Institute of Smart Systems and Artificial Intelligence

NAZARBAYEV UNIVERSITY

COVID-19 Simulator for Kazakhstan
Part 4 – Simulations for Developing Strategies

Prof. H. Atakan Varol

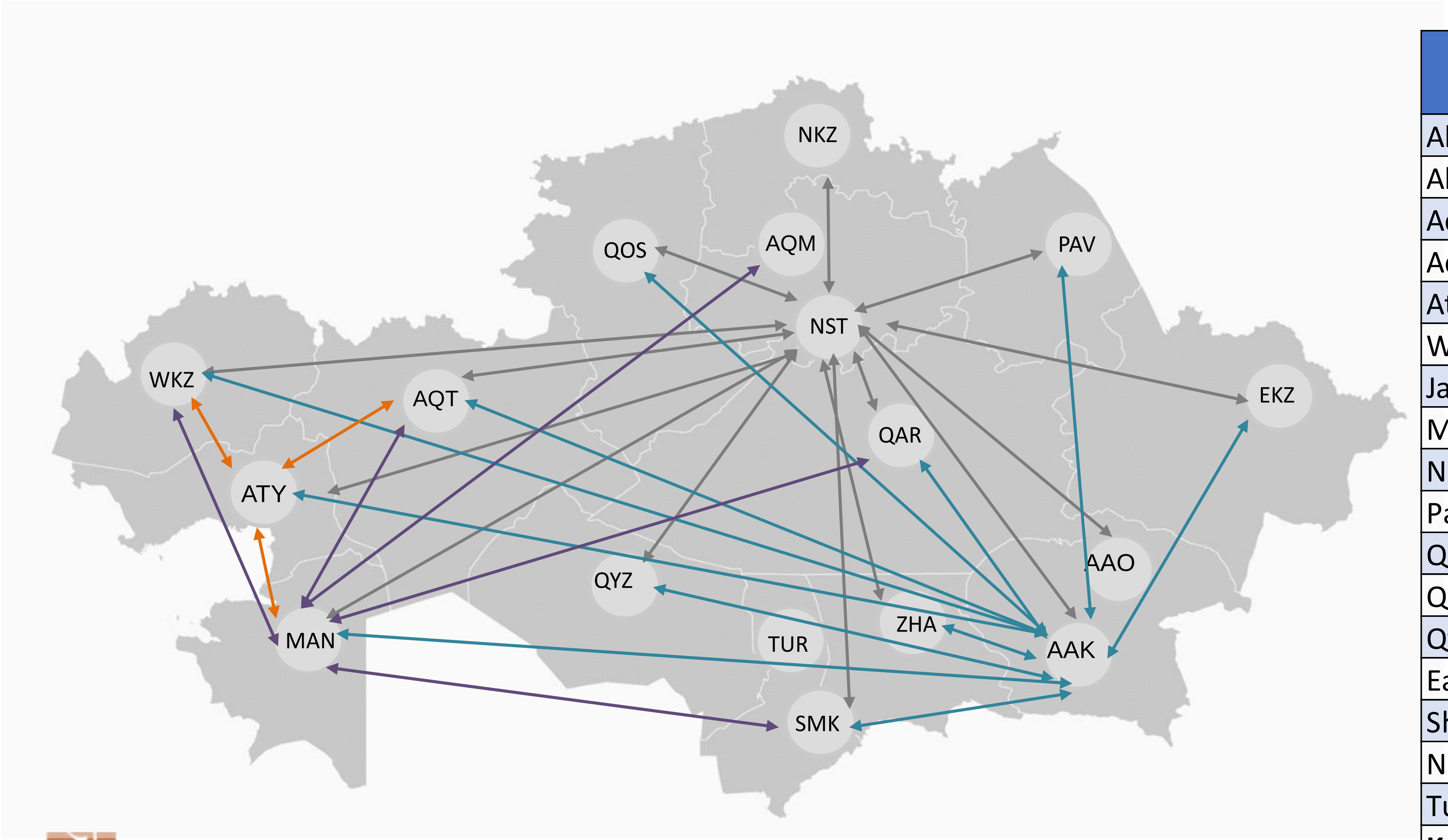
Founding Director of ISSAI

6 April 2020

ahvarol@nu.edu.kz, issai.nu.edu.kz/episim

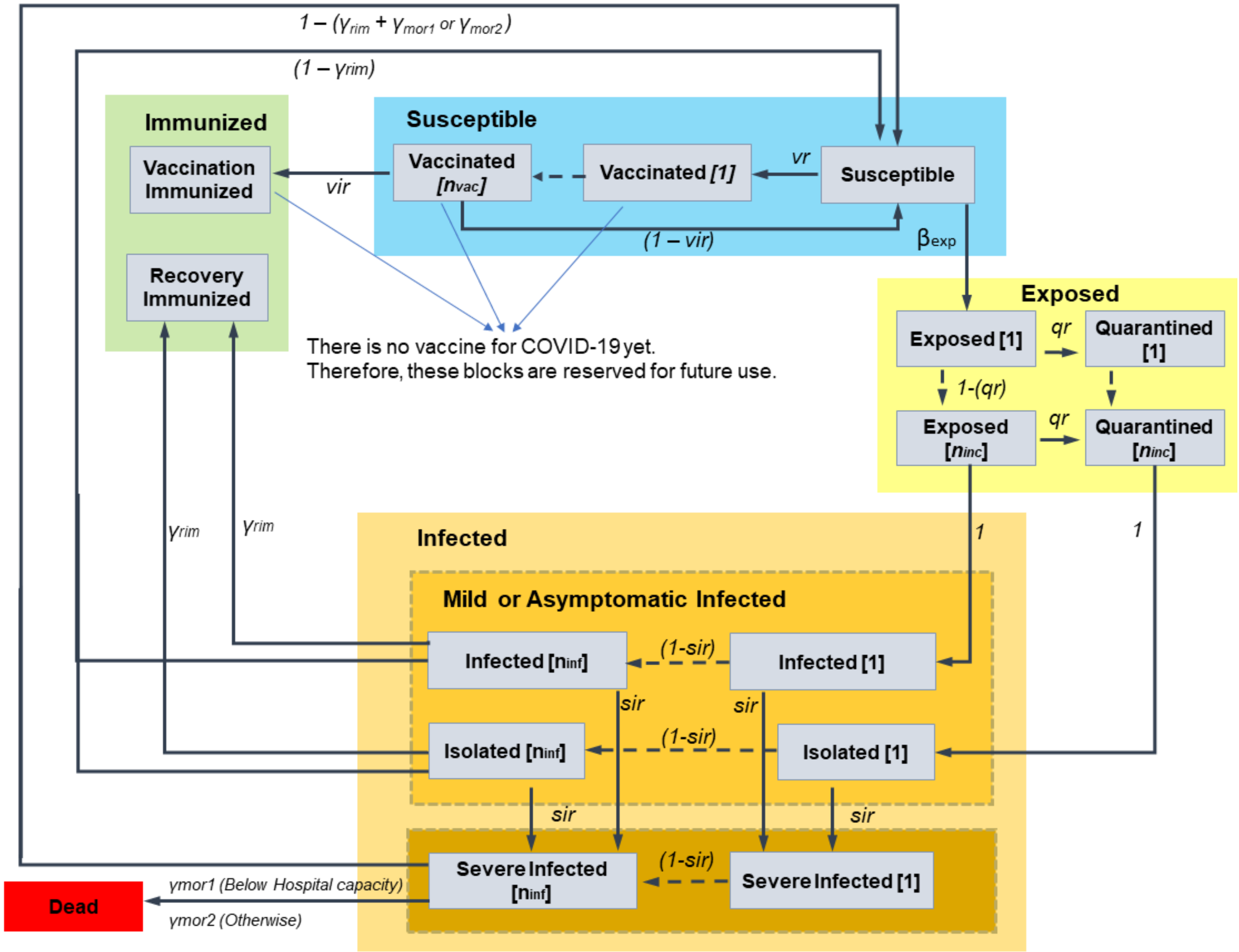
Team: Askat Kuzdeuov, Daulet Baimukashev, Mukhamet Nurpeiissov, Aknur Karabay, Bauyrzhan Ibragimov, and Almas Mirzakhmetov

Recap: Network-Based Epidemic Simulation



Administrative Region	Population
Almaty	2039376
Almaty Qalasy	1854556
Aqmola	738587
Aqtobe	869603
Atyrau	633801
West Kazakhstan	652314
Jambyl	1125297
Mangystau	678224
Nur-sultan	1078362
Pavlodar	753804
Qaragandy	1378554
Qostanai	872736
Qyzylorda	794165
East Kazakhstan	1378504
Shymkent	1011511
North Kazakhstan	554519
Turkistan	1981747
Kazakhstan	**18395660**

Recap: Stochastic Epidemic Node Simulator



Epidemic Control as an Optimization Problem

- Ingredients of the Epidemic Mitigation/Suppression Problem:

  - **An epidemic model** that can closely project future trajectories of system states (number of infected, exposed, susceptible, death,…) based on inputs.
  - **Inputs** (Actions, measures):
    - Transmission rates (beta values) for each region. This value will change based on the taken measures such as lockdown or social isolation.
    - Quarantine rate of the Exposed for each region
    - Vaccination rate for each region (no vaccine yet available, reserved for future use)
    - Disconnecting/reconnecting some of the edges of the network
  - **Cost Function**: A function which determines the quality of the epidemic response based on the measures.
  - **Optimizer** which minimizes the cost function
    - A graduate student who tries different parameters using his/her insight
    - A classical optimization theory algorithm
    - An artificial intelligence algorithm

The hardest part is to find the cost function.

Why is the Cost Function Hard to Find?

1. **Narrow Domain of the Epidemiological Model:**
   - An epidemiological simulator only models the dynamics of the disease. It does not consider the effects on the economy and other problems of the society due to the measures taken.

2. **Human Life is Priceless:**
   - It is very hard to quantify the value of a human life versus the hardships due to measures taken to control the epidemic.
   - Indeed, it is even very hard to quantify the cost of the deaths of different persons.
   - For instance, in our model, the death of a 5-year old is the same as the death of an 83-year-old person.
   - A 5-year old child has 80 years of remaining life expectancy versus the two years remaining life expectancy of an 83-year old.

3. **Uncertainty About Future Events**
   - The virus might mutate to a more deadly form.
   - A miracle drug or vaccine might be introduced.
   - Unfortunately, we don't know the dates and probabilities of such events.

What Will We Do?

Develop Different Scenarios, Simulate Them, and Assess Their Results with Human Reasoning for Deciding the Best Strategy.

Strategy 1
Complete Lockdown Until the Epidemic is Over

- We might continue the present emergency state in the country until the epidemic is over (staying at home except for essentials, online work, online education, no travel, no shopping centers, no sport/cultural events).

- Even under these circumstances, there will be some interaction between people (e.g. healthcare workers, law enforcement, basic utilities, grocery stores, critical facilities).

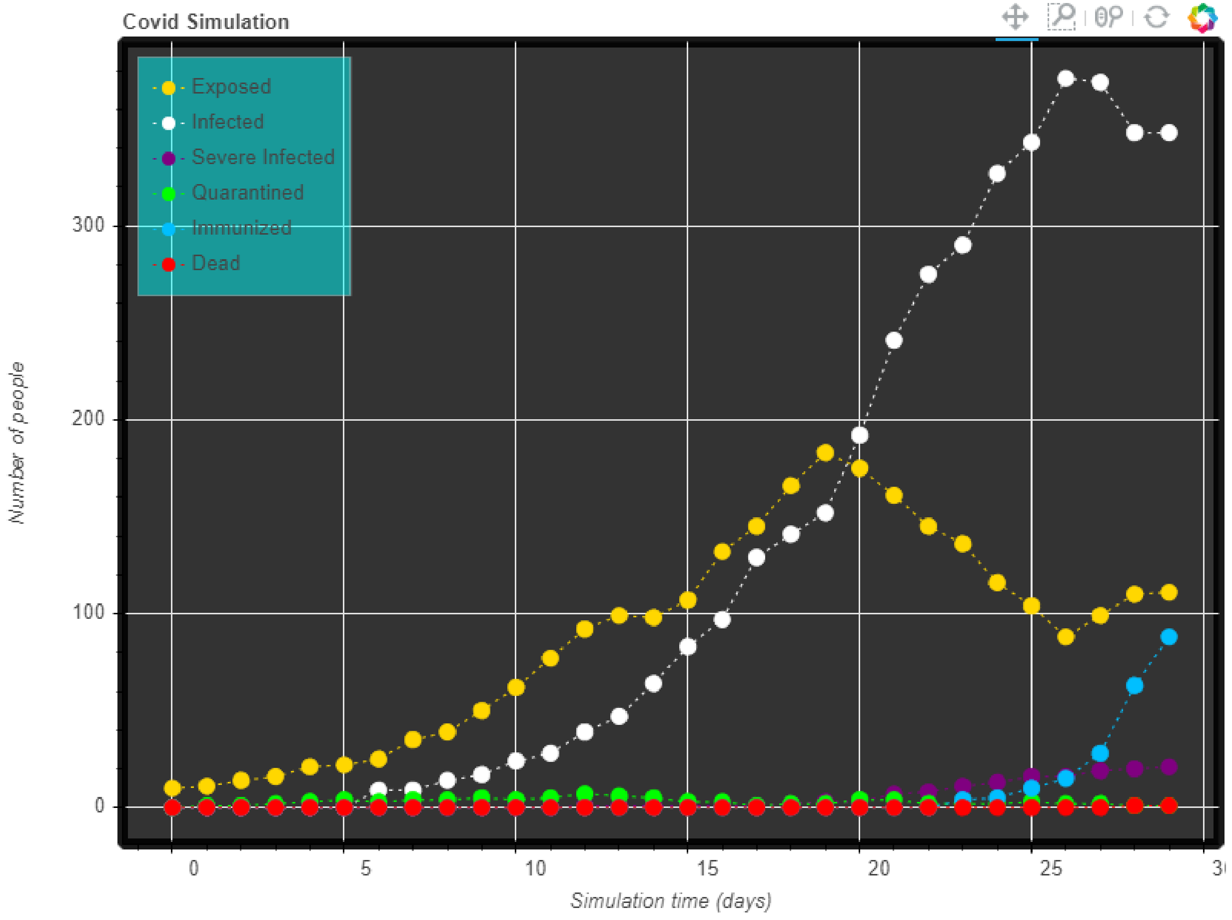
- Assuming beta can be decreased to 0.03, our simulations indicate that the epidemic will **last till the end of November 2020 in Kazakhstan with 37 total COVID-19 related deaths.**

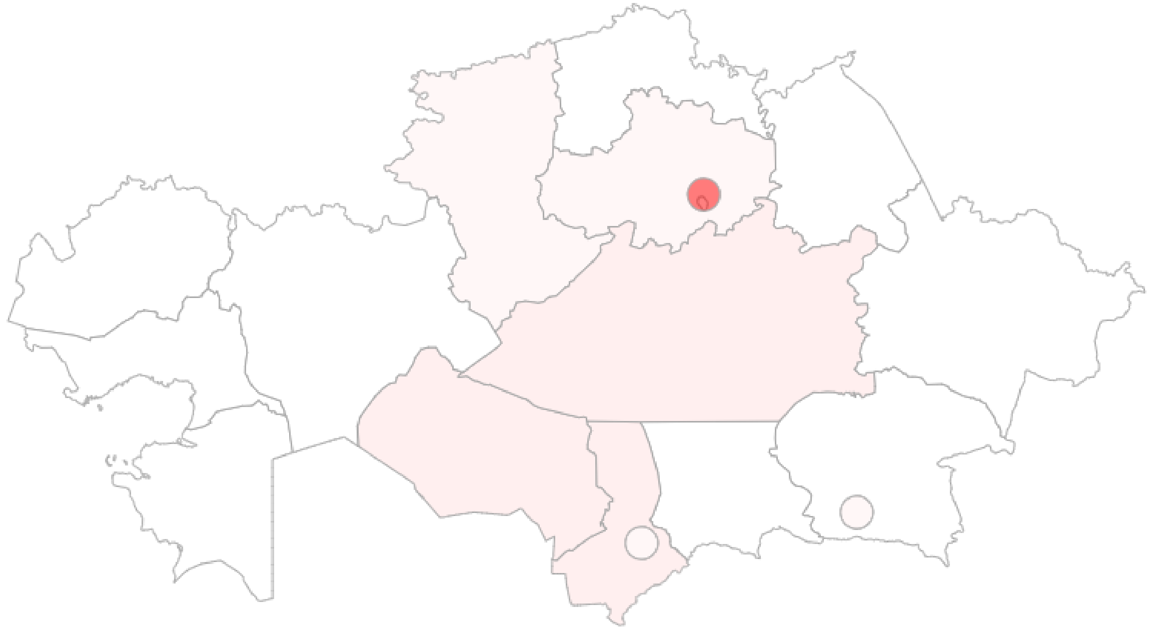
- The cost to the society might be extreme:
  - Economic problems: Unemployment, contraction of the economy, inflation…
  - Health problems: Psychological issues and higher suicides due to isolation, increased marital violence and divorce, other health issues due to the sedentary lifestyle…

- Another risk is the lack of herd immunity. Once the international travel starts again, the disease will start with high likelihood again.

Simulation Results for Scenario 1 – 30 March 2020

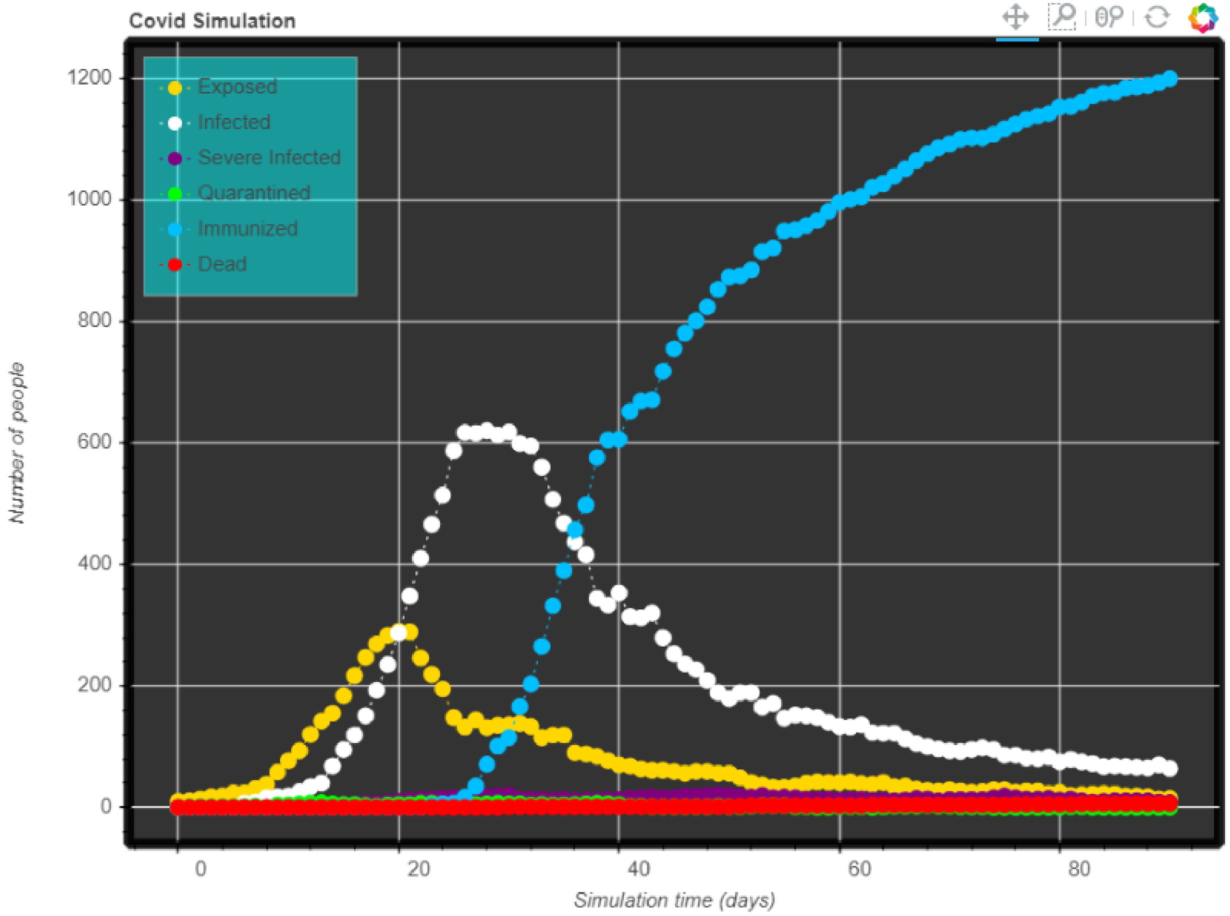
Nur-Sultan	Quarantined 1	Infected 348	Exposed 111	Severe Infected 21	Immunized 88	Death 1	Susceptible 1077655	Start date: 01 Mar 2020
Kazakhstan	Quarantined 9	Infected 1059	Exposed 350	Severe Infected 54	Immunized 241	Death 3	Susceptible 18393967	Current date: 30 Mar 2020

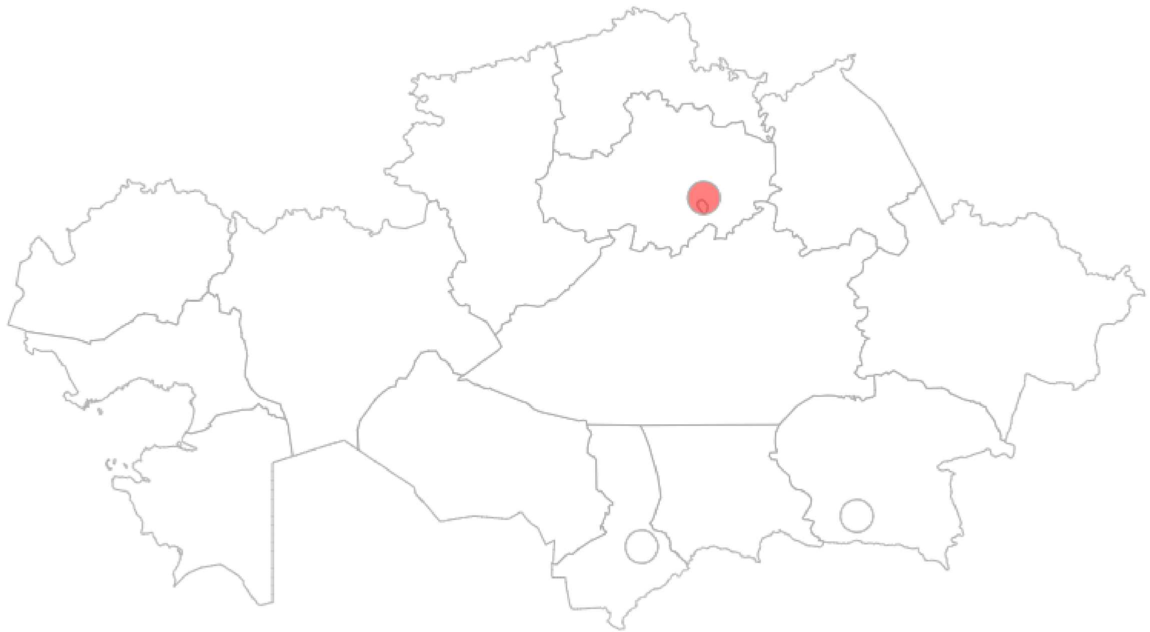




Simulation Results for Scenario 1 – 30 May 2020

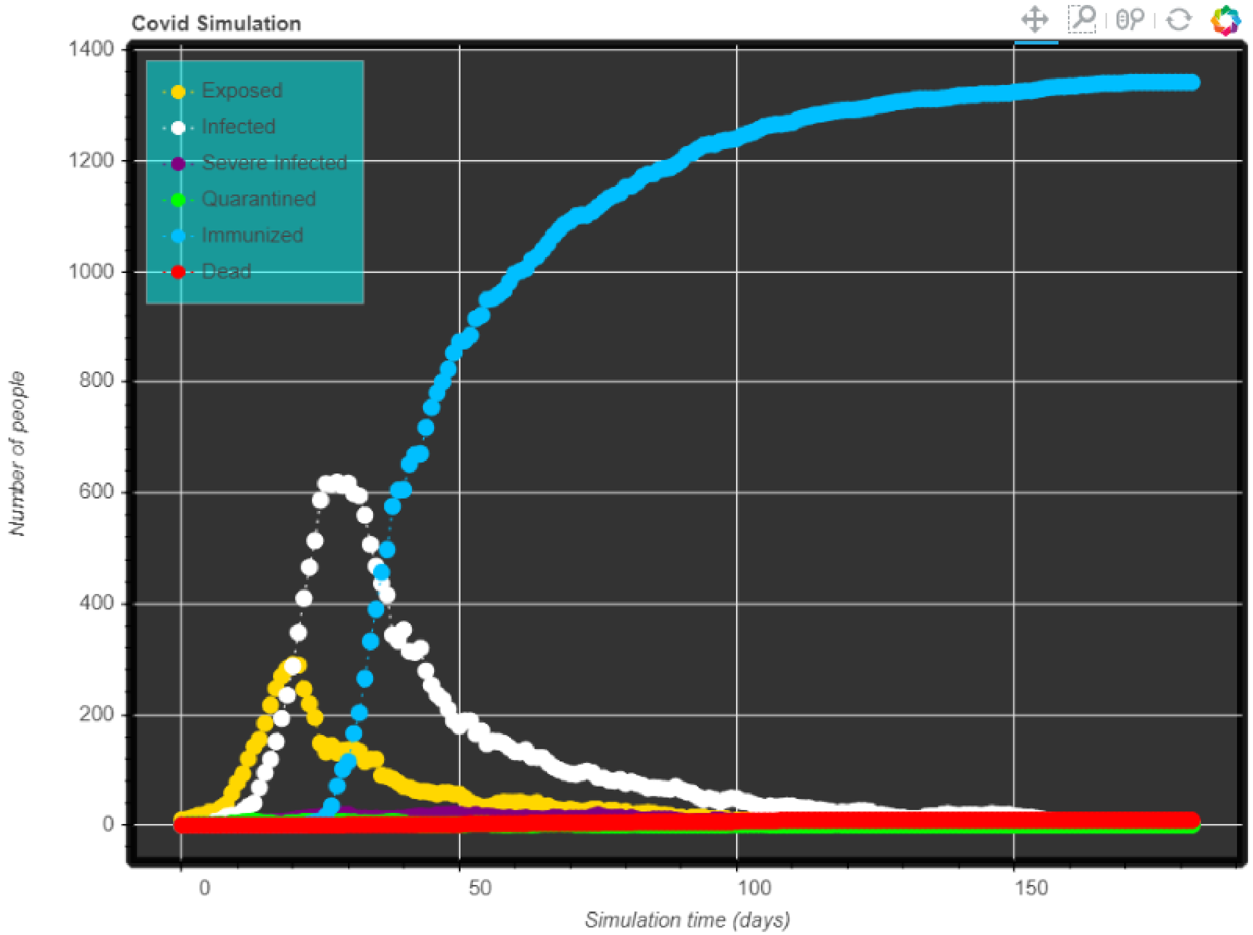
Nur-Sultan	Quarantined 0	Infected 64	Exposed 15	Severe Infected 8	Immunized 1200	Death 6	Susceptible 1076937	Start date: 01 Mar 2020
Kazakhstan	Quarantined 0	Infected 154	Exposed 38	Severe Infected 22	Immunized 2561	Death 26	Susceptible 18392882	Current date: 30 May 2020

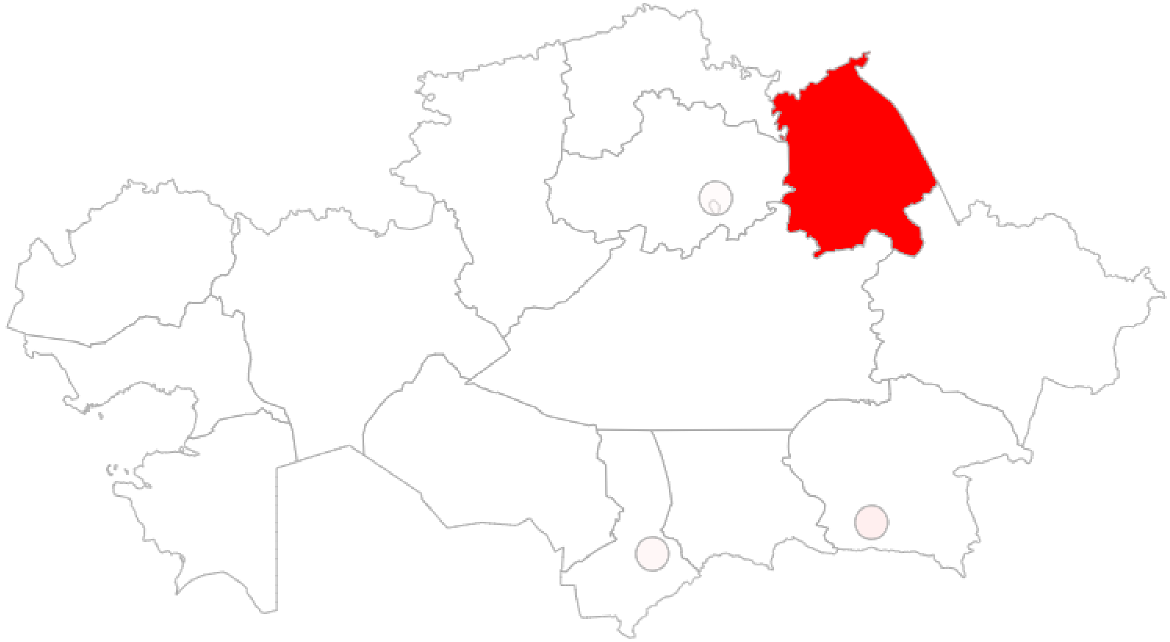




Simulation Results for Scenario 1 – 30 August 2020

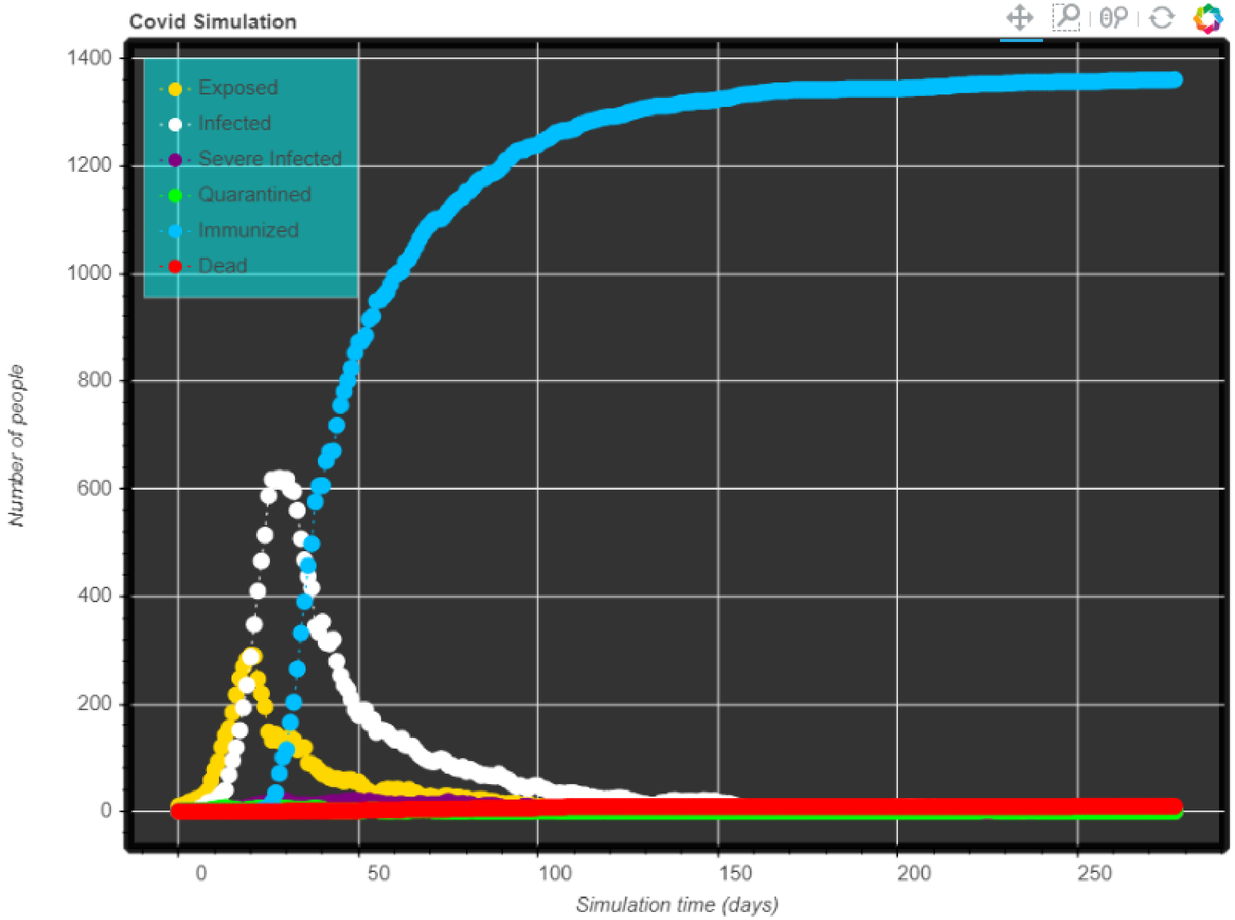
Nur-Sultan	Quarantined 0	Infected 3	Exposed 2	Severe Infected 0	Immunized 1342	Death 9	Susceptible 1076874	Start date: 01 Mar 2020
Kazakhstan	Quarantined 0	Infected 16	Exposed 5	Severe Infected 0	Immunized 2915	Death 36	Susceptible 18392711	Current date: 30 Aug 2020

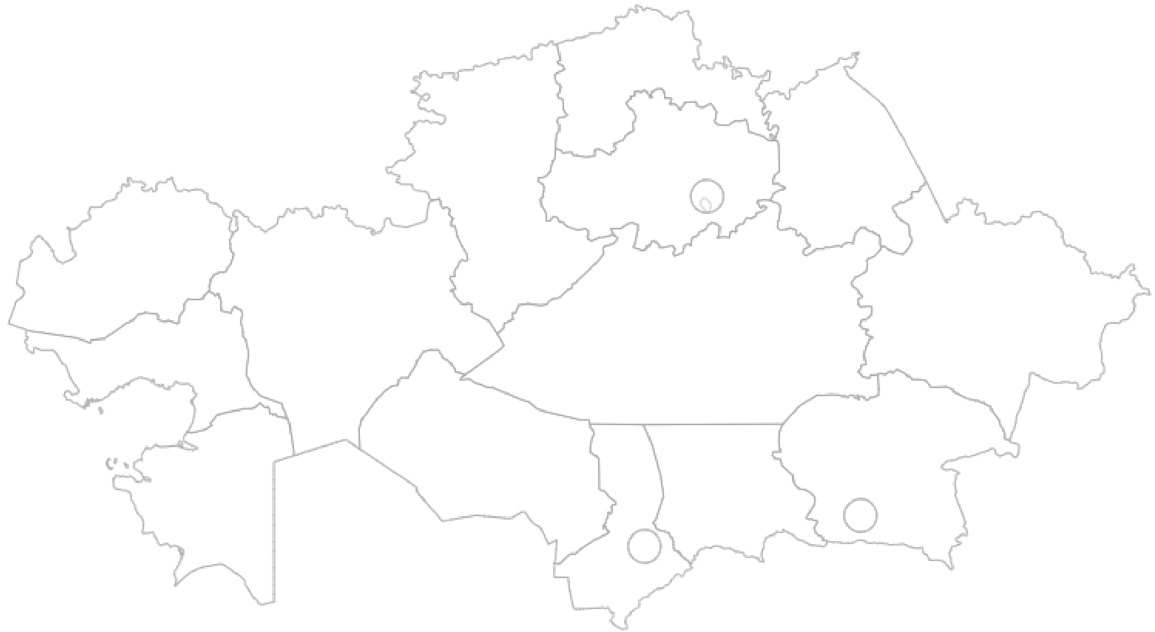




Simulation Results for Scenario 1 – 3 December 2020

Nur-Sultan	Quarantined 0	Infected 0	Exposed 0	Severe Infected 0	Immunized 1361	Death 10	Susceptible 1076859	Start date: 01 Mar 2020
Kazakhstan	Quarantined 0	Infected 0	Exposed 0	Severe Infected 0	Immunized 2959	Death 37	Susceptible 18392687	Current date: 03 Dec 2020





Strategy 2
Go Back to Normal and Hope Things Will Be Fine.

- Let us assume that the present emergency state ends in the country on 14 April 2020.

- We go back to our daily lives. We wash our hands more frequently and do some voluntary social distancing (slightly reduced beta values compared to the original).

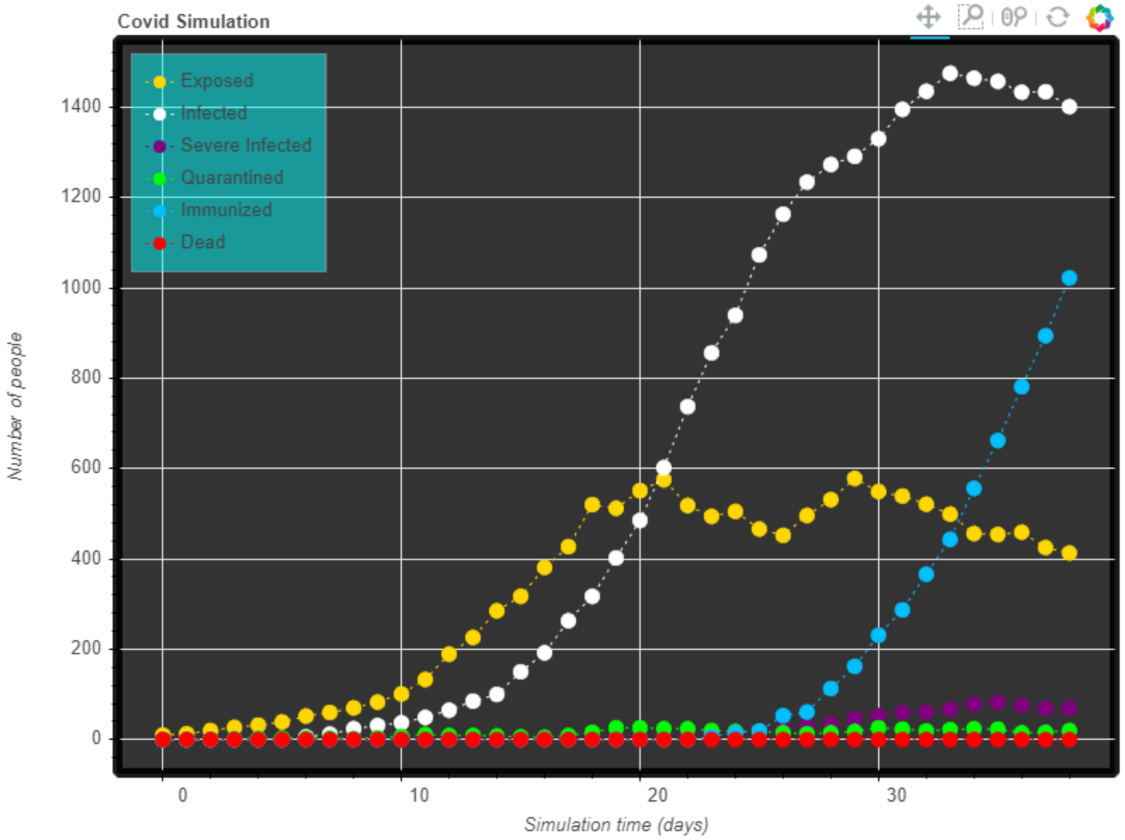
- Our simulations indicate that if we relax the measures after the extreme state, the exponential rise of the epidemic starts again.

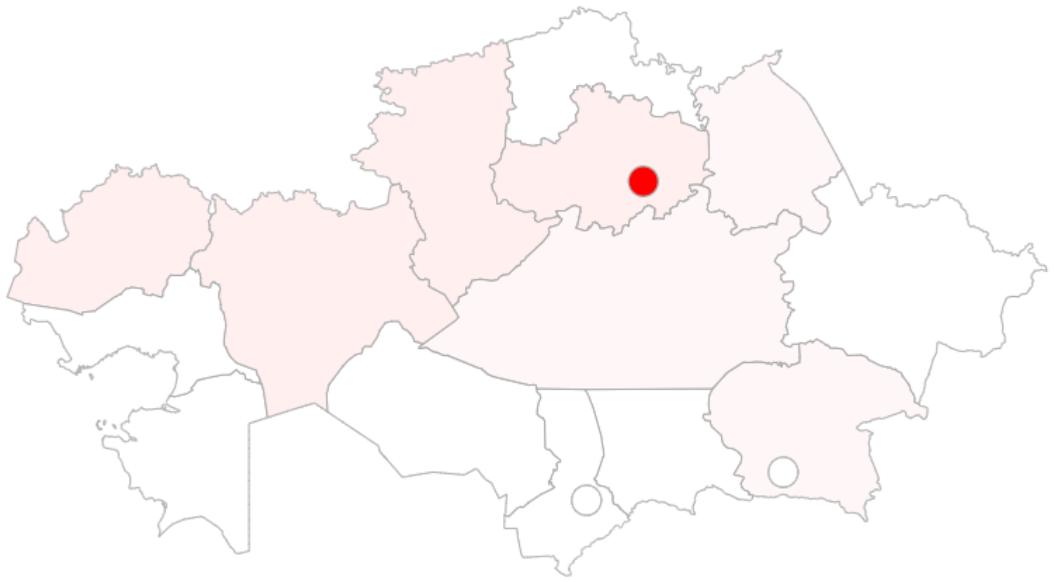
Scenario 2 – 8 April

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Qaragandy	Quarantined 2	Infected 203	Exposed 76	Severe Infected 8	Immunized 20	Death 1	Susceptible 1378109	Start date: 01 Mar 2020
Kazakhstan	Quarantined 54	Infected 3725	Exposed 1215	Severe Infected 209	Immunized 2288	Death 6	Susceptible 18388186	Current date: 08 Apr 2020



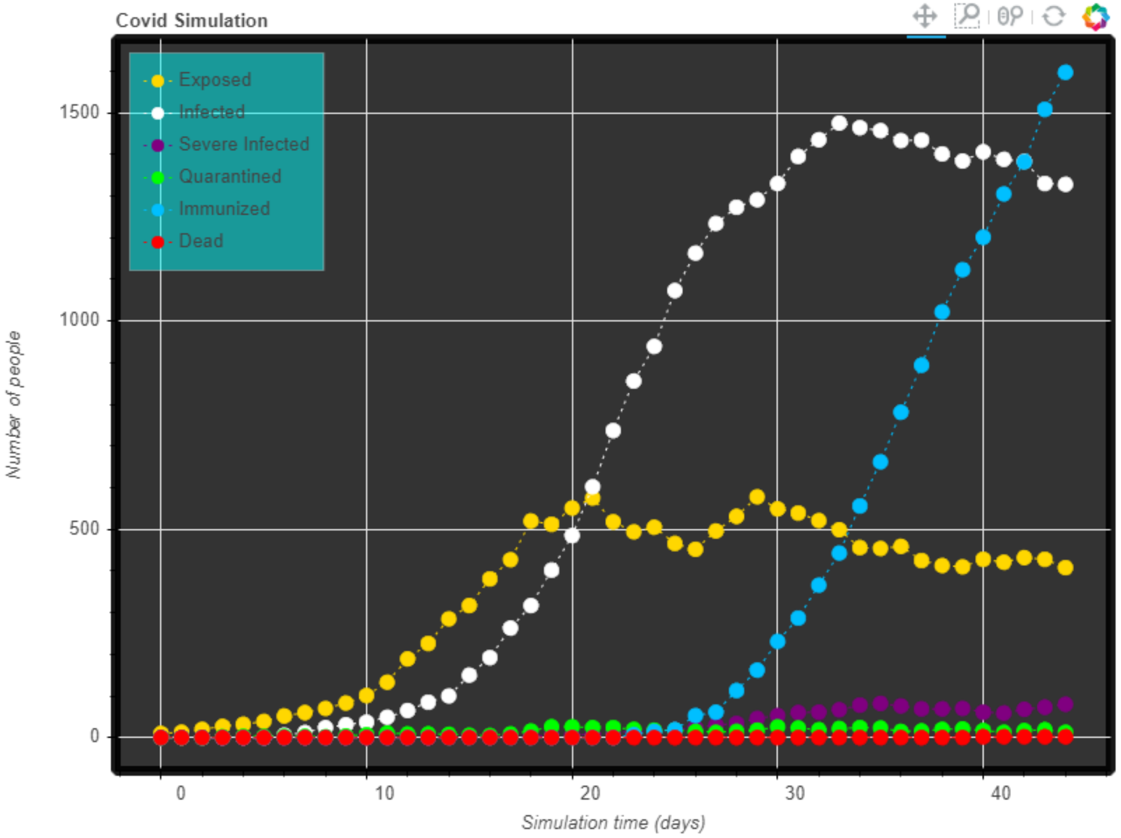


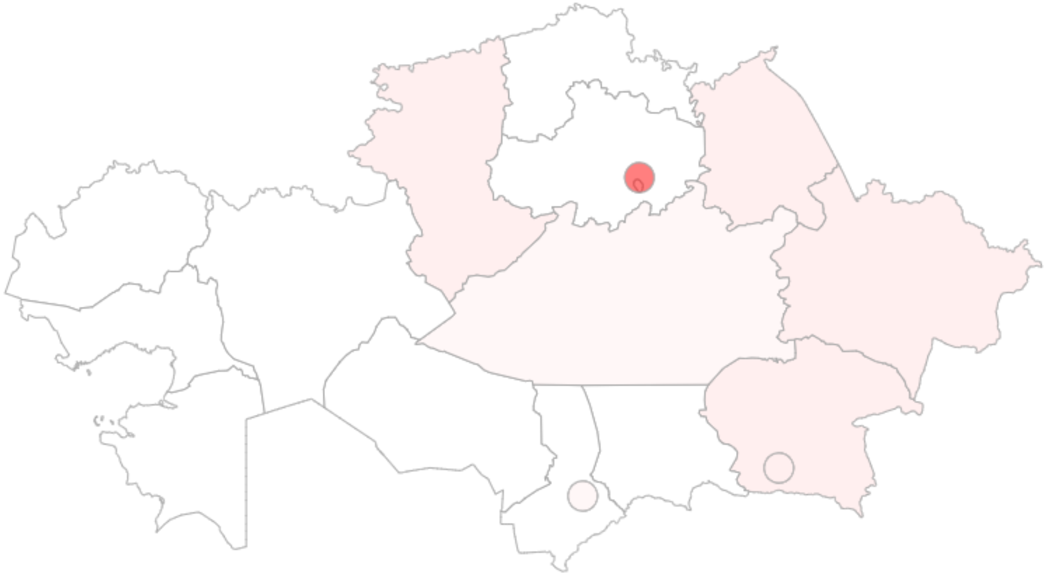
Scenario 2 – 14 April

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 13	Infected 1328	Exposed 408	Severe Infected 80	Immunized 1597	Death 2	Susceptible 1074794	Start date: 01 Mar 2020
Kazakhstan	Quarantined 46	Infected 3678	Exposed 1178	Severe Infected 210	Immunized 3778	Death 16	Susceptible 18386777	Current date: 14 Apr 2020



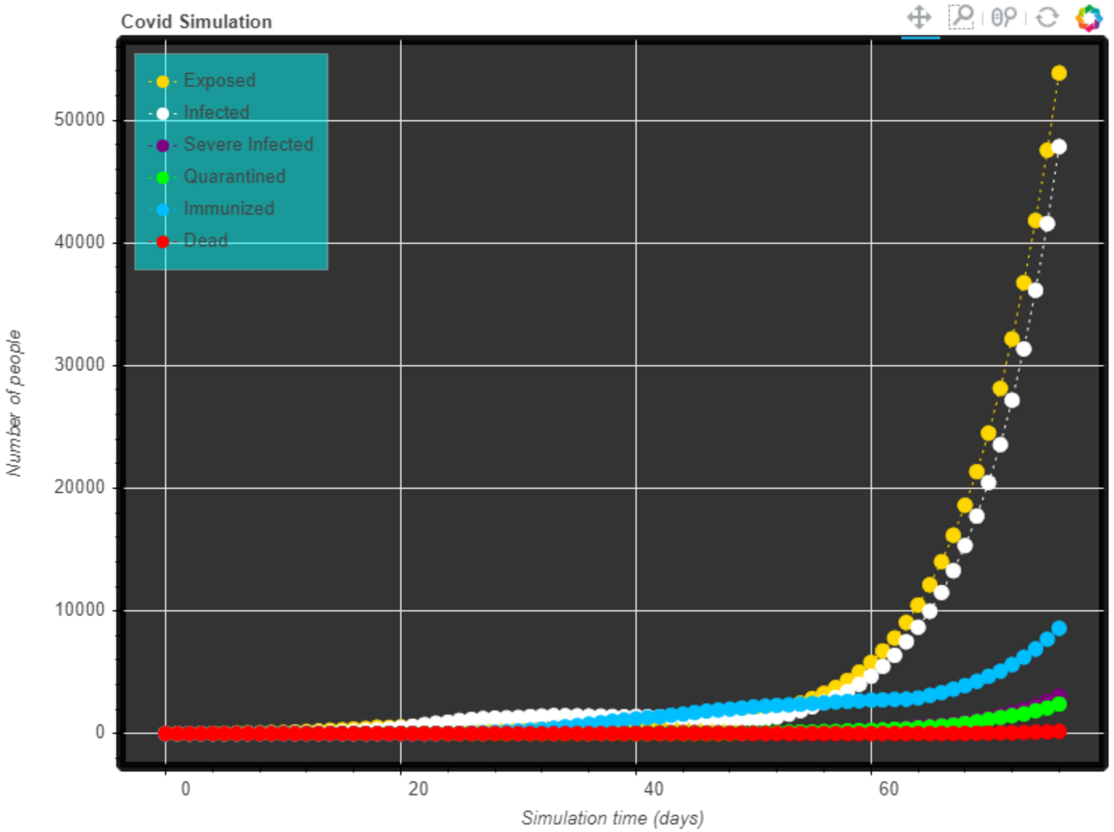


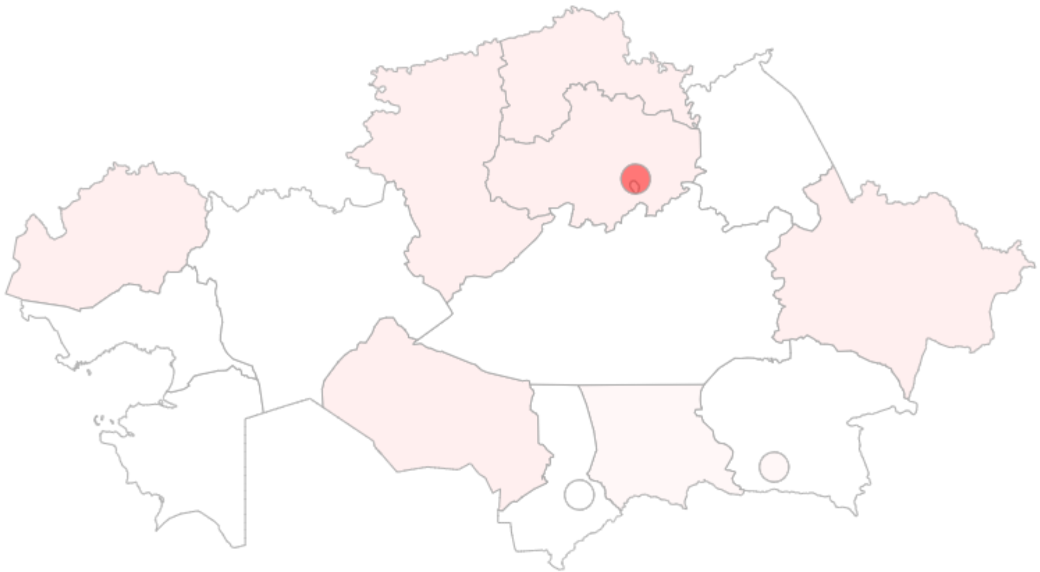
Scenario 2 – 16 May

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 2414	Infected 47843	Exposed 53844	Severe Infected 3053	Immunized 8592	Death 186	Susceptible 962474	Start date: 01 Mar 2020
Kazakhstan	Quarantined 10851	Infected 204342	Exposed 241878	Severe Infected 11746	Immunized 33217	Death 480	Susceptible 17893169	Current date: 16 May 2020



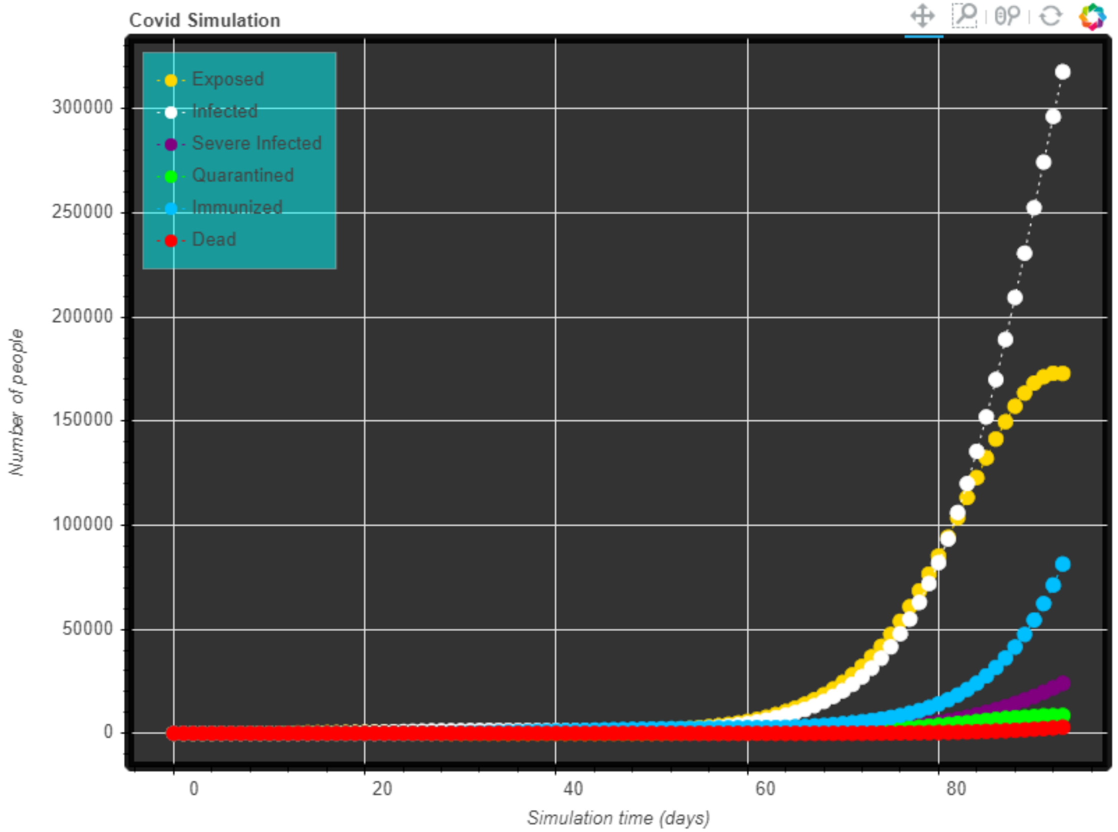


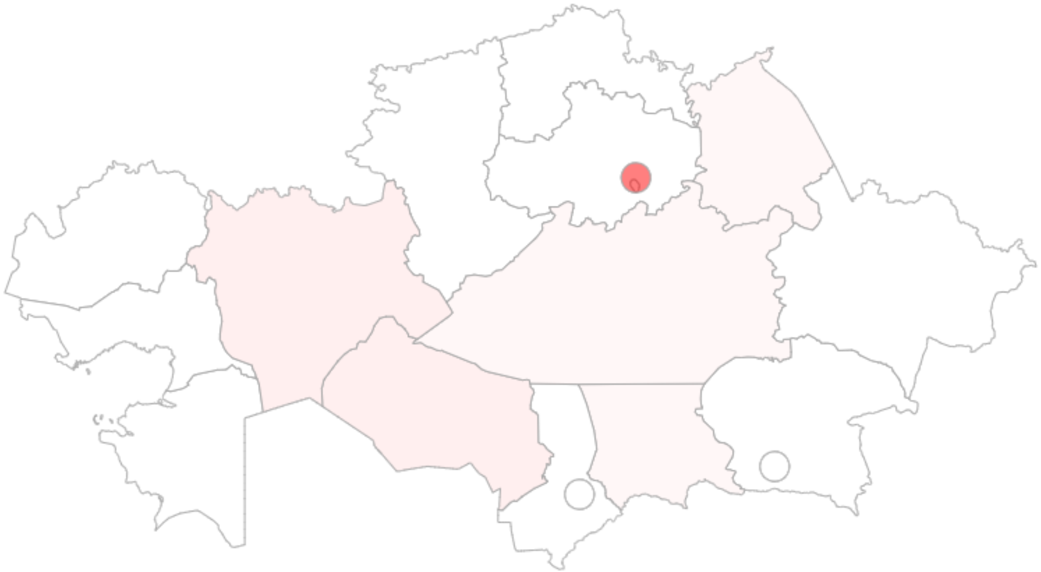
Scenario 2 – 2 June

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 8594	Infected 317750	Exposed 172852	Severe Infected 24038	Immunized 81330	Death 3003	Susceptible 474297	Start date: 01 Mar 2020
Kazakhstan	Quarantined 80060	Infected 2106516	Exposed 1714781	Severe Infected 140761	Immunized 409390	Death 13365	Susceptible 13930810	Current date: 02 Jun 2020





Strategy 3
Prepare and Create the New Normal

- If it is not possible to continue the extreme measures for many months and if we don't want very high number of COVID-19 related deaths, we should adopt a hybrid strategy.

- Let us assume that we prepare and start the "new normal" on 14 April 2020.

- The objective is to enable the society operate as normal as possible while minimizing the number of COVID-19 related deaths (like the present case in South Korea and Taiwan)

- While living in the **new normal** condition, one of the following developments might happen:
    - A new therapy which decreases mortality rate
    - A new vaccine which enables vaccination immunization
    - Reduced transmission of COVID-19 due the higher temperature and humidity of the Summer.

Strategy 3
Prepare and Create the New Normal

- **Preparations for decreasing mortality rate:**
  - Build hospitals in major cities to treat COVID-19 patients.
  - Increase the number of ICUs and critical equipment for COVID-19 treatment (e.g. ventilators).
  - Ensure the supply and distribution of critical drugs for COVID-19 treatment.
  - Improve air quality in major cities (prevent burning of low-quality coal and complete gasification projects).
  - Provide services to 65+ and other vulnerable persons in the society such that they can socially isolate themselves (e.g. delivery of groceries).

Note that these lists are not comprehensive lists. We created these lists after brainstorming and studying the measures taken by other countries. To benefit from the wisdom of the crowds, we invite medical professionals, public health experts, and others to provide their valuable suggestions as well.

Strategy 3
Prepare and Create the New Normal

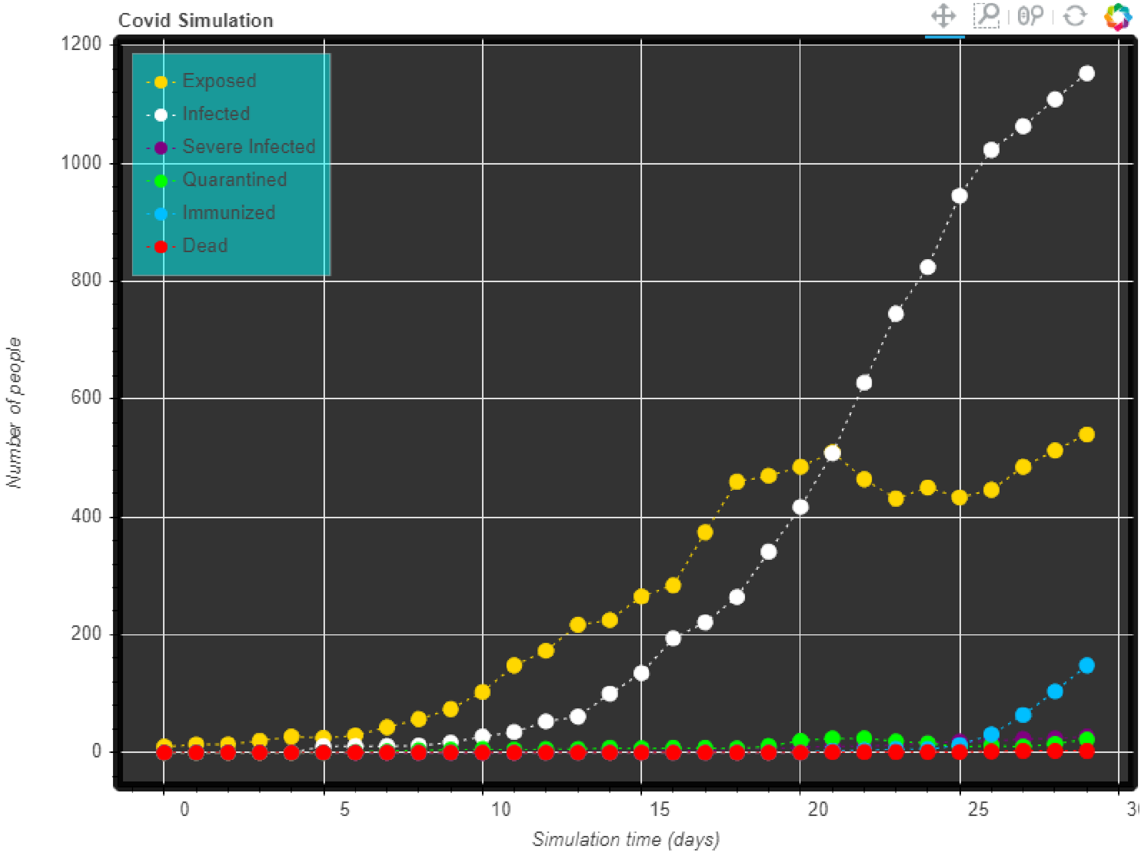
- **Preparations for decreasing transmission rate of COVID-19:**
  - Ramp up local production of personal protective equipment (masks, gloves, goggles, hazmat suits) and make sure that all healthcare personnel has access to these.
  - Masks should be mandatory for using public transportation and visiting busy places such as shopping malls and grocery stores.
  - Increase testing capacity for both COVID-19 disease and COVID-19 antibodies (i.e. serological testing to identify the immunized).
  - Create testing facilities which minimize interaction and transmission of the disease (for instance, drive-in testing in South Korea).
  - Introduce mandatory home quarantine after traveling between regions.
  - Improve broadband Internet access and bandwidth in the whole country to enable online working and learning.
  - Allow employees to work from home if their presence at workplace is not mandatory (use electronic signatures).
  - Start sport and cultural events for online or TV broadcast (without spectators).
  - Create a mandatory national COVID-19 tracking app for smartphones to utilize big data analytics to control the disease (see next slide for details). (Strategy 3++)

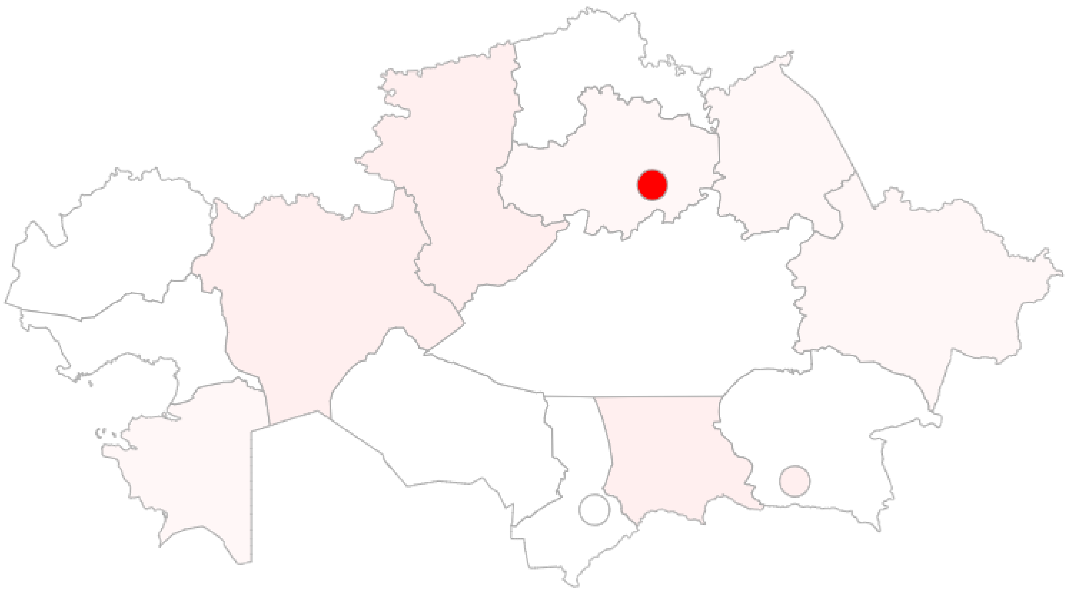
Scenario 3 – 30 March

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Akmola	Quarantined 3	Infected 54	Exposed 67	Severe Infected 2	Immunized 1	Death 0	Susceptible 738573	Start date: 01 Mar 2020
Kazakhstan	Quarantined 71	Infected 3368	Exposed 1645	Severe Infected 129	Immunized 422	Death 4	Susceptible 18390044	Current date: 30 Mar 2020



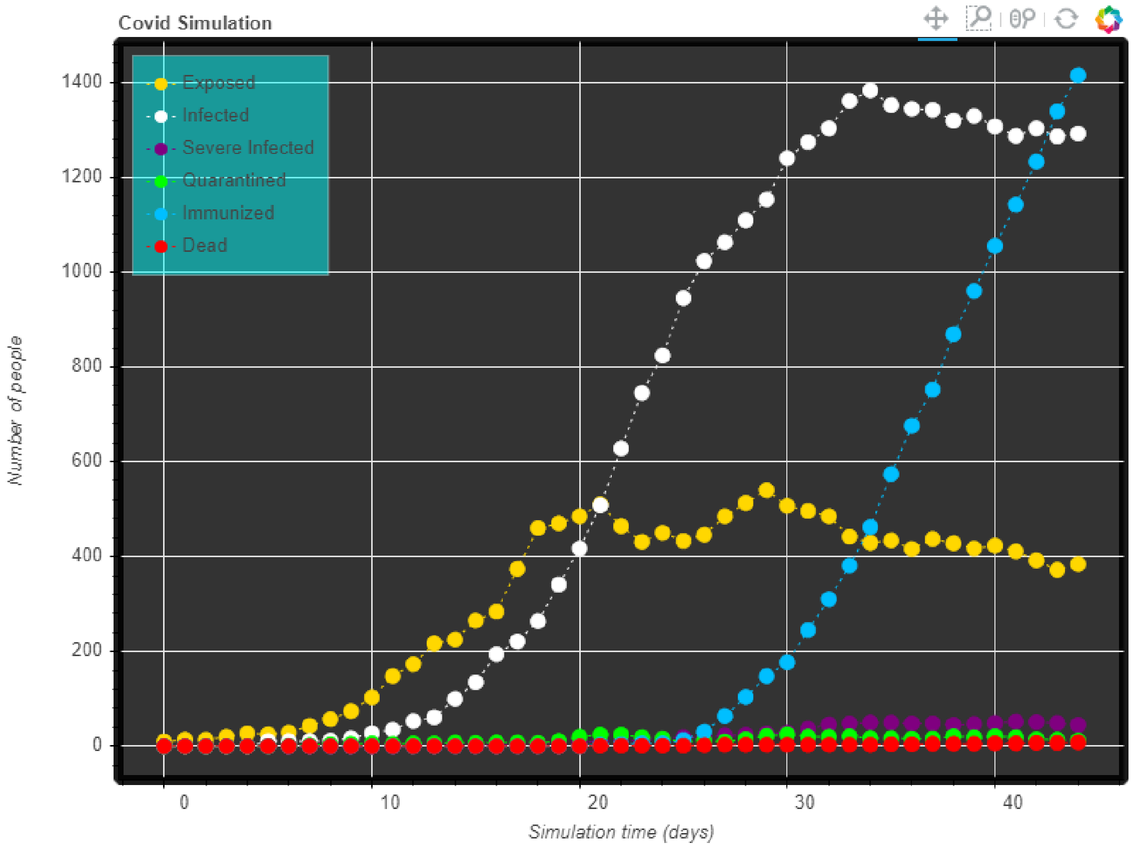


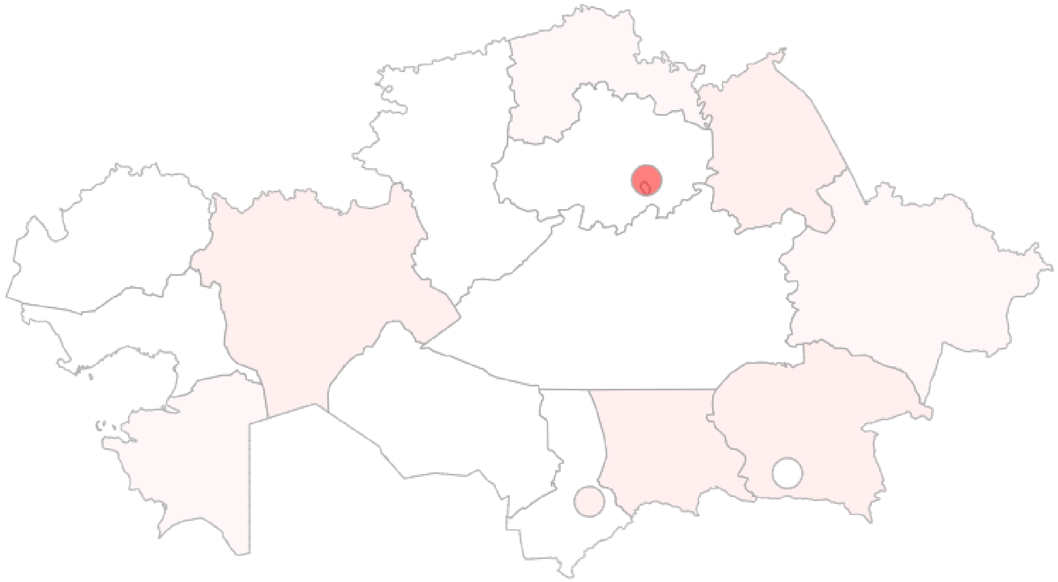
Scenario 3 – 14 April

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 12	Infected 1292	Exposed 384	Severe Infected 45	Immunized 1415	Death 8	Susceptible 1075075	Start date: 01 Mar 2020
Kazakhstan	Quarantined 35	Infected 3855	Exposed 1197	Severe Infected 215	Immunized 4016	Death 25	Susceptible 18386340	Current date: 14 Apr 2020



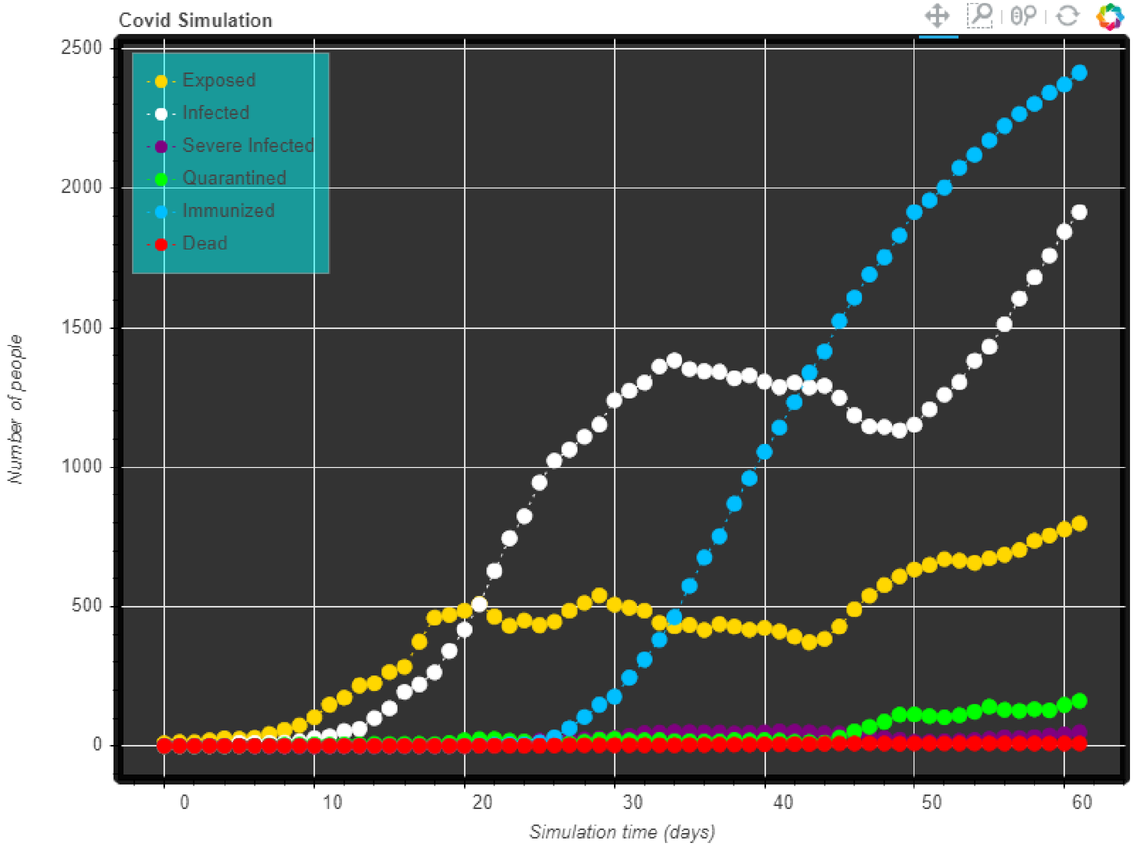


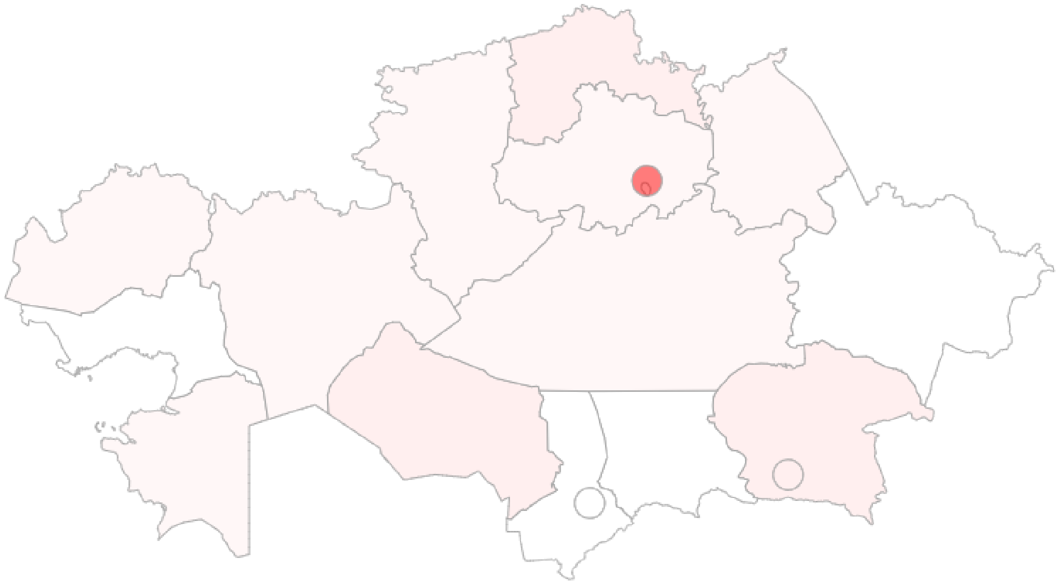
Scenario 3 – 1 May

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 162	Infected 1915	Exposed 798	Severe Infected 49	Immunized 2415	Death 9	Susceptible 1072801	Start date: 01 Mar 2020
Kazakhstan	Quarantined 537	Infected 7177	Exposed 3342	Severe Infected 312	Immunized 8366	Death 41	Susceptible 18375908	Current date: 01 May 2020



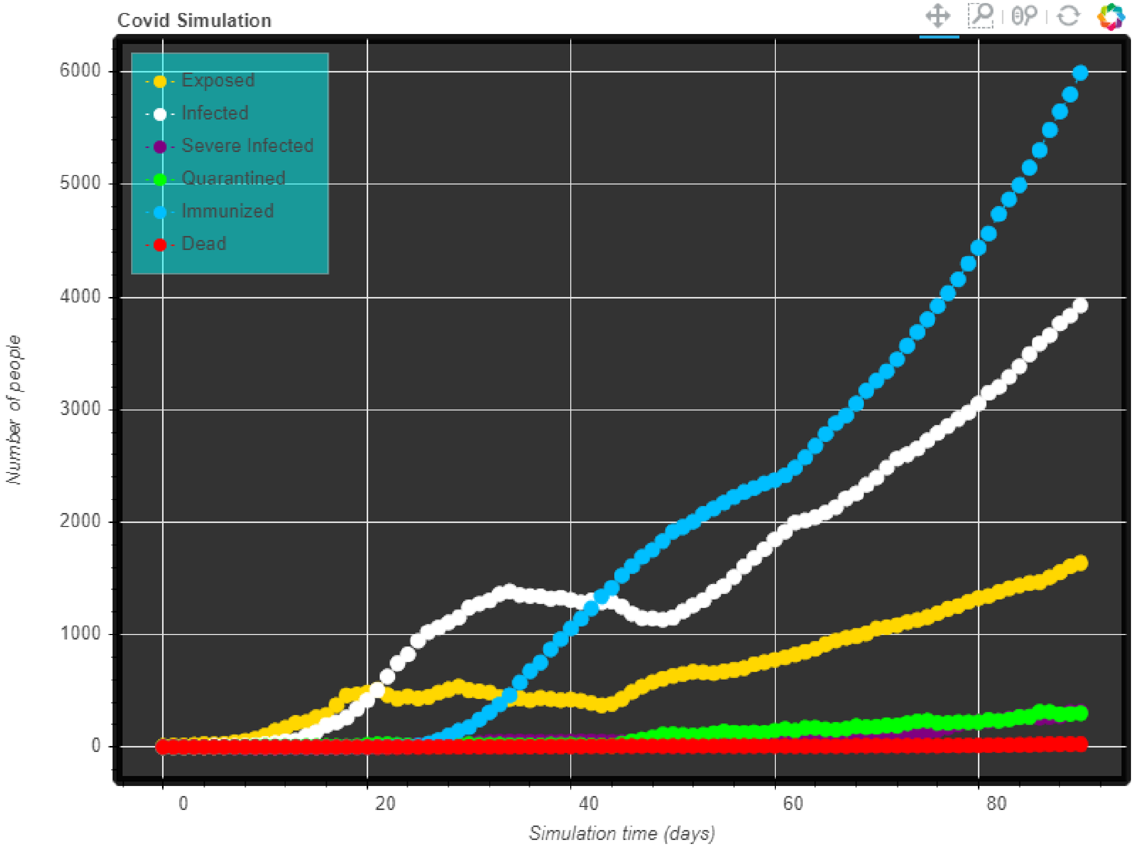


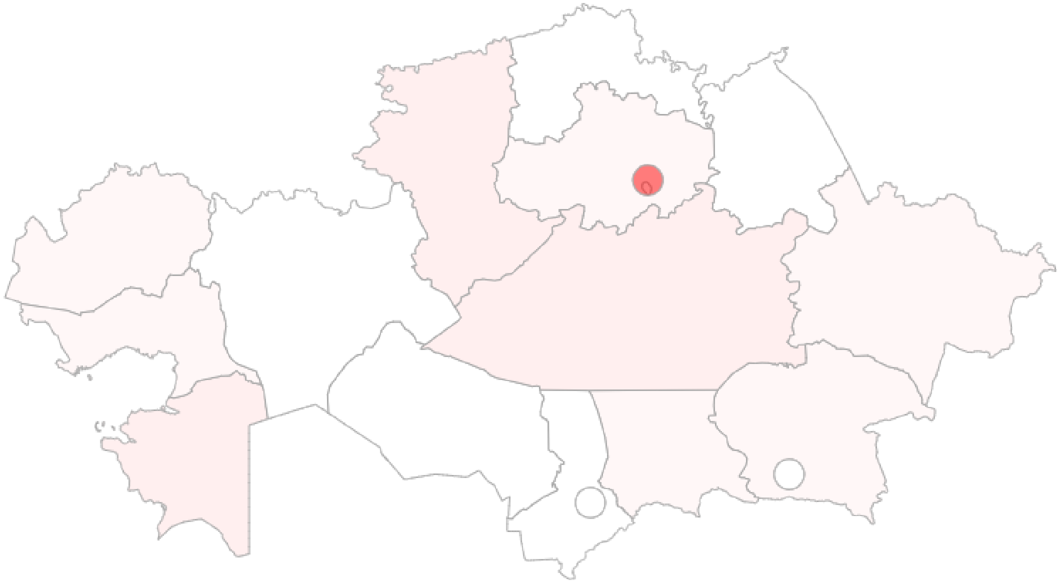
Scenario 3 - 30 May

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 302	Infected 3925	Exposed 1637	Severe Infected 315	Immunized 5993	Death 27	Susceptible 1065928	Start date: 01 Mar 2020
Kazakhstan	Quarantined 1944	Infected 26038	Exposed 11973	Severe Infected 1218	Immunized 30355	Death 164	Susceptible 18323991	Current date: 30 May 2020



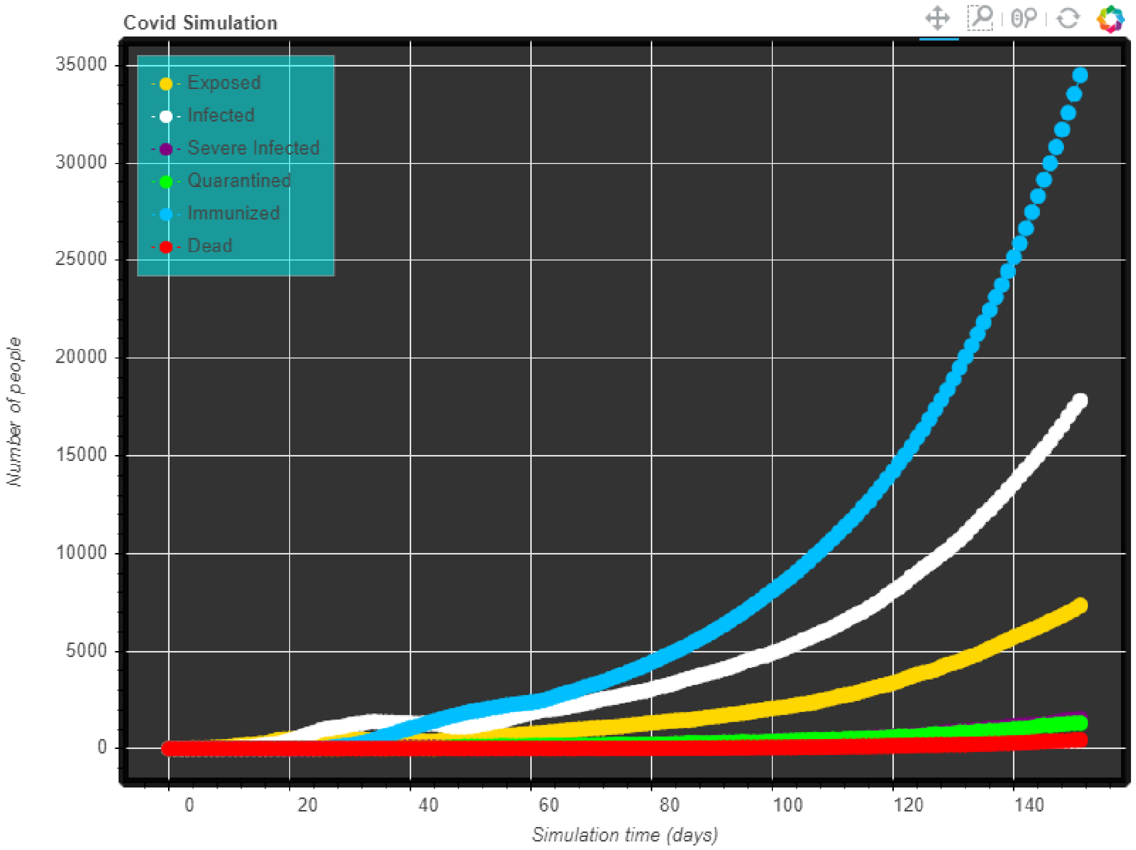


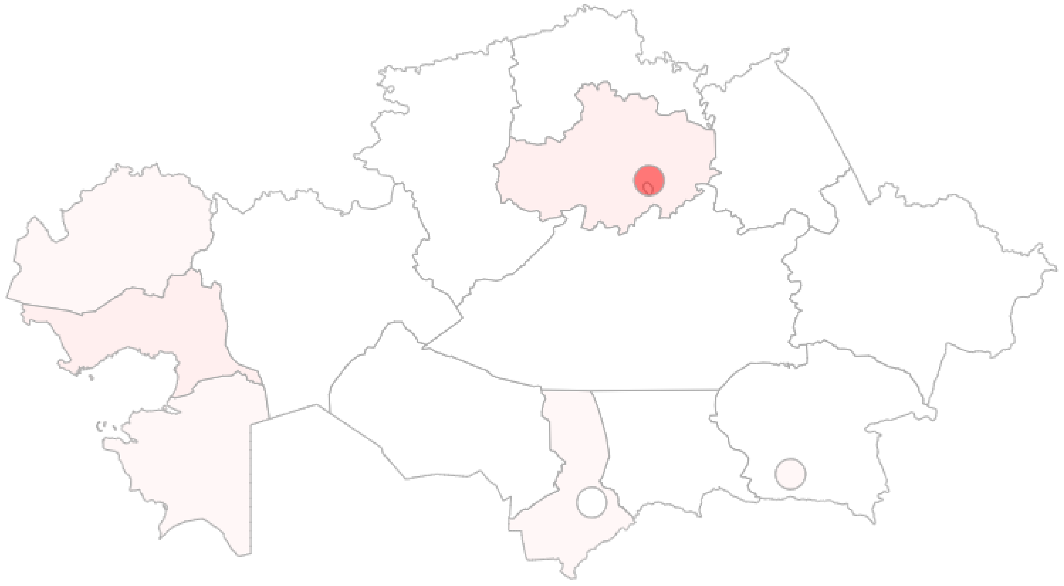
Scenario 3 - 30 July

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 1312	Infected 17829	Exposed 7338	Severe Infected 1539	Immunized 34509	Death 452	Susceptible 1015689	Start date: 01 Mar 2020
Kazakhstan	Quarantined 15225	Infected 204744	Exposed 85190	Severe Infected 16601	Immunized 366110	Death 4859	Susceptible 17702954	Current date: 30 Jul 2020





Strategy 3++
Kazakhstan National COVID-19 Control App

- Nearly all adults in Kazakhstan have smartphones.
- Data transmission and GPS localization capabilities of these phones can be utilized to control the COVID-19 epidemic.
- Each adult will install to their registered phones the “National COVID-19 Control App”.
- Outside of home, every person will be required to carry their smartphones with the “Kazakhstan National COVID-19 Control App” installed and running.
- Outside, law enforcement will check whether the individuals are carrying their smartphones with the installed application.
- The app needs to be shown to enter busy places such as malls.
- The longitudinal location data of each person using the application will be warehoused in a datacenter.
- This data will be mined **strictly for public health purposes** in real-time.

- For instance, if a cashier in a grocery store tests positive for COVID-19, the app will be able to identify the contacts and contacts will be requested to quarantine themselves at home for 14 days. Their app will change its display color to red and this way, the contacted individuals will not be allowed to go out.

- This will effectively increase the quarantine rate of the exposed in our model and decrease transmission.

Strategy 3++
Back-of-the-Envelope Data Calculations for Feasibility

- Let us assume that we will track 10 million smartphones in Kazakhstan, and we will transmit the GPS-based position of the smartphones as 32-byte packages every 5 minutes (288 entries per day) to a data warehouse .

Data Size Calculation:

- The total daily log size would be 10,000,000 x 288 x 32 bytes =~ **92 gigabytes (GB).**
- The total log size for one year would be 34 terabytes (TB) which would fit to 5 hard drives sold at Technodom.

Network Load Calculation:

- Let us assume that the TCP/IP package to send the data to the warehouse is 60 bytes including the header.
- Data transfer rate per sec. can be calculated as (10,000,000 x 288 x 60 bytes) / 86,400 sec = **2 MB/sec**.
- Currently, the broadband connection in most homes has higher bandwidth.

Contact Tracing Calculation:

- Let us assume that we want each day to track the contacts of 1,000 Infected persons for the last two weeks.
- For each person, we would have 14 x 288 position entries → 1,000 x 14 x 288 entries = 4 million locations.
- A lazy search would require 4 million x 10 million distance computations = 40 trillion calculations.
- This can be reduced by orders of magnitude using space partitioning data structures (e.g. KD-trees).
- In general, this part is also computationally feasible.

Strategy 3++
Disclaimer

We are scientists and we are neither recommending nor not recommending the tracking of individuals using their smartphone position data.

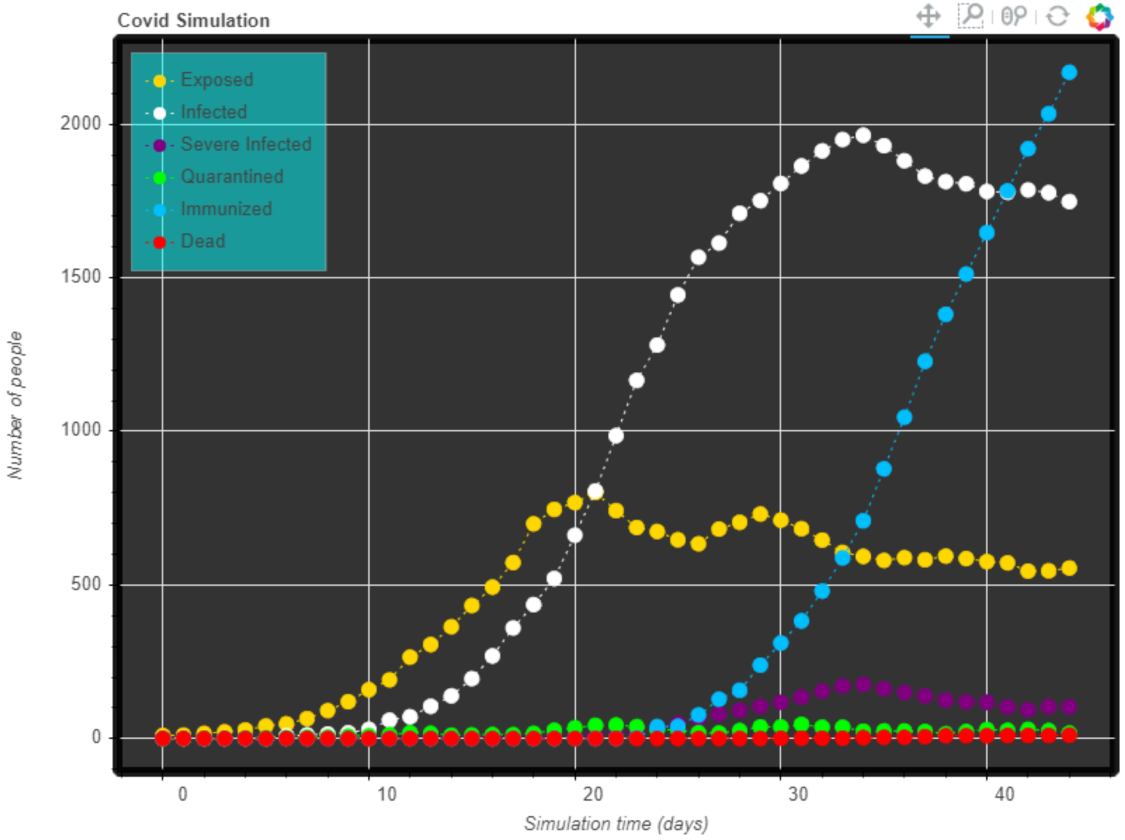
We only highlight the technical feasibility of the approach and show how it would affect the spread of the COVID-19 disease in Kazakhstan based on our simulations.

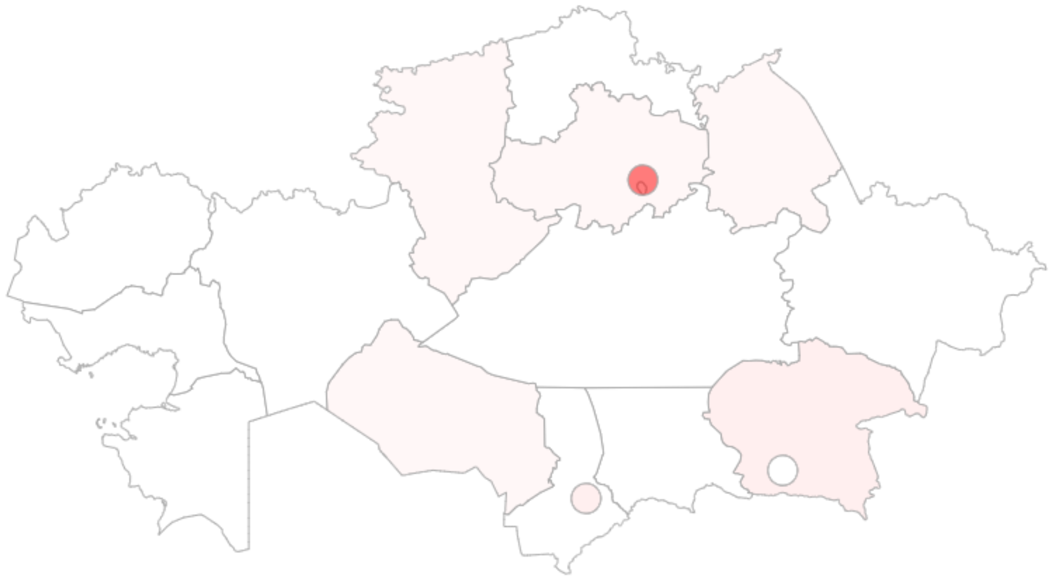
Scenario 3++ - 14 April

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 18	Infected 1748	Exposed 555	Severe Infected 103	Immunized 2169	Death 11	Susceptible 1073623	Start date: 01 Mar 2020
Kazakhstan	Quarantined 52	Infected 3871	Exposed 1291	Severe Infected 196	Immunized 4031	Death 15	Susceptible 18386227	Current date: 14 Apr 2020



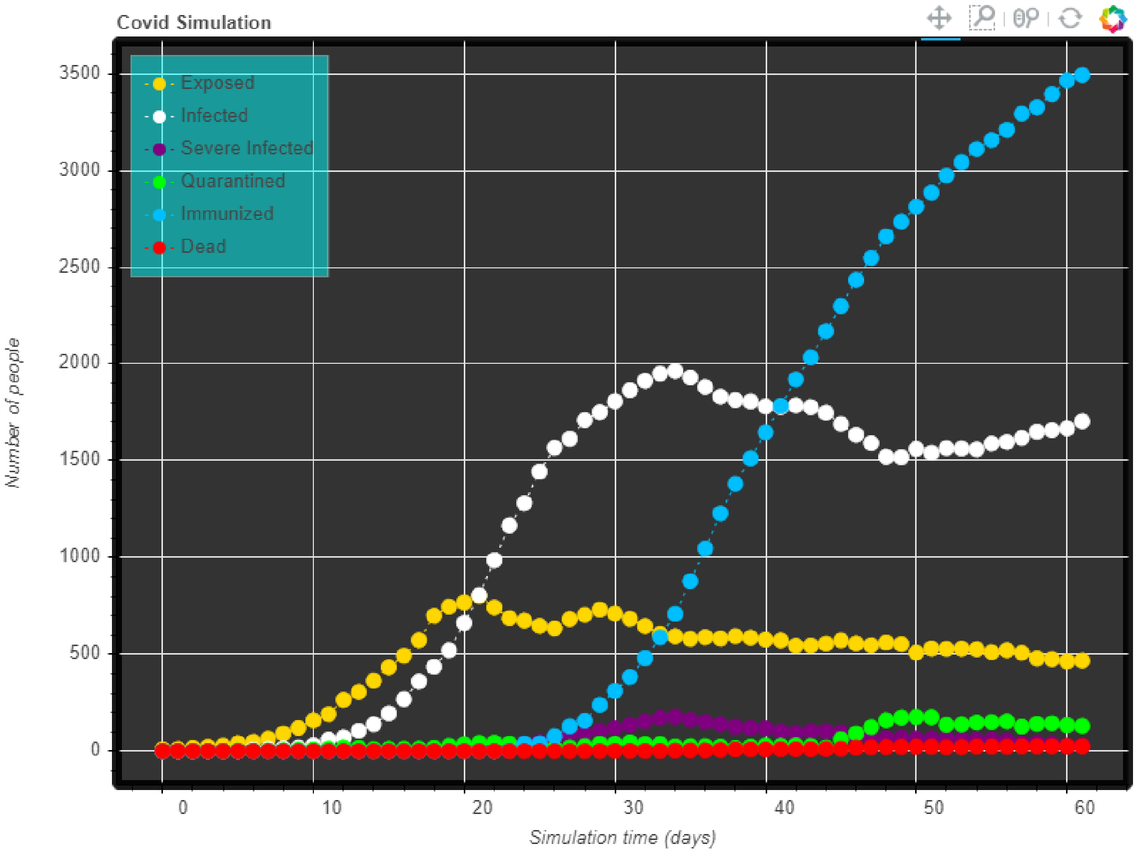


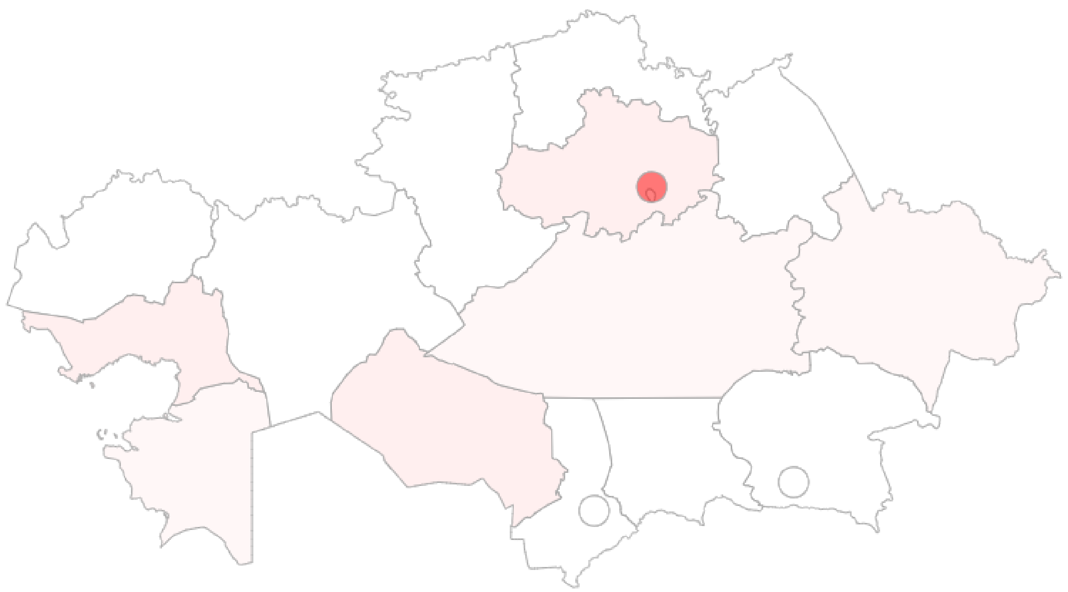
Scenario 3++ - 1 May

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 130	Infected 1704	Exposed 468	Severe Infected 29	Immunized 3492	Death 25	Susceptible 1072271	Start date: 01 Mar 2020
Kazakhstan	Quarantined 398	Infected 5053	Exposed 1633	Severe Infected 168	Immunized 8377	Death 55	Susceptible 18379999	Current date: 01 May 2020



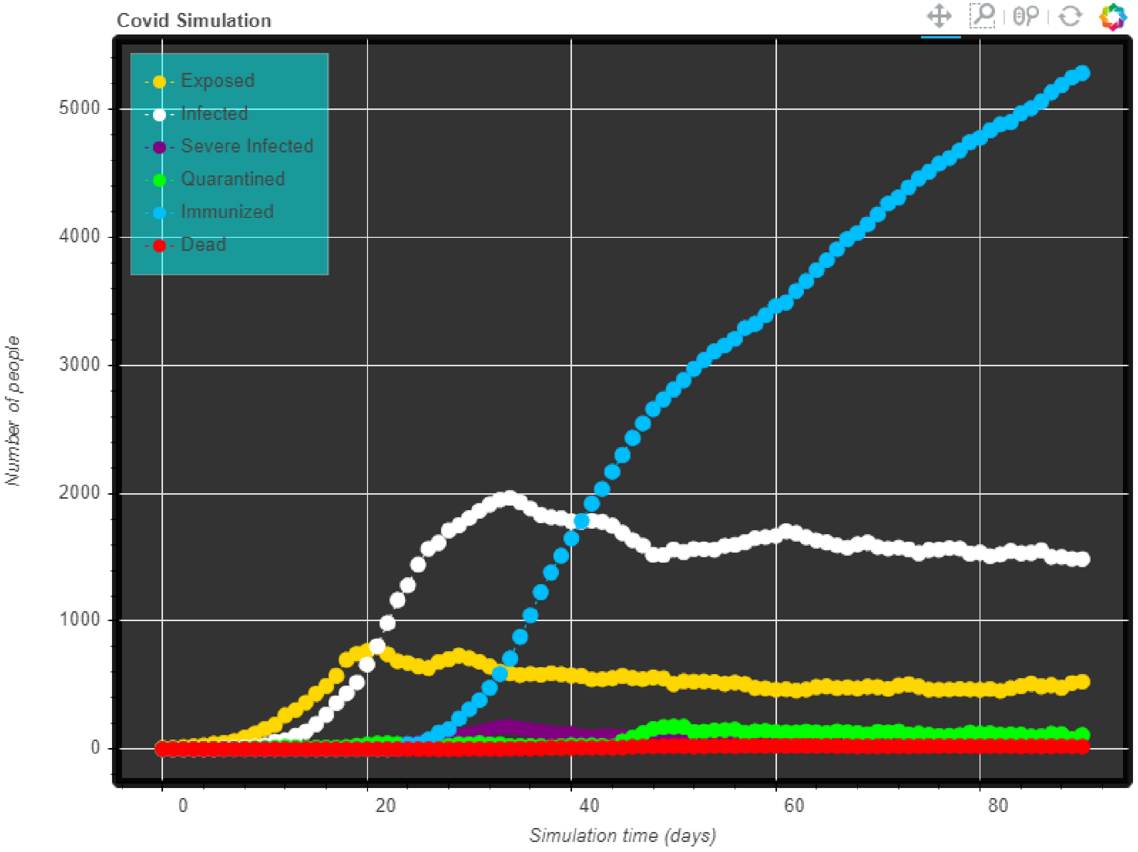


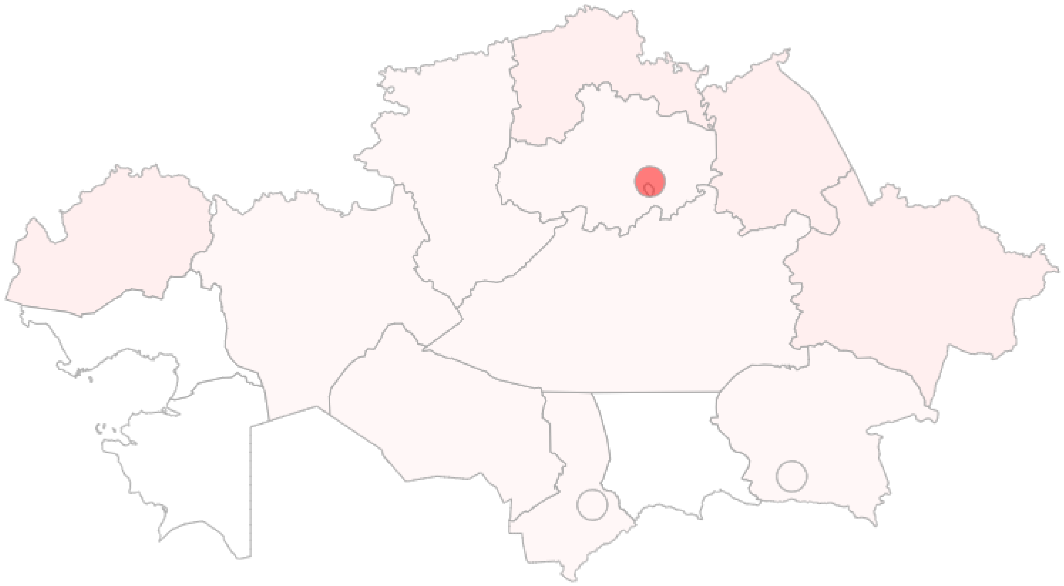
Scenario 3++ - 30 May

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 110	Infected 1486	Exposed 527	Severe Infected 29	Immunized 5286	Death 20	Susceptible 1070743	Start date: 01 Mar 2020
Kazakhstan	Quarantined 576	Infected 7033	Exposed 2388	Severe Infected 274	Immunized 19027	Death 86	Susceptible 18366299	Current date: 30 May 2020



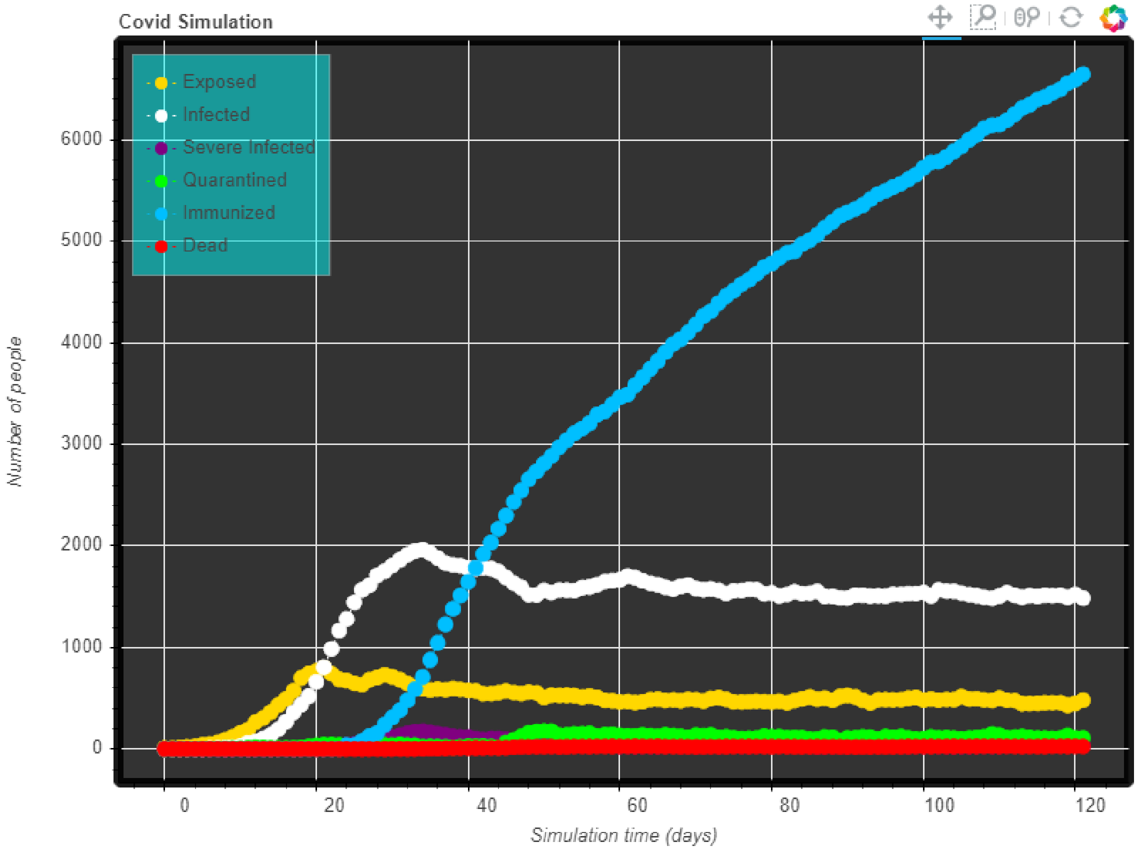


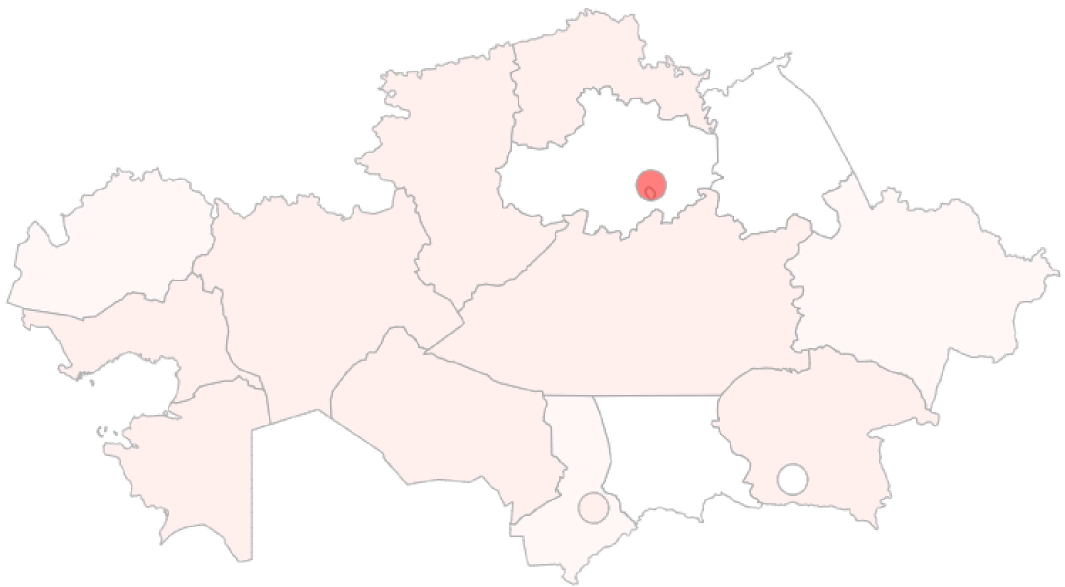
Scenario 3++ - 30 June

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 109	Infected 1486	Exposed 481	Severe Infected 37	Immunized 6646	Death 25	Susceptible 1069341	Start date: 01 Mar 2020
Kazakhstan	Quarantined 749	Infected 9805	Exposed 3292	Severe Infected 346	Immunized 35609	Death 147	Susceptible 18345735	Current date: 30 Jun 2020



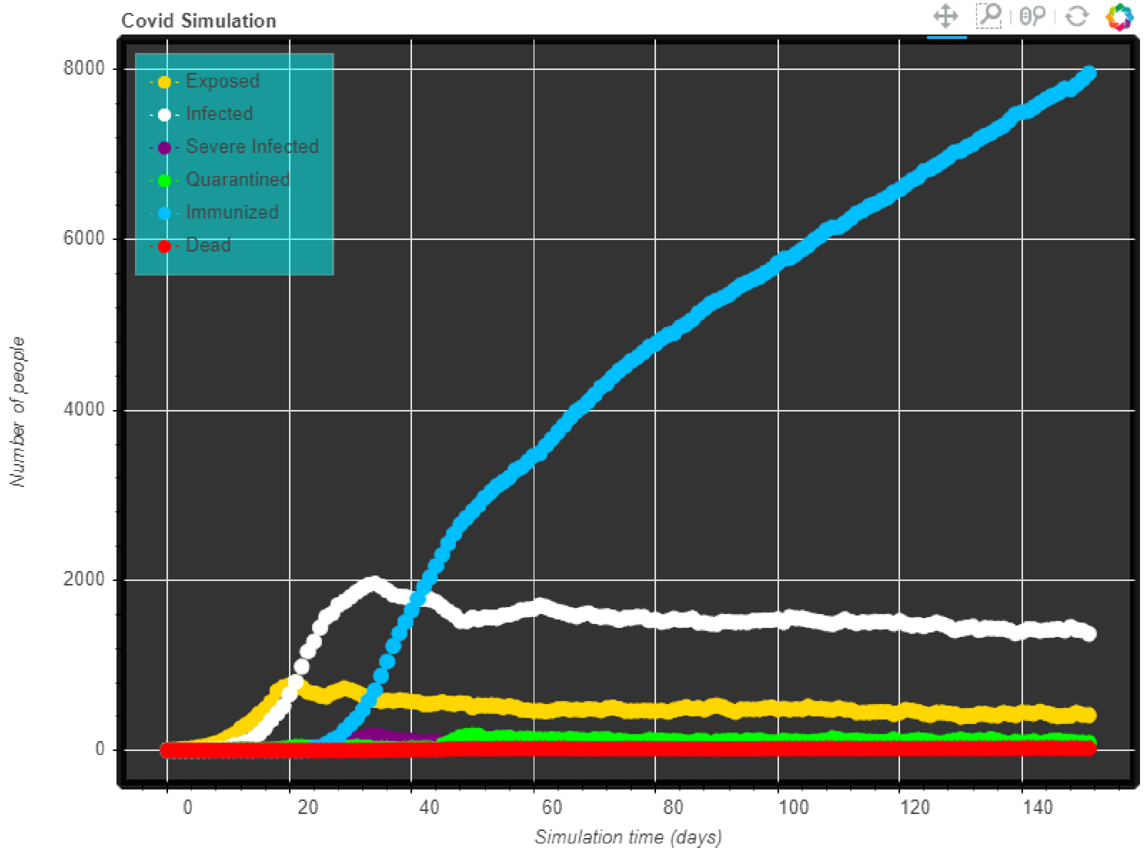


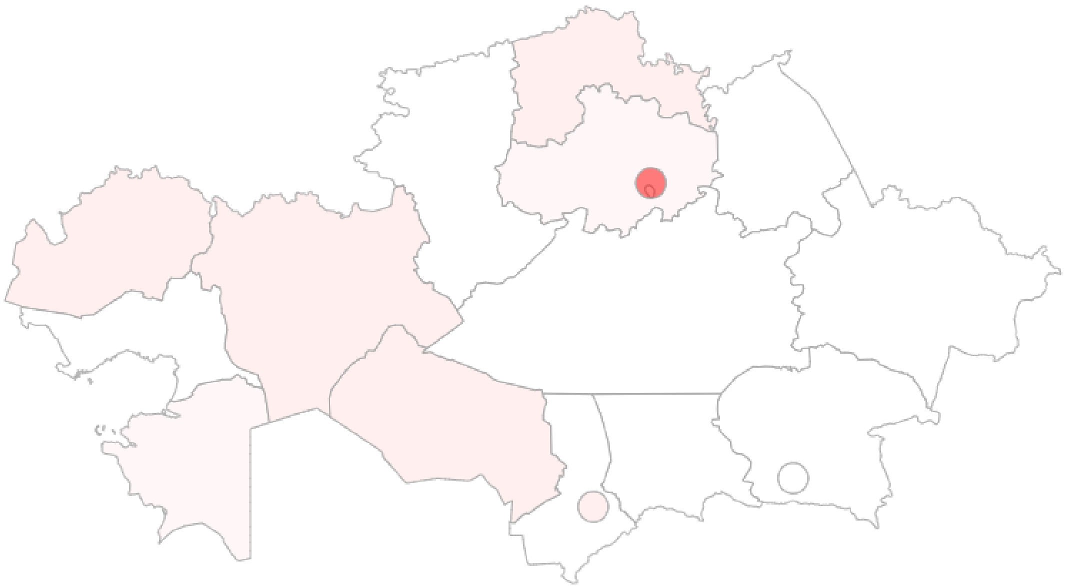
Scenario 3++ - 30 July

COVID-19 Epidemic Simulator for Kazakhstan

Institute of Smart Systems and Artificial Intelligence (issai.nu.edu.kz/episim)

Nur-Sultan	Quarantined 93	Infected 1372	Exposed 415	Severe Infected 35	Immunized 7955	Death 27	Susceptible 1068143	Start date: 01 Mar 2020
Kazakhstan	Quarantined 940	Infected 13380	Exposed 4519	Severe Infected 328	Immunized 58271	Death 214	Susceptible 18318031	Current date: 30 Jul 2020





Final Remarks

In this series of presentations, we describe the design of a sophisticated epidemic modeling tool, calibrated with historical data (H1N1) and recent experience of COVID-19 in different regions of the world (Diamond Princess, China, and Lombary). The simulator incorporates factors such as population demographics and mobility, hospital capacities, and propagation characteristics of the virus.

The simulator was customized for use in the Republic of Kazakhstan in order to evaluate scenarios based on the projected outcomes of policy decisions. On one extreme, the lack of control will yield unmitigated disaster, with overwhelmed healthcare system and high rates of mortality. On the other extreme, persistent suppression (via quarantines and strict social distancing) will cause economic harm and instigate other forms of social distress.

The projections of the simulator suggest that going forward, it will be necessary to maintain some level of social controls (labeled as option 3++) so as to constrain propagation and minimize social and economic impact, until such time as the so-called "herd" immunity is gradually achieved, or a vaccine is introduced.

It should be noted that our simulation results show the general trends based on the entered set of parameters. More realistic epidemic simulations can be done when more accurate estimates of the Infected and Immunized can be obtained by extensive randomized testing of the population.