Evolution of an epidemic disease with different sanitary measures in a multi-agent system.

By Nicolas Gouwy.

Introduction

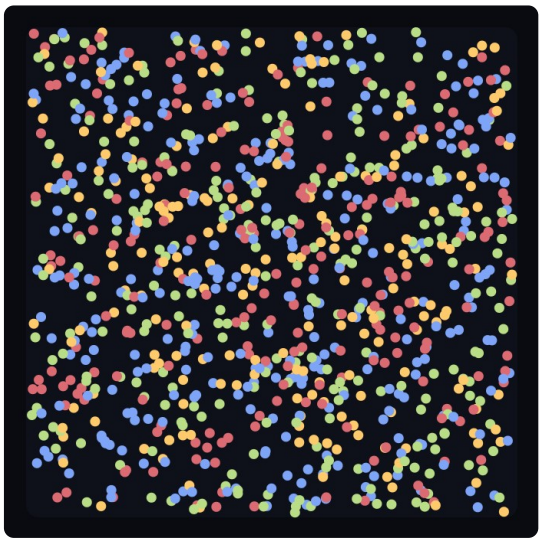
This study is about the evolution of a non-lethal epidemic disease in a multi-agent system for a period of 4 years. The government will use different sanitary measures in order to:

- Prevent **hospital overload**, here defined by more than **20%** of the population being infected.
- Limit the **total number of infections** during the studied period.
- **Eradicate** the disease.

We will see how the different measures affect the evolution of the disease and how they help to achieve theses goals.

Model

The model is based on the SIRV model. We have a square-shaped world of size **20** and **1000** agents represented by a circle of diameter **1**. The agents are distributed randomly in the world and move with random direction and acceleration. Once they hit the borders they bounce.



The agents are divided in four groups:

- **Susceptible** (in blue)
- **Infected** (in red)
- **Recovered** (in green)
- **Vaccinated** (in yellow)

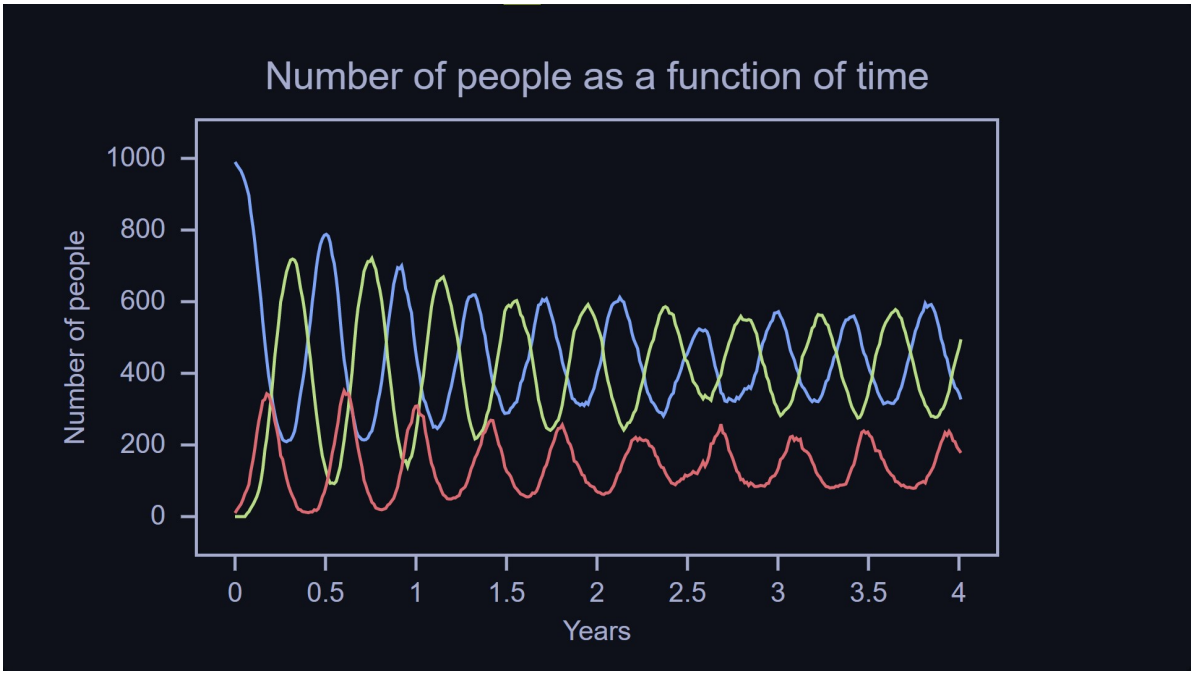
Epidemic

Among the population of 1000 agents, **10** agents are **infected** at the beginning of the simulation. They are contagious and can infect **susceptible** agents. The probability of getting infected is **8%** per day of contact so if a **susceptible** agent is in contact with an **infected** agent for half a day, there is a **4%** chance that the **susceptible** agent gets **infected**.

The disease is not lethal and the recovery time is between **20** and **30** days after which the **infected** agent will be **recovered** and immune to the disease for the next **60** to **90** days (about 2 to 3 months) before becoming **susceptible** again.

Susceptible agents can become **Vaccinated** depending on the vaccination policy implemented by the government. In this case the agent has **90%** less chance of getting infected. The vaccine is effective for the next **120** to **180** days (about 4 to 6 months) after which the agent will be **susceptible** again.

Here is a graph of the number of **susceptible**, **infected** and **recovered** agents during the simulation of 4 years without any sanitary measures:



We can see that the number of **infected** agents peaks at **366** in 2 months. This is more than **1/3** of the population. That means that there is a massive **hospital overload** with **166** people over the limit of **20%** of the population. There is a total of **10** peaks of **infected** agents during the 4 years and all of them are above this limit.

The **total number of infections** is **8285** which means each agent gets infected **8.3** times in average during the 4 years period.

As expected, the disease was not **eradicated**.

Sanitary measures

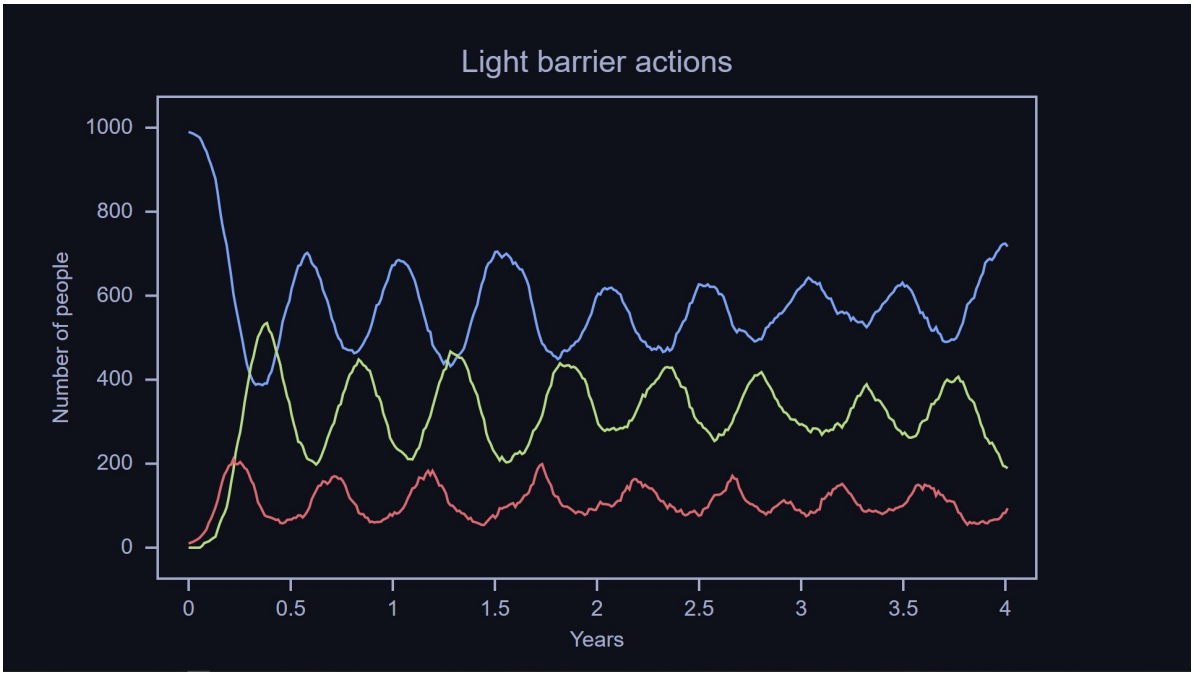
Barrier actions

Barrier actions are the first measure we will simulate as it is the first thing people do in case of epidemics. No need of government intervention for people to:

- Wash their hands and avoid touching their face
- Cough and sneeze in their elbow
- Limit contact with others and stay at safe distance
- Wear masks

To simulate barrier actions we will reduce the probability of agents getting infected by **25%** in case of light barrier actions and **50%** in case of heavy barrier actions.

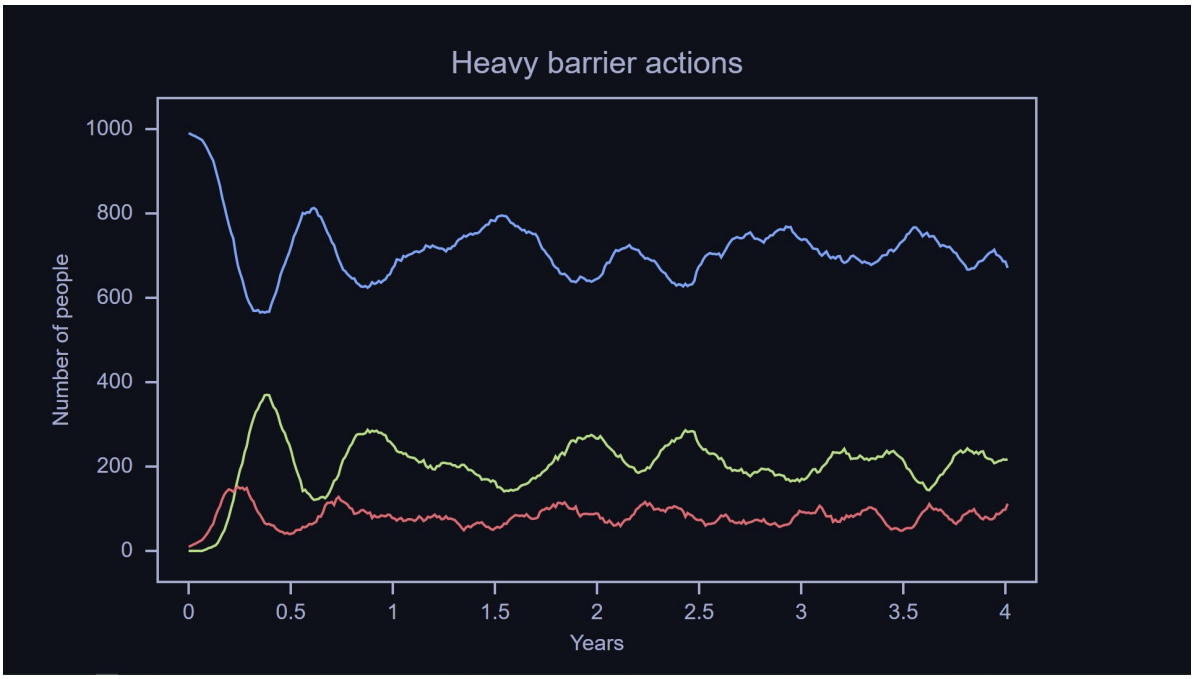
Light barrier actions



We can see in this simulation with light barrier gestures that there are now only **8** distinct peaks of **infected** agents and only the 1st (in the first half year) and the 5th (at year 2) peaks are above the limit of **20%** of the population with respectively **242** and **208** **infected** agents. This means that there are two **hospital overloads** with about two years of difference.

The **total number of infections** is **6297** which is **24%** less than without barrier actions.

Heavy barrier actions



We can see in this simulation with heavy barrier gestures that there are still two distinct peaks in the 1st year but then the number of **infected** agents stays between **48** and **116**. The number of **infected** agents never goes over **152** which means that there is no **hospital overload**.

The **total number of infections** also dropped to **4215** which is **49%** less than without barrier actions.

Conclusions

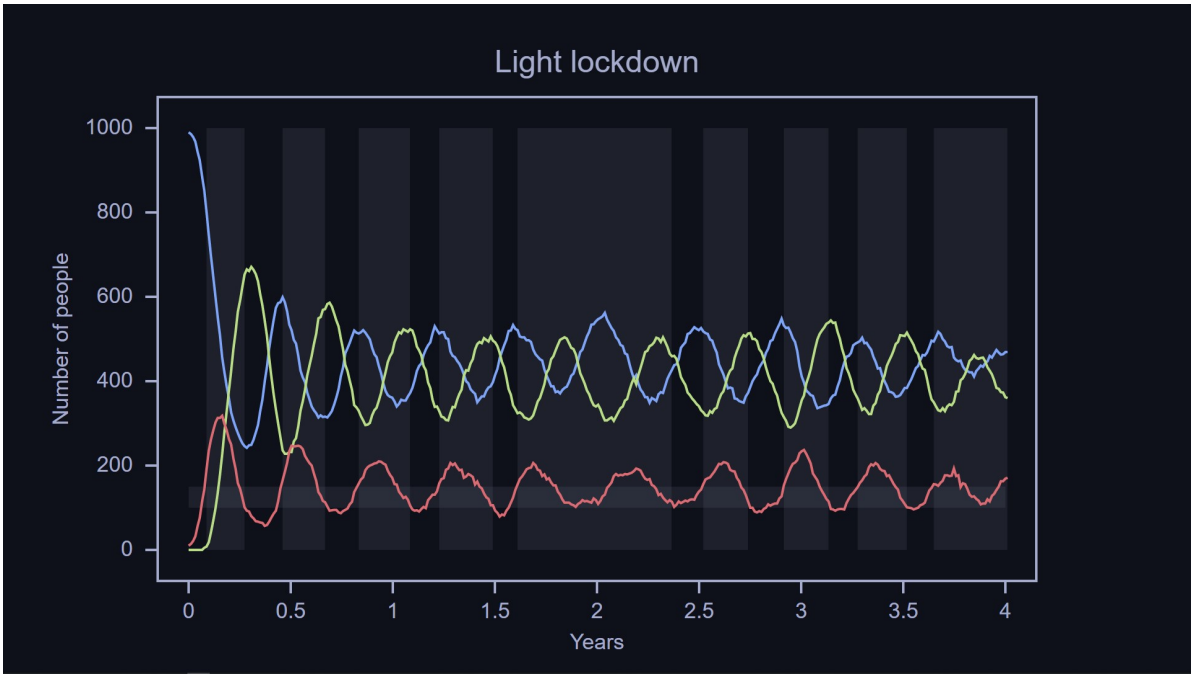
The disease could not be **eradicated** with barrier actions but it certainly helped a lot with limiting and even eliminating **hospital overload**. It has also helped to reduce the **total number of infections** by up to half.

Lockdown

The lockdown is the second measure we will simulate. The government tells people to stay at home and to avoid going out. Sometimes even a travel distance limit is imposed. To simulate the lockdown we will reduce the speed of the agents by **75%** in case of light lockdown and **90%** in case of strict lockdown.

The people can not be in lockdown forever so the government will impose a **lockdown** only if the number of **infected** agents is above **150** and cancel it of the number of **infected** agents goes back below **100** with a minimal delay of **14** days. These limits are shown on the graph by a horizontal rectangle and locked down periods are shown by vertical rectangles.

Light lockdown

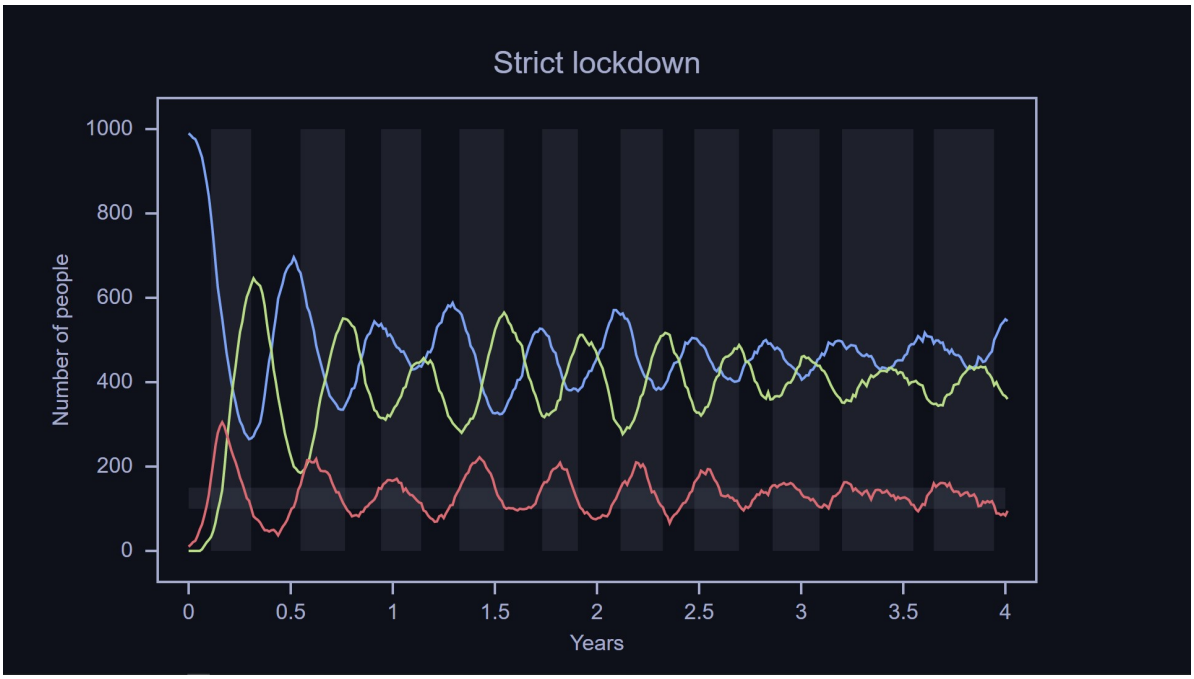


We can see in this simulation with light lockdown that there still **10** peaks of **infected** agents and all of them were above the lockdown limit. The 5^{th} and 6^{th} peaks were even in the same lockdown since the number of **infected** agents after the 5^{th} peak did not go below the lockdown limit before the 6^{th} peak (minimum of **102**). This means that there is a total of **9** lockdown periods.

There are **8** peaks of **infected** agents above the limit of **20%** of the population so for a peroid of 4 years, light lockdown only prevented two **hospital overloads**.

The **total number of infections** is **8208** which is only **1%** less than without lockdown.

Strict lockdown



We can see in this simulation with strict lockdown that there are **10** peaks that are all above the lockdown limit. This time the lock down is efficient enough to drag all peaks down below the lockdown limit before the next one.

Out of **10** peaks there are **5** peaks only above the **20%** limit of the population. This means that strict lockdown could prevent **5 hospital overloads**.

The **total number of infections** is **7872** which is **5%** less than without lockdown.

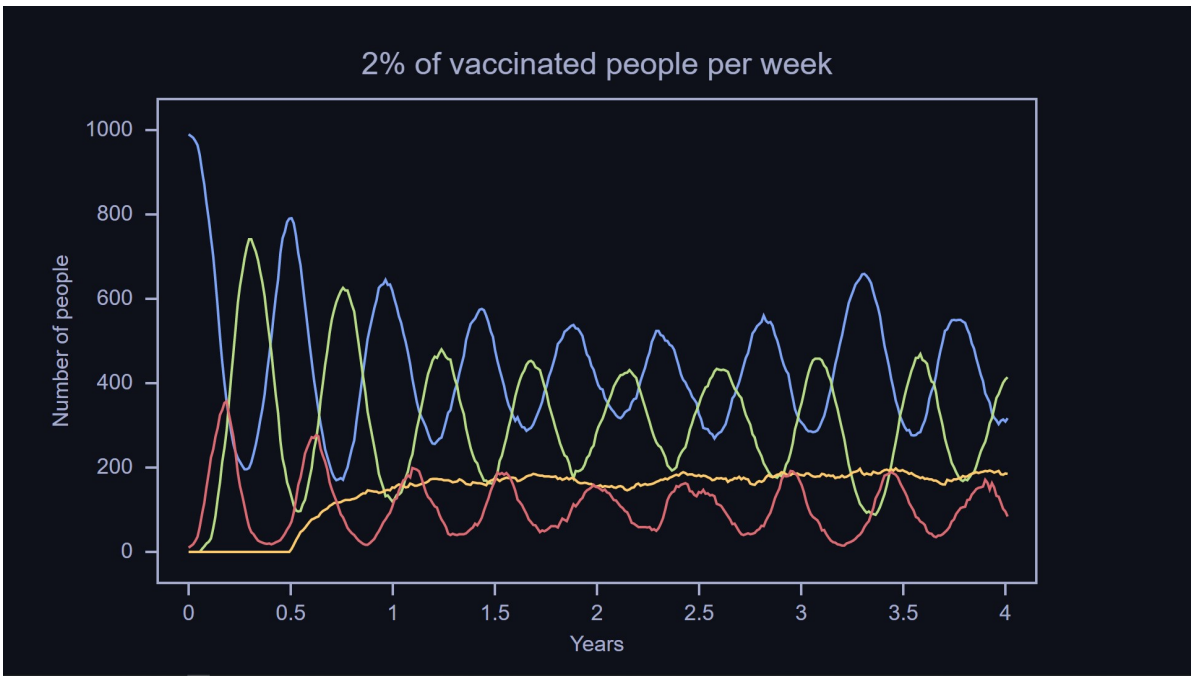
Conclusions

Lock down are effective to limit the number of **hospital overloads** but they are not effective to prevent the **total number of infections**. The fact that the lockdown stops below a number of **100 infected** agents makes it impossible to **eradicate** the disease.

Vaccination

In case of the appearance of a new disease, the government can also work hard to elaborate a vaccine and make a vaccination campaign. After 6 months, **susceptible** agents will start to get vaccinated. The probability of getting vaccinated is calculated from the percentage of **susceptible** agents the campaign targets to vaccinate in a week.

Simulation with 2% of vaccinated people per week



We can se the number of **vaccinated** agents starts to increase after 6 months and stabilizes around **174** one year after the beginning of the disease. Obviously the first 6 months of the simulation are not different from the initial situation but the vaccine campaign allows to prevent the number of **infected** agents to go over **199**, right at the limit of **20%** of the population. This means that after 6 months of a 2% vaccination campaign, there are no longer **hospital overloads**.

The **total number of infections** is **6358** which is **23%** less than without vaccination but not enough to **eradicate** the disease.

Comparing different vaccination campaigns

To see how the percentage of vaccinated people per week affects the disease and helps us to reach the different goals we can compare the simulation with different vaccination campaigns:

Campaign	Hospital overloads	Total infections	Eradication
0%	10	8285	No
1%	9	7202 (-13%)	No
2%	2	6358 (-23%)	No
3%	2	5945 (-28%)	No
4%	2	4752 (-42%)	No
5%	2	3905 (-53%)	No

We can see that from **2%** of vaccinated people per week the number of **hospital overloads** remains at **2** because the campaign is enough to prevent them but only after a year of simulation so the first 2 peaks are not affected by the vaccination campaign.

The vaccine drastically reduces the number of **infected** agents with up to **53%** less of **total infections**. This means that the vaccine campaign is effective to prevent the disease but it is not enough to **eradicate** it.

Combining different measures

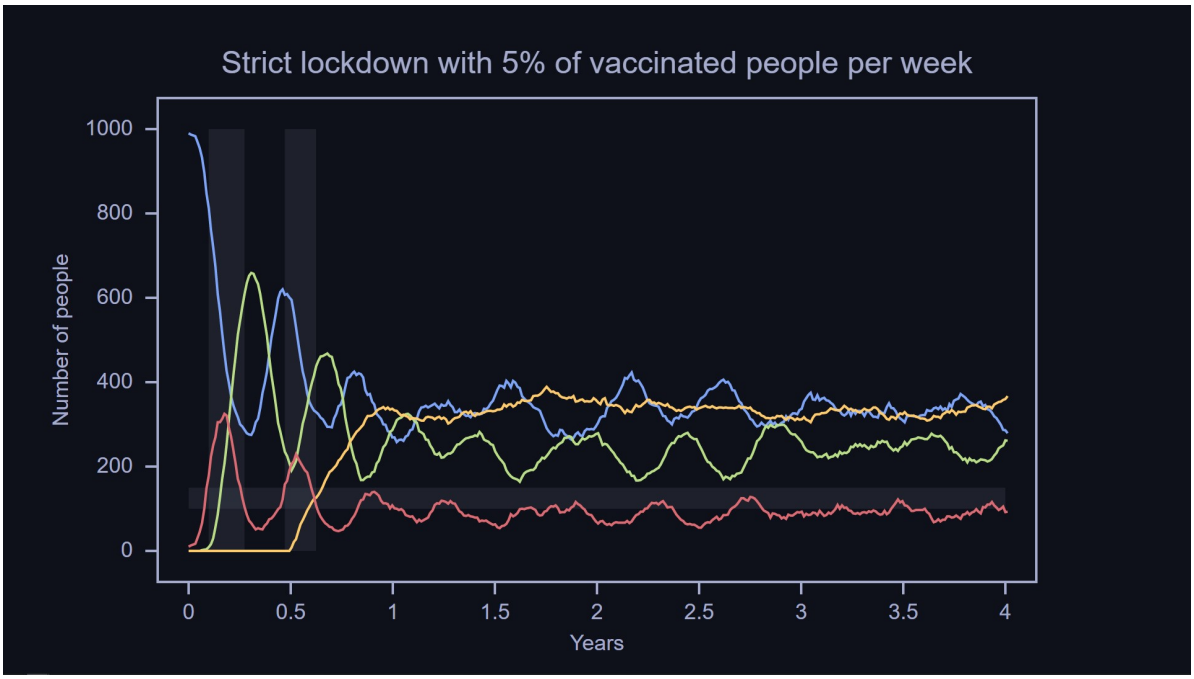
Using only one measure at a time is not enough to reach all goals. We will try to combine different measures in order to do so.

Barrier actions and lockdown

As heavy barrier actions were effective enough to prevent them, combining them with lockdown (which happened only on the 1st peak) does not change anything about **hospital overloads** that are still **0**.

The **total number of infections** is **3126** which is **62%** less than without sanitary measures. No **eradication** yet.

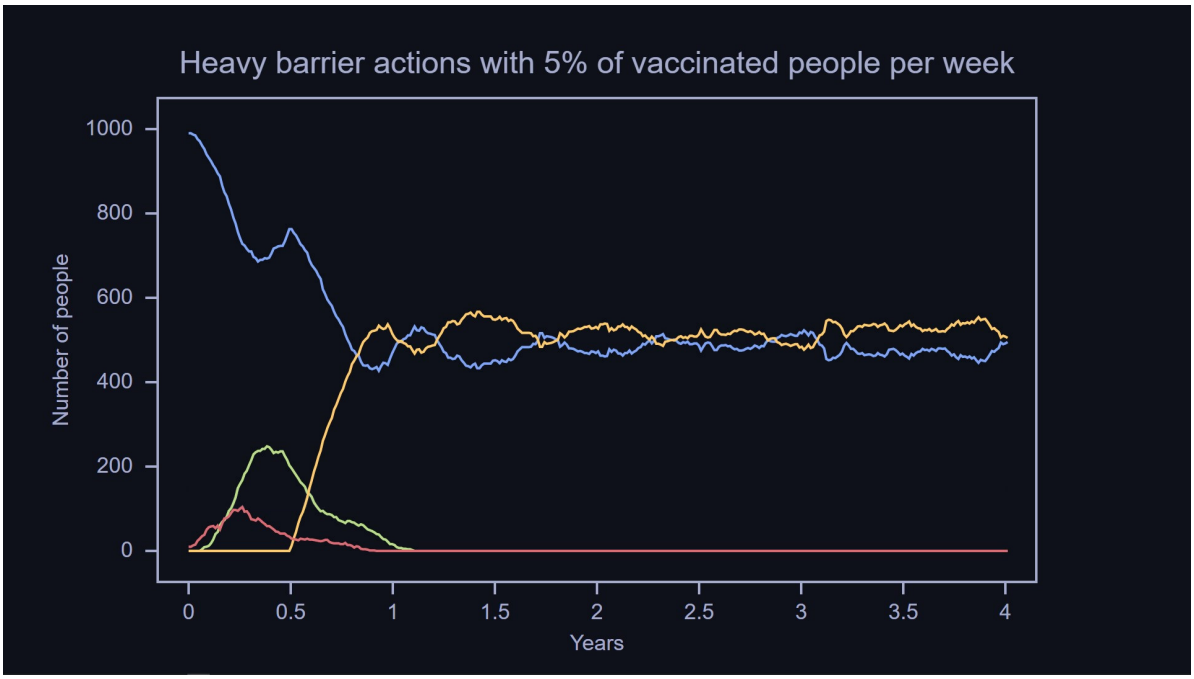
Vaccination and lockdown



The issue with the vaccine campaign is that it only starts after 6 months of simulation so the first 2 peaks are not affected by the vaccination campaign. The lockdown helps it by reducing the number of **infected** agents from **336** to **325** in the first peak but this is far from enough to prevent **hospital overloads**.

The **total number of infections** is **5244** which is **37%** less than without sanitary measures. No **eradication** yet.

Barrier actions and vaccination



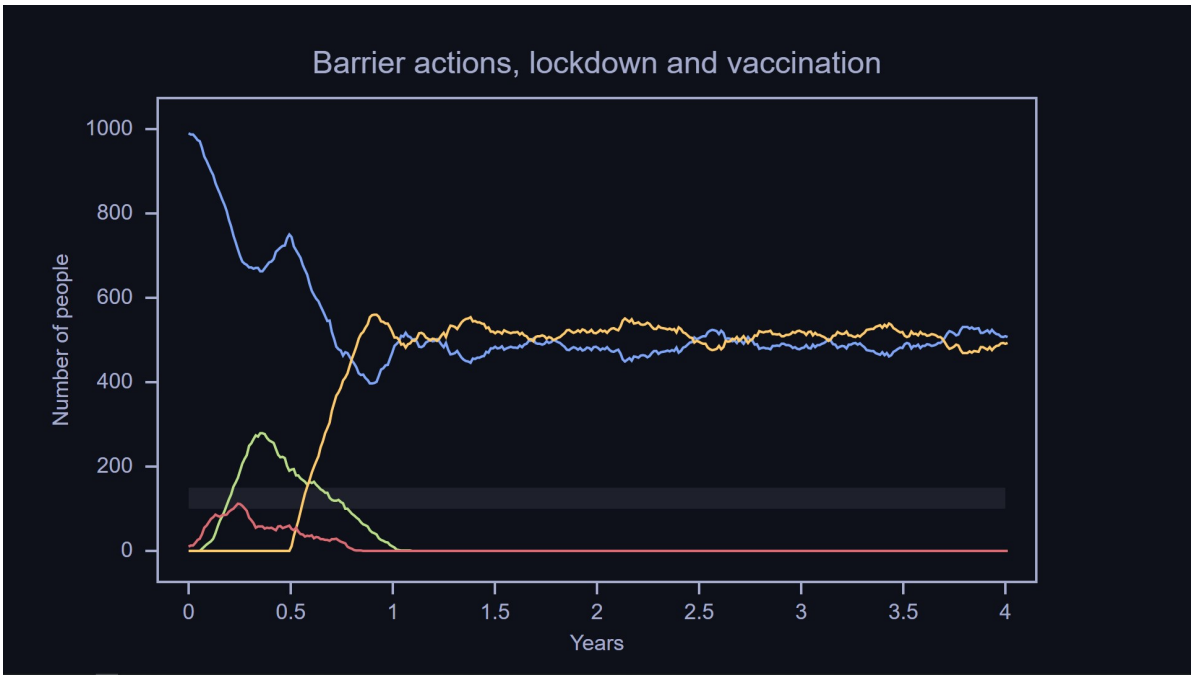
This time the problem about the vaccine campaign starting after 6 months is solved by the barrier actions. The barrier actions are effective enough to prevent the **hospital overloads** on its own as soon as the simulation starts.

It may sound not so effective to combine the two since barrier actions on their own prevent **hospital overloads** but it really does something other combinations do not do: It lowers the contamination so much that the disease is **eradicated** after less than a year of simulation.

Since the contamination was reduced by both measures, and the disease is **eradicated** really soon, the **total number of infections** is naturally really low at **534** which is **93%** less than without sanitary measures.

We can consider this combination as a solution to our goals.

Combining all measures



As the combination of barrier actions and vaccination lowers the contamination enough to never reach the limit of **150** **infected** agents, lockdown are never imposed by the government. The result is the same as combining the barrier actions and vaccination only with no **hospital overloads**, a **total number of infections** of **607** and the **eradication** of the disease in less than a year.

Conclusion

The combination of different sanitary measures taken by the government can be used to reach the goals. The combination of barrier actions and vaccination is the most effective combination to reach all the goals and makes the lockdown unnecessary. This is not really the same as in real life conditions where lockdowns are more effective. This difference is due to the model we used. Even if the agents move 90% slower, a lot of them touch each other and the virus still spreads faster than with a real life lockdown.

Most diseases are not totaly non-lethal. Even a cold can be lethal in rare cases. It would be intersting to see a similar model with a mortality rate. For instance a disease with a short period of contagiousness and a high mortality rate would act like the black plague and eradicate itself because of the number of deaths. It would be interesting to see how sanitary measures could have helped with this epidemic.