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Susc. at t = 0</td>
<td>109</td>
<td>64</td>
<td>239</td>
<td>1584</td>
<td>1183</td>
<td>258</td>
<td>913</td>
</tr>
<tr>
<td>Susc. when vacc. starts</td>
<td>104</td>
<td>62</td>
<td>142</td>
<td>1226</td>
<td>1000</td>
<td>247</td>
<td>905</td>
</tr>
</tbody>
</table>

Table 15: Experiment IV: susceptible persons at the beginning of the simulation and when the vaccination campaign starts, day 373, Feb. 12\textsuperscript{th}, 2021

8.2.1 Vaccinated people still spreading the infection

Figure 62: The sequence of contagions in Experiment IV, after day 413: GAs vaccination campaign, with vaccinated people still spreading the infection: best GAs strategy
Table 16: GAs best strategy in experiment IV, with vaccinated people still spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns.

Applying the quotas of Table 16 to the group composition of Experiment IV, as in Table 15 the effects on the numbers of vaccinated people in each group are in Fig. 63.

Some of the coefficients in Table 16 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.

<table>
<thead>
<tr>
<th>From day</th>
<th>Q. of vaccines (000)</th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
</tr>
</thead>
<tbody>
<tr>
<td>373</td>
<td>5</td>
<td>0.56</td>
<td>0.03</td>
<td>0.36</td>
<td>0.02</td>
<td>0</td>
<td>0.08</td>
<td>0.65</td>
</tr>
<tr>
<td>433</td>
<td>10</td>
<td>0.19</td>
<td>0.21</td>
<td>0.07</td>
<td>0</td>
<td>0.13</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>493</td>
<td>10</td>
<td>0.67</td>
<td>0.8</td>
<td>0.52</td>
<td>0</td>
<td>0.94</td>
<td>0</td>
<td>0.04</td>
</tr>
<tr>
<td>553</td>
<td>10</td>
<td>0.34</td>
<td>0.72</td>
<td>0.96</td>
<td>0.49</td>
<td>0.57</td>
<td>0.01</td>
<td>0.73</td>
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<tr>
<td>613</td>
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<td>0.9</td>
<td>0.08</td>
<td>0.44</td>
<td>0.93</td>
<td>0.97</td>
<td>0.21</td>
<td>0.24</td>
</tr>
<tr>
<td>738</td>
<td>end</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
8.2.2 Vaccinated people not spreading the infection

Figure 64: The sequence of contagions in Experiment IV, after day 413: GAs vaccination campaign, with vaccinated people not spreading the infection: best GAs strategy

<table>
<thead>
<tr>
<th>From day</th>
<th>Q. of vaccines (000)</th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
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Table 17: GAs best strategy in experiment II, with vaccinated people not spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns.

Applying the quotas of Table 17 to the group composition of Experiment IV, as in Table 15 the effects on the numbers of vaccinated people in each group are in Fig. 33.
Some of the coefficients in Table 17 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.
8.2.3 Vaccinated people 50% spreading the infection

![Graph showing sequence of contagions](image)

Figure 66: The sequence of contagions in Experiment IV, after day 413: GAs vaccination campaign, with *vaccinated people 50% spreading the infection: best GAs strategy*

<table>
<thead>
<tr>
<th>From day</th>
<th>Q. of vaccines (000)</th>
<th>g1</th>
<th>g2</th>
<th>g3</th>
<th>g4</th>
<th>g5</th>
<th>g6</th>
<th>g7</th>
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</table>

Table 18: GAs best strategy in experiment IV, with *vaccinated people 50% spreading the infection: from the day of the first column, considering the quantity of the second column, the vaccination of each group follows the quota of the related columns*

Applying the quotas of Table 18 to the group composition of Experiment IV, as in Table 15, the effects on the numbers of vaccinated people in each group are in Fig. 67
Some of the coefficients in Table 18 are not used, e.g., if the daily quantity of doses is finished before considering a specific group or if the whole group has already received the vaccine. The GAs procedure does not optimize those coefficients.

8.3 A very short comment on Experiment IV

The advantage of the GAs strategy is present in all the situations, but relevant uniquely in the case of vaccinated people not spreading the contagion. Note: a difference from experiment II is that we have a less significant number of infected people at the date the validity of the initial vaccinations. “Wise” strategy is a bit better than “plain” strategy.

The main attention of the GAs in the three cases seems related to $g_3$, $g_4$, and $g_5$ groups, i.e., fragile workers, workers, fragile people. Again, they are composed—at least partially—of highly circulating persons. Group $g_2$, the teachers, is always early vaccinated here.
9 Experiment synopsis

<table>
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<tr>
<th>Exper.</th>
<th>At Final</th>
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<th>Final “wise”</th>
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<th>Final “wise”</th>
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</tbody>
</table>

Table 19: Results of the vaccination campaigns in the four experiments, considering symptomatic people (the second row in each experiment report the results minus the number of symptomatic people at day 413)

We will add other experiments.

10 To do

Using GAs, add the capability to replicate a specific search with the same parameters, but changing the vaccinated people randomly (so-called best-checking replicates).

We can do that using newSeed before the vaccination action. How to save, and where, that value, to exactly replicate the calculations? In a file?

References

URL https://rofasss.org/2020/10/20/sisar/