Institute of Smart Systems and Artificial Intelligence

NAZARBAYEV UNIVERSITY

COVID-19 Simulator for Kazakhstan
Part 3 – Summary of Current Results

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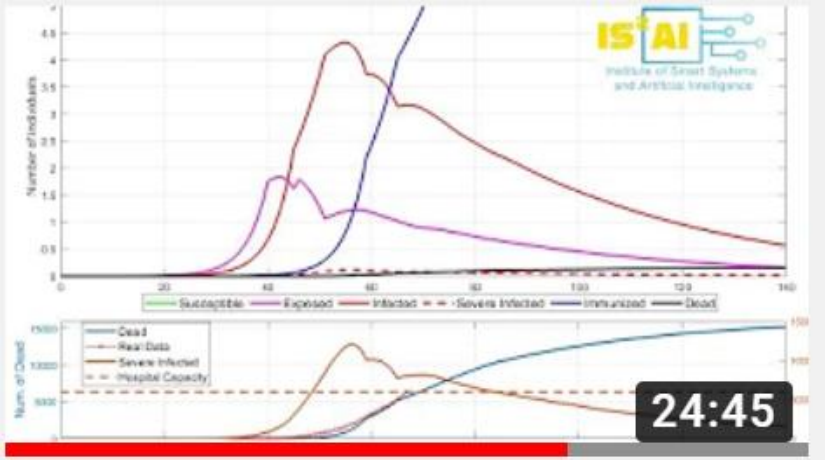
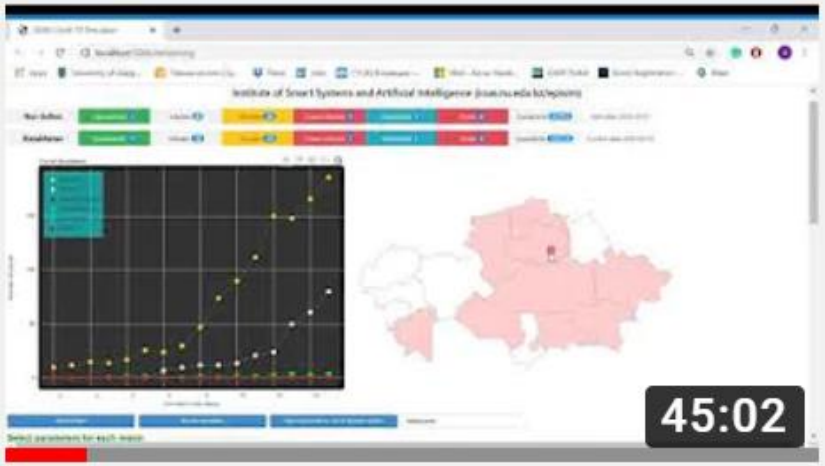
Outline

- We posted so far two videos to our ISSAI Youtube Channel.
- The first video summarized our project objectives and underlying assumptions based on the study of the China, Diamond Princess and Lombardy cases.
- The second video is a tutorial on how to use our COVID-19 simulator.
- The second video simulates the spread of COVID-19 in the Republic of Kazakhstan starting 1 March 2020.
- Since both videos are quite long, we decided to make a shorter summary video before sharing our further work on mitigation and suppression strategies.
- In this video, we will initially provide a short summary of our project and then discuss the results obtained in our simulation.



Covid-19 Simulator for Kazakhstan: Part 1 - Project...



COVID-19 Simulator for Kazakhstan: Part 2 - Tutoria...

Project Objectives

- To help in this time of crisis, the ISSAI team of Nazarbayev University has developed a stochastic **epidemic simulator**, calibrated with real-world experience, and customized for the Republic of Kazakhstan (RoK).

- The simulator utilizes real RoK data, ranging from population density to health care capacity of each region to predict the dynamics of the spread of COVID-19 in Kazakhstan, and thereby inform government policy-making.

- We model Kazakhstan as a graph of 17 connected nodes (14 oblasts and 3 cities of Republican significance) where each node runs a separate SEIR epidemiological model.

- Based on air, rail and highway connections between the nodes, we also model the spread of the disease between different geographic regions.

The COVID-19 Simulator

- First some definitions to avoid confusion:
  - **Simulator**: a system or program that enables the operator to reproduce or represent under test conditions phenomena likely to occur in actual performance (from Merriam-Webster dictionary).
  - **Visualizer:** A program which visualizes on the computer screen a given set of data (e.g. daily number of infected and deaths due to COVID-19 until present date).

- Our program is a **simulator** which has extensive visualization capability..

- Detailed videos describing our project and providing a tutorial on how to use our software is at our ISSAI Youtube channel: **https://www.youtube.com/channel/UCr7o_0wW4nkqx-G5b7Zopgw**

- ISSAI shares the source code such that it can be used, adapted, and improved by others.
  https://github.com/baimukashev/COVID-19_simulation/tree/master

Disclaimer: This is a research tool which will show general future trends based on the entered parameters. Projected outcomes are dependent on correct initial conditions, and the accuracy of the parameters.

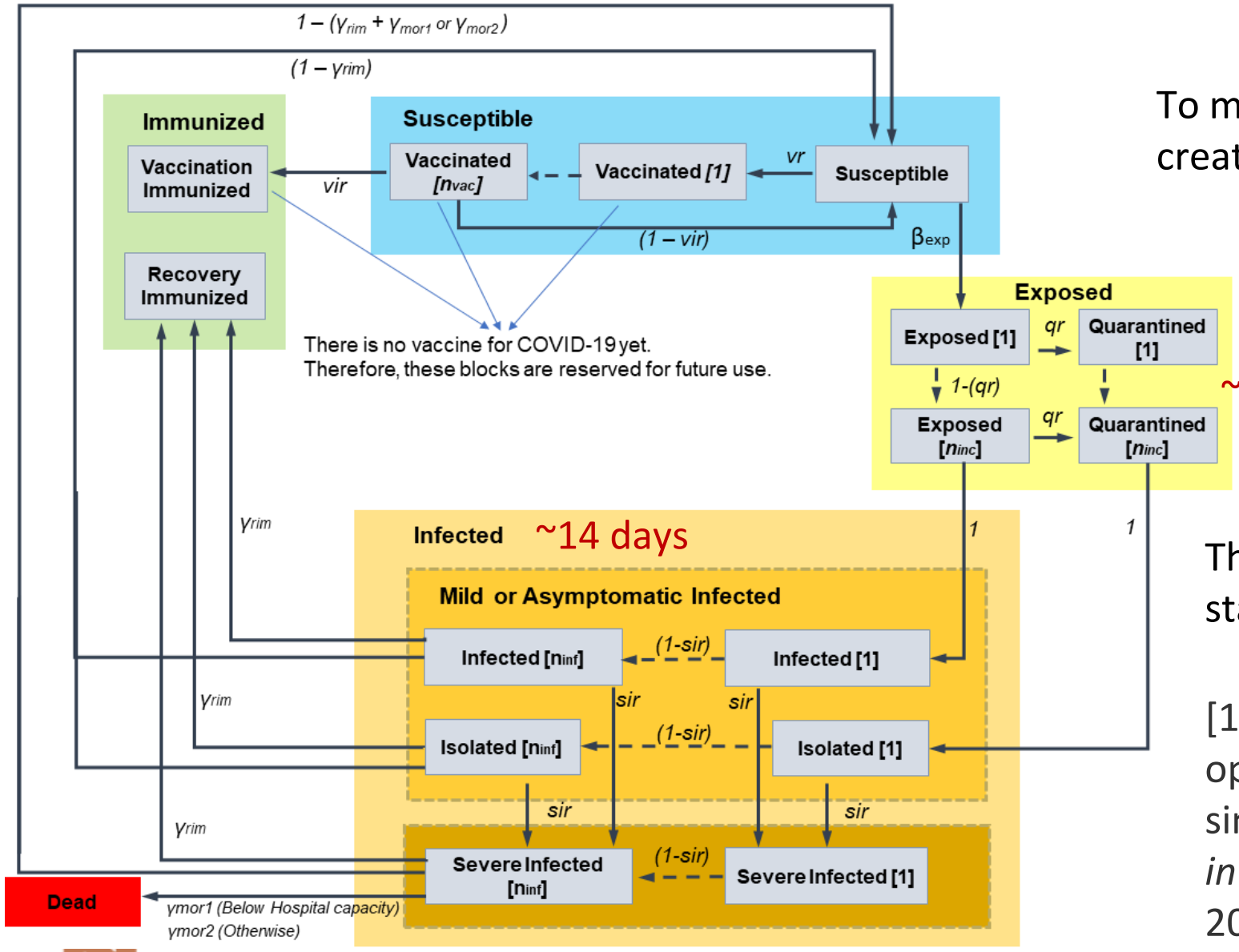
Lombardy COVID-19 Timeline

Day	Date	Death	Confirmed Cases	Tests	Event
-36	**1/21/2020**	**??**	**??**	**??**	COVID-19 infected person comes from China.
-10	**2/14/2020**	**??**	**??**	**??**	Male person who met the person from China feels bad, goes to doctor, he and his wife were later confirmed positive for COVID-19.
-4	**2/20/2020**	**??**	**3**	**??**	Three confirmed cases in Lombardy.
0	**2/24/2020**	**6**	**172**	**1463**	Data is saved regularly in the national repository. COVID-19 was already spreading for 36 days with already 6 deaths.
7	**3/2/2020**	38	1254	7925	Red zone in Lombardy locked down.
13	**3/8/2020**	267	4189	18534	Whole Lombardy locked down.
16	**3/11/2020**	617	7280	25629	All bars and restaurants are closed
27	**3/22/2020**	3456	27206	70598	Factories, nonessential production closed.
34	**3/28/2020**	5944	39415	102503	Date of last data available.

- On 24 February 2020, when there were 6 registered COVID-19 deaths in Lombardy, we assume there was already 857 cases of COVID-19 in Lombardy (based on 0.77 percent mortality rate estimated for Italy).

- We will first start with the simulation of the Lombardy region.
- If our model predicts the current recorded deaths accurately, we might either have a good model or we simply might be overfitting our model to the available data.
- If our model shows good predictive accuracy for the next one week or so, then we can state that we have a good model and our assumptions were solid.

Stochastic SEIR-S Model Simulator

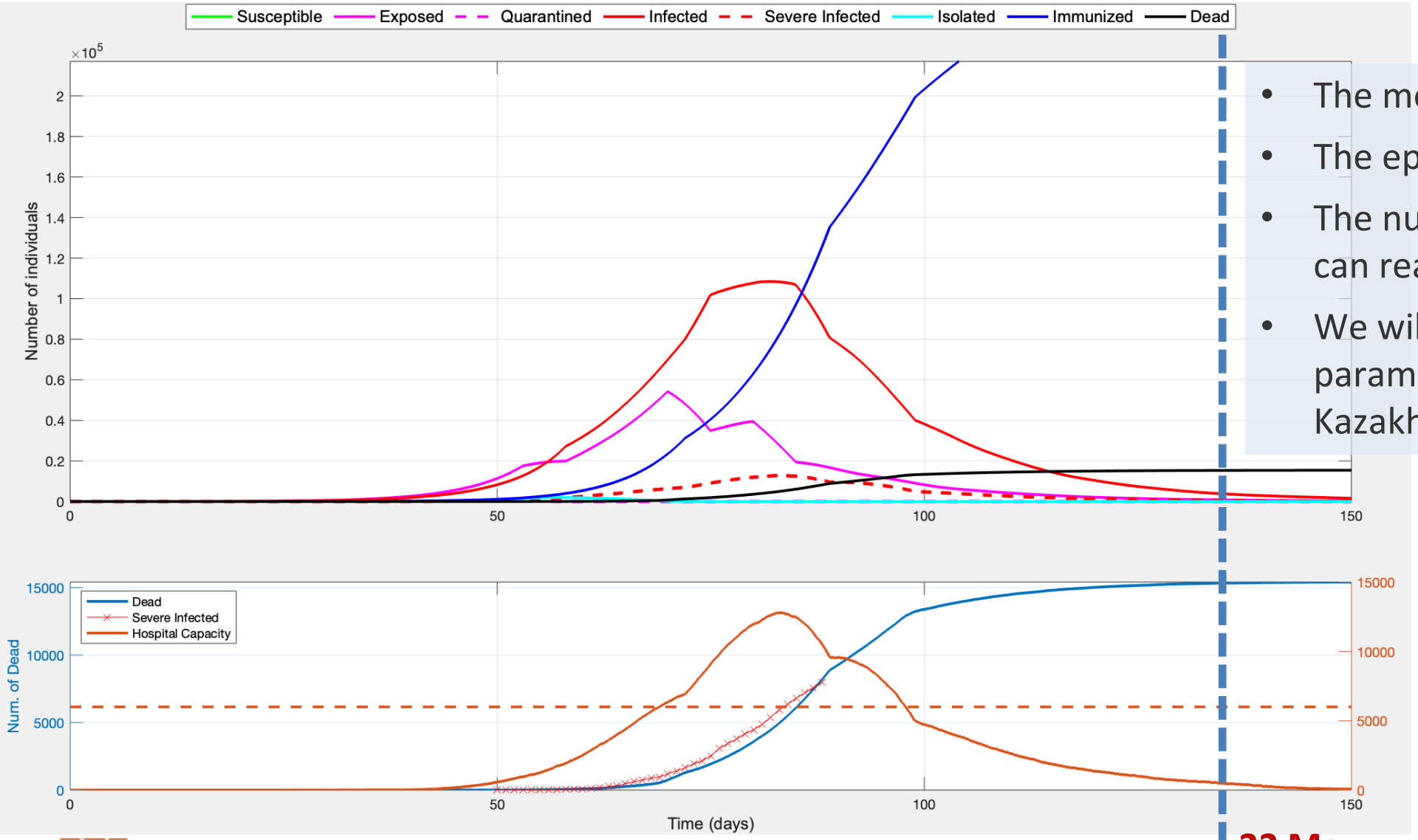


To model the COVID-19 epidemic in Lombardy, we created a simulator based on our earlier work [1].

The stochastic model transitions between states based on probabilities.

[1] H. A. Varol, "MOSES: A Matlab-based open-source stochastic epidemic simulator," *IEEE Int. Conf. of the Engineering in Medicine and Biology Society (EMBC)*, 2016, pp. 2636-2639.

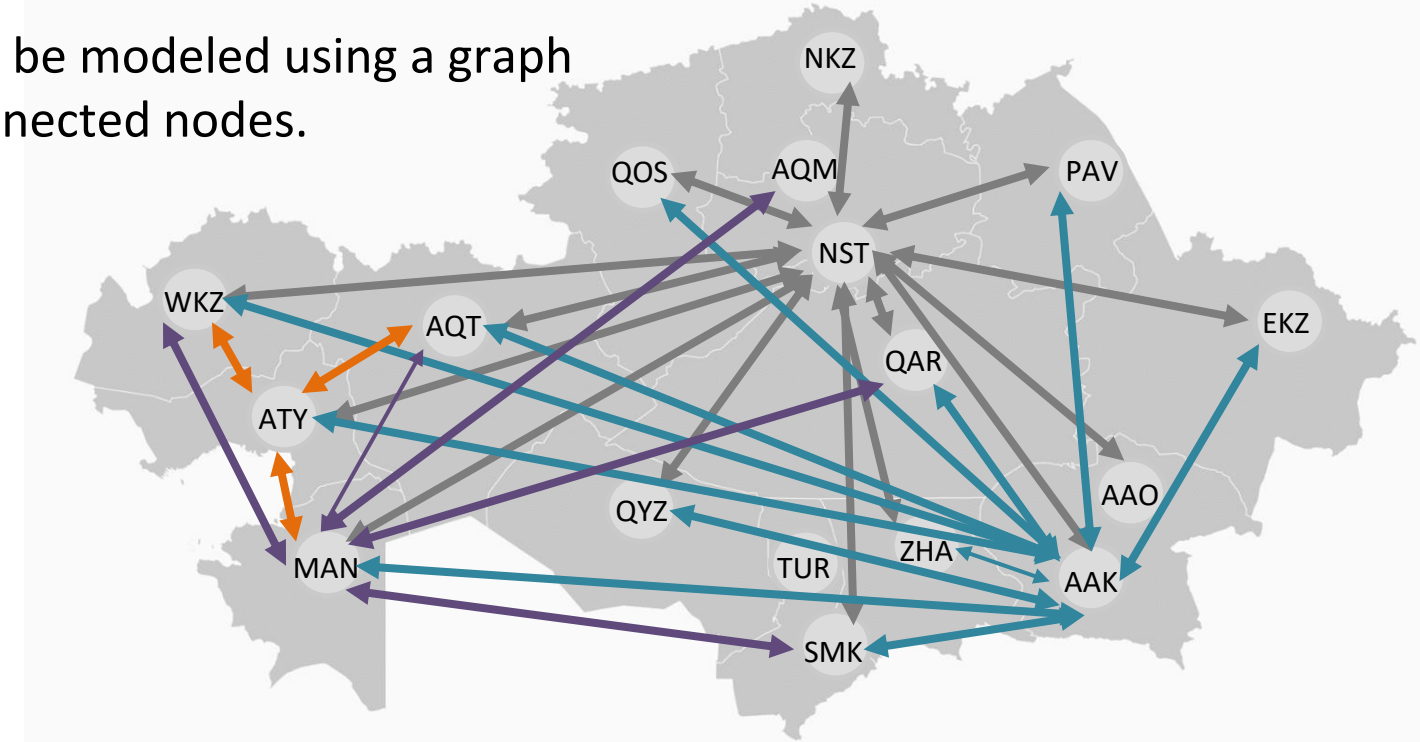
Lombardy Simulation Results



- The model fits available data well.
- The epidemic might last till June.
- The number of deaths in Lombardy can reach 15,000.
- We will use Lombardy model parameters as a baseline for Kazakhstan nodes.

Kazakhstan As a Network

- During epidemics, measures are usually taken for specific administrative regions (for example, restricting movement within or between regions).
- These regions are also connected via air, railway and highway networks.
- Epidemics start usually in hubs with the import of the disease from another country and propagates to other regions via transportation between regions.
- Statistical data on the population, hospital capacity, and transportation connections of each region is usually available.
- Therefore, a country can be modeled using a graph consisting of a set of connected nodes.



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**

Daily Transition Matrix Between Nodes of Kazakhstan

- We collected data from open sources on the daily air, rail, and motorway travel between different regions of Kazakhstan and combined this information in a daily transition matrix.

$$T_{total} = T_{air} + T_{rail} + T_{highway}$$

- In our simulation, we randomly sample the population of a node for each transfer.
- For instance, there are 1042 persons traveling from Almaty to Nursultan daily. Almaty has a population of around 2,000,000. Assuming there are 15,000 Infected persons in Almaty, 8 Infected persons would be transferred from Almaty to Nursultan on average daily.

Node (from/to)	Almaty	Almaty Qalasy	Aqmola	Aqtobe	Atyrau	West Kazakhstan	Jambyl	Mangystau	Nur-sultan	Pavlodar	Qaragandy	Qostanai	Qyzylorda	East Kazakhstan	Shymkent	North Kazakhstan	Turkistan
Almaty	0	5100	0	0	0	0	0	0	1042	0	120	0	0	60	0	0	0
Almaty Qalasy	5100	0	0	824	654	668	1281	688	1194	744	1352	827	893	1532	1454	0	240
Aqmola	0	0	0	0	461	0	0	478	2057	0	180	0	0	0	0	0	0
Aqtobe	0	824	0	0	496	0	0	515	651	0	721	0	0	0	0	0	0
Atyrau	0	654	461	496	0	615	0	503	540	0	587	0	0	0	527	0	0
West Kazakhstan	0	668	0	0	615	0	0	450	550	0	0	0	0	0	0	0	0
Jambyl	0	1281	0	0	0	0	0	0	745	0	60	0	0	0	0	0	0
Mangystau	0	688	478	515	503	450	0	0	563	0	1035	0	0	0	549	0	0
Nur-sultan	1042	1194	2057	651	540	550	745	563	0	660	1770	652	798	1058	706	718	0
Pavlodar	0	744	0	0	0	0	0	0	660	0	103	0	0	0	0	0	0
Qaragandy	120	1352	180	721	587	0	60	1035	1770	103	0	766	801	1078	969	60	240
Qostanai	0	827	0	0	0	0	0	0	652	0	766	0	0	0	0	0	0
Qyzylorda	0	893	0	0	0	0	0	0	798	0	801	0	0	0	0	0	0
East Kazakhstan	60	1532	0	0	0	0	0	0	1058	0	1078	0	0	0	0	0	0
Shymkent	0	1454	0	0	526	0	0	549	706	0	969	0	0	0	0	484	900
North Kazakhstan	0	0	0	0	0	0	0	0	718	0	60	0	0	0	484	0	0
Turkistan	0	240	0	0	0	0	0	0	0	0	240	0	0	0	900	0	0

The rows and columns for hubs (Nur-Sultan and Almaty) are highlighted.

Kazakhstan COVID-19 Timeline

Day	Date	Death	Confirmed Cases	Tests	Event
-6	**3/13/2020**	**0**	**2**	**?**	Russia and Kyrgyzstan put restriction on free border crossings. Announcement of online classes. Country wide events are postponed.
-3	**3/16/2020**	**0**	**3**	**?**	Restriction on large gatherings.
0	**3/19/2020**	**0**	**44**	**?**	National emergency state. Closure of Nur-Sultan and Almaty. Restriction on working hours of restaurants. Penalties for quarantine violation are officially set.
3	**3/22/2020**	**0**	**56**	?	Lockdown of Nur-Sultan and Almaty.
7	**3/26/2020**	**1**	**81**	?	First death. Restrictions of movement in Shymkent. Limitation to go outside in Nur-Sultan and Almaty except for essentials.
11	**3/30/2020**	**1**	**293**	?	Lockdown of Aktobe, Kostanai, Atyrau, Turkistan, Karaganda regions.

1. Assuming average duration of 19 days for the disease, the first person who passed away should have contracted it on around 7 March 2020.
2. The first deaths in Lombardy were reported 33 days later than the import of COVID-19 from China.
3. Even though Almaty and Nur-Sultan are locked down since 22 March 2020, there are COVID-19 cases in other regions which cannot be traced back to confirmed cases.

- Therefore, combining (1), (2), and (3), we will assume in our simulations that there were 10 Exposed persons in both Almaty and Nursultan on 1 March 2020.

Comparing Lombardy and Kazakhstan

- **Lombardy**
  - Predicted COVID-19 arrival: 21 January 2020
  - First serious measure: 2 March 2020
  - Delay between the first case and the response is 39 days.

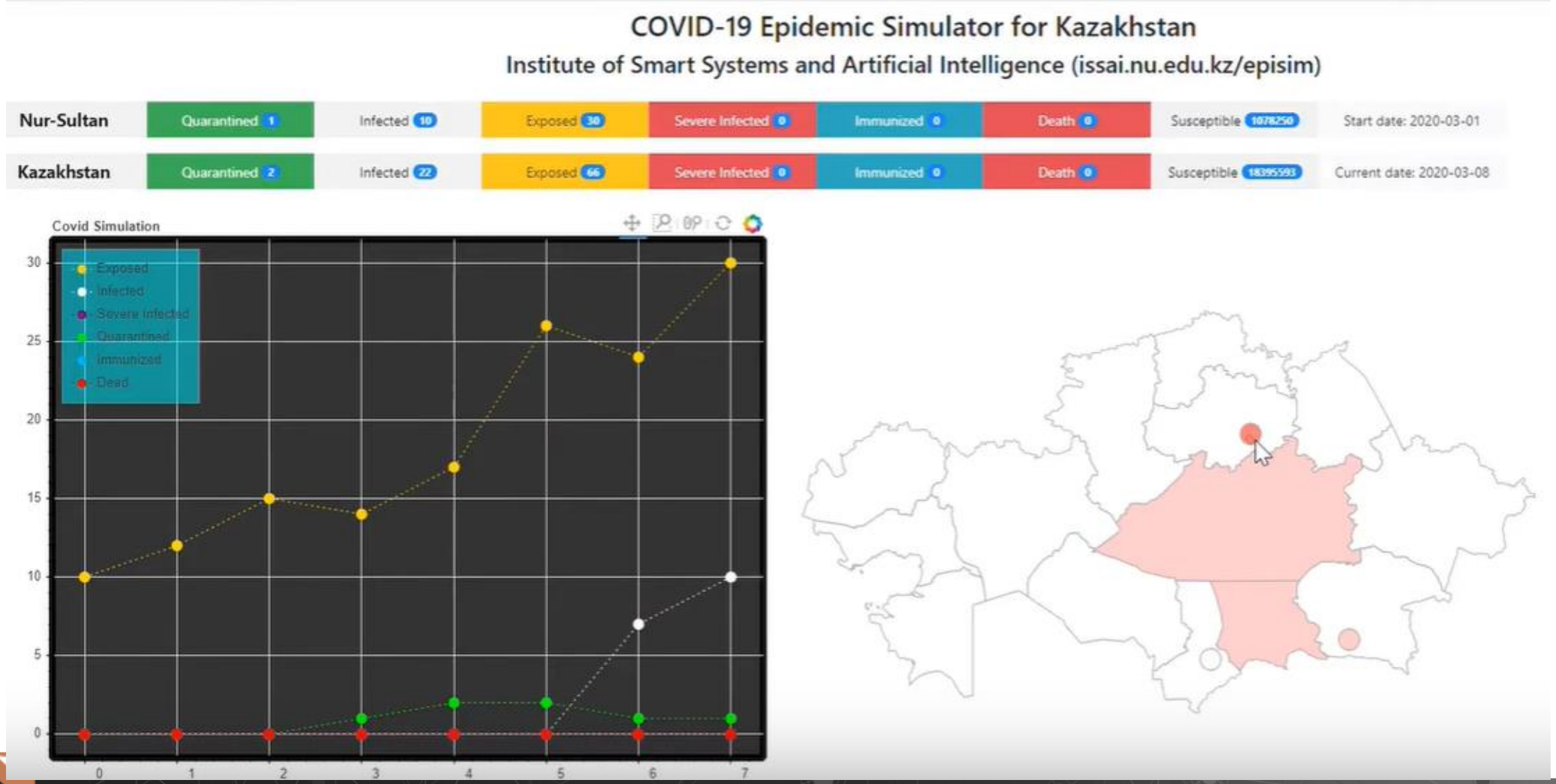
- **Kazakhstan**
  - Predicted COVID-19 arrival: 1 March 2020
  - First serious measure: 13 March 2020
  - Delay between the first case and the response is 12 days.

Kazakhstan was aware of the danger due to the extent of the epidemic in other countries and was quick to make interventions to prevent the spread of COVID-19.

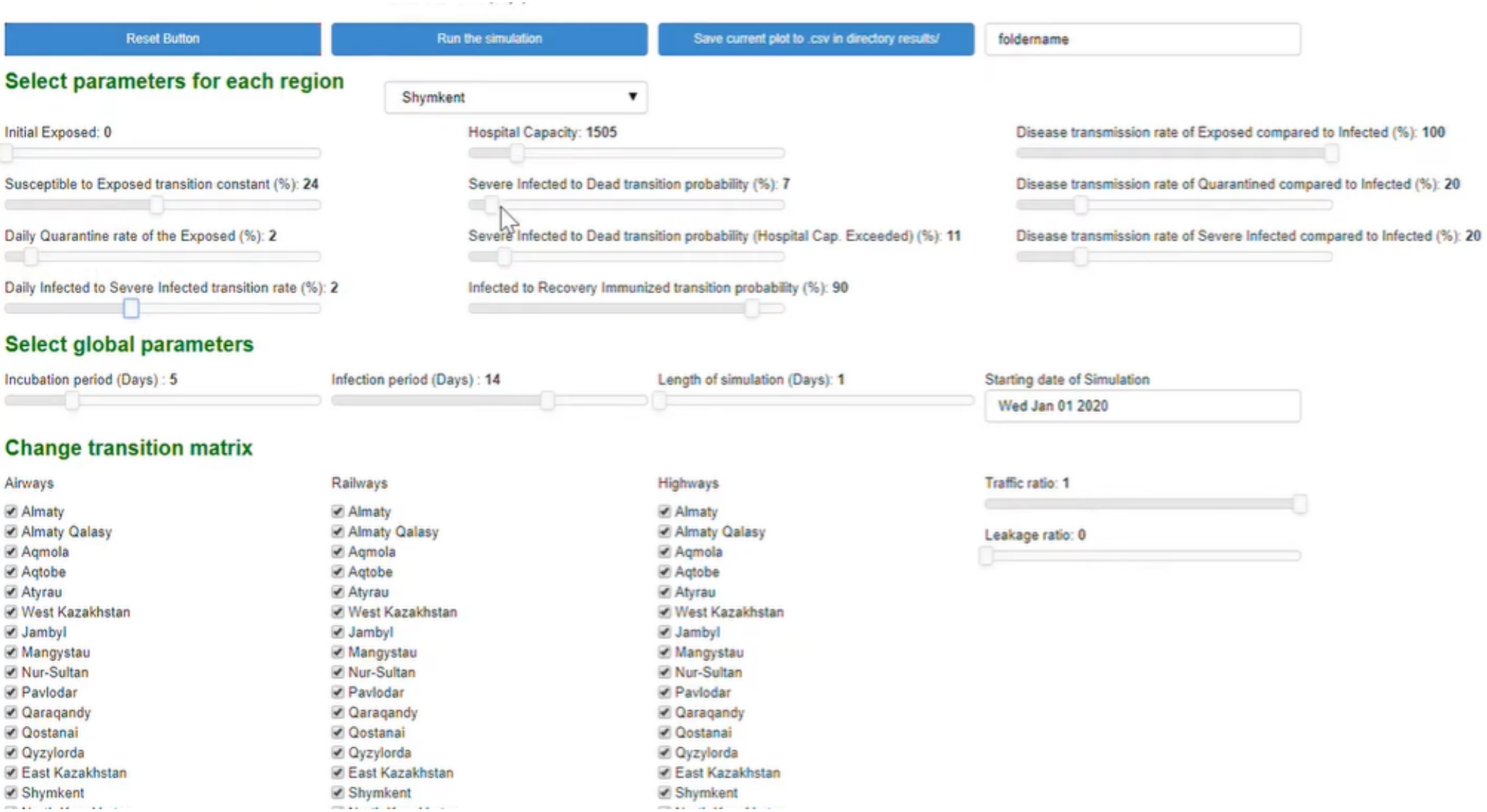
Fortune favors the prepared.

Louis Pasteur (French biologist)

Simulator Visual Interface



Simulator Control Interface

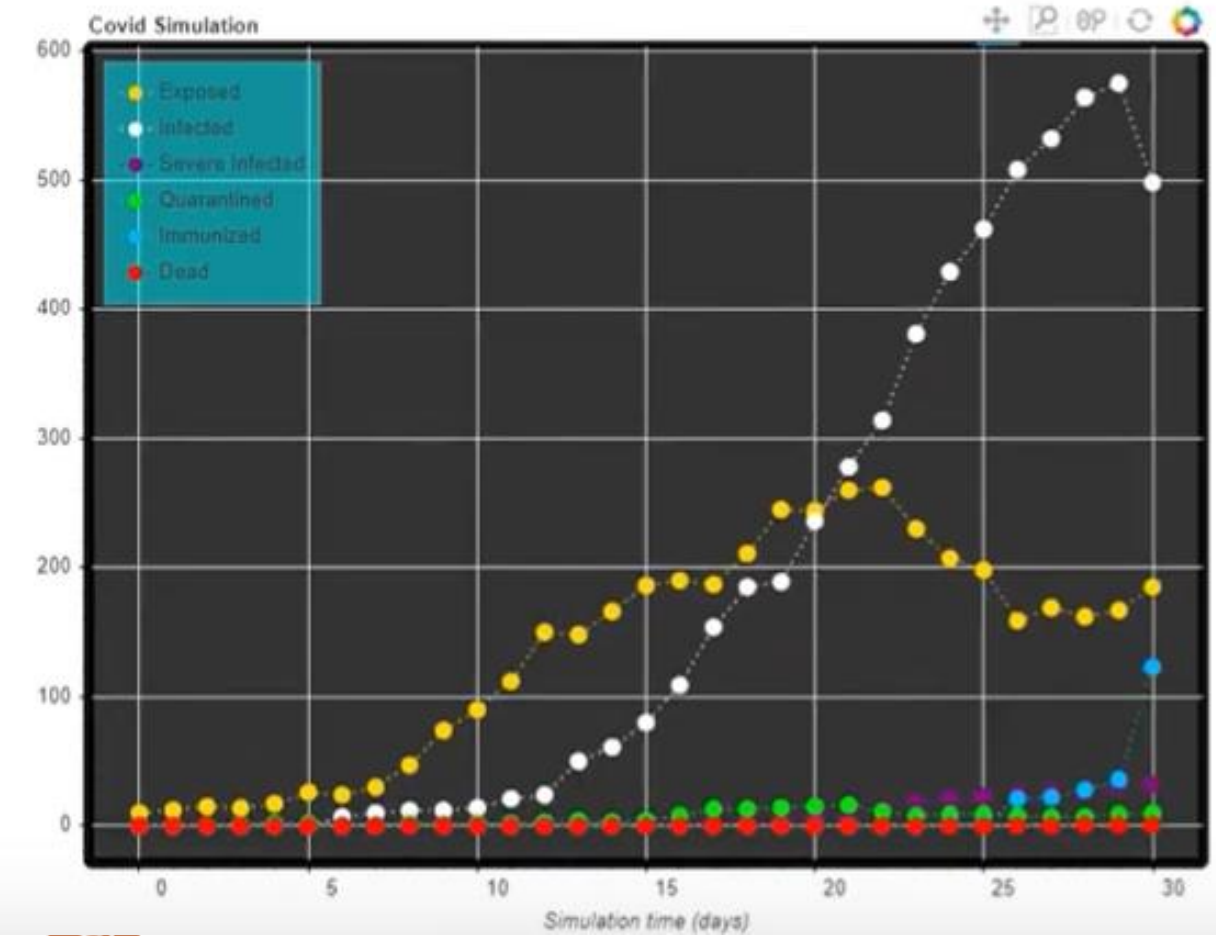


Simulation Scenario for Kazakhstan

Day	Date	Parameters
1	01.03.2020	• Death rate is 20% for Severe cases and 40% for Severe Infected (if the hospital capacity is exceeded). • Daily Infected to Severe Infected Transition rate is 1 percent. • 10 exposed in Almaty and 10 exposed in Nur-Sultan. • Beta is 0.24 for the whole country. • 5% daily quarantine rate for Almaty and Nur-Sultan (Initially, it is easy to track the contacts of the imported cases from other countries).
12	13.03.2020	• Beta is 0.17 for whole country. • Quarantine rate for Almaty and Nur-Sultan is set 2% daily.
18	19.03.2020	• Almaty and Nur-Sultan locked. Beta for Almaty and Nur-Sultan is 0.10
21	22.03.2020	• No going out in Almaty and Nur-Sultan. Beta is 0.05 for Almaty and Nur-Sultan. • Beta is 0.10 for remaining regions.
26	27.03.2020	• Beta is 0.07 for whole country except Almaty and Nur-Sultan. • Aktobe, Kostanai, Atyrau, Turkistan, Karaganda, Shymkent locked.
29	30.03.2020	• Lockdown of all regions. Beta is 0,05 for the country
79	20.05.2020	• Openings the regions and cities: Nur-Sultan, Almaty, Shymkent. • Transition matrices are set to initial. • Beta is 0.23 for the whole country

Simulation Results – 31 March 2020

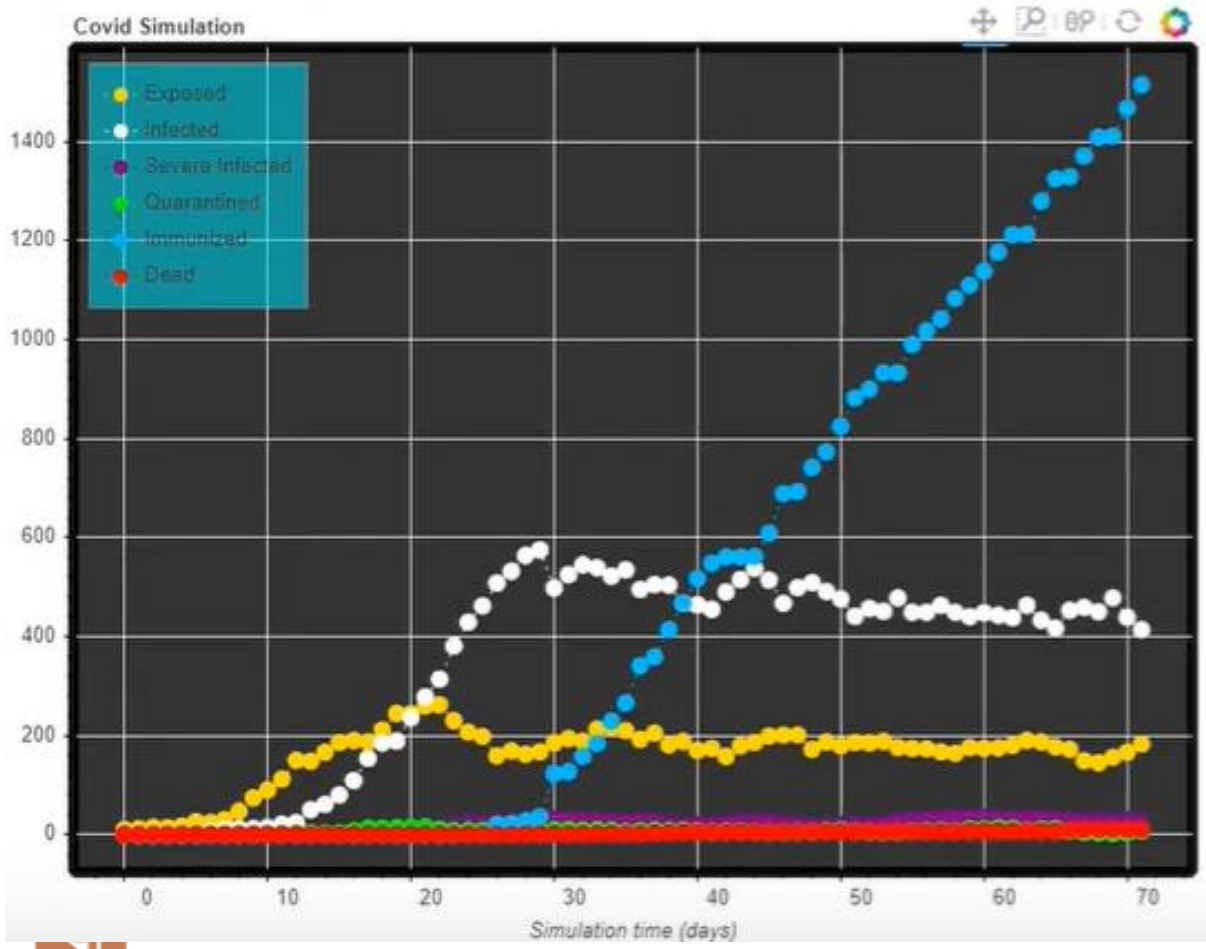
Nur-Sultan	Quarantined 10	Infected 496	Exposed 385	Severe Infected 32	Immunized 123	Death 1	Susceptible 1077310	Start date: 2020-03-01
Kazakhstan	Quarantined 17	Infected 1177	Exposed 517	Severe Infected 73	Immunized 151	Death 2	Susceptible 18393240	Current date: 2020-03-31



Results are visualized on the screen and can be saved as csv file to generate plots in other software such as Excel.

Simulation Results – 10 May 2020

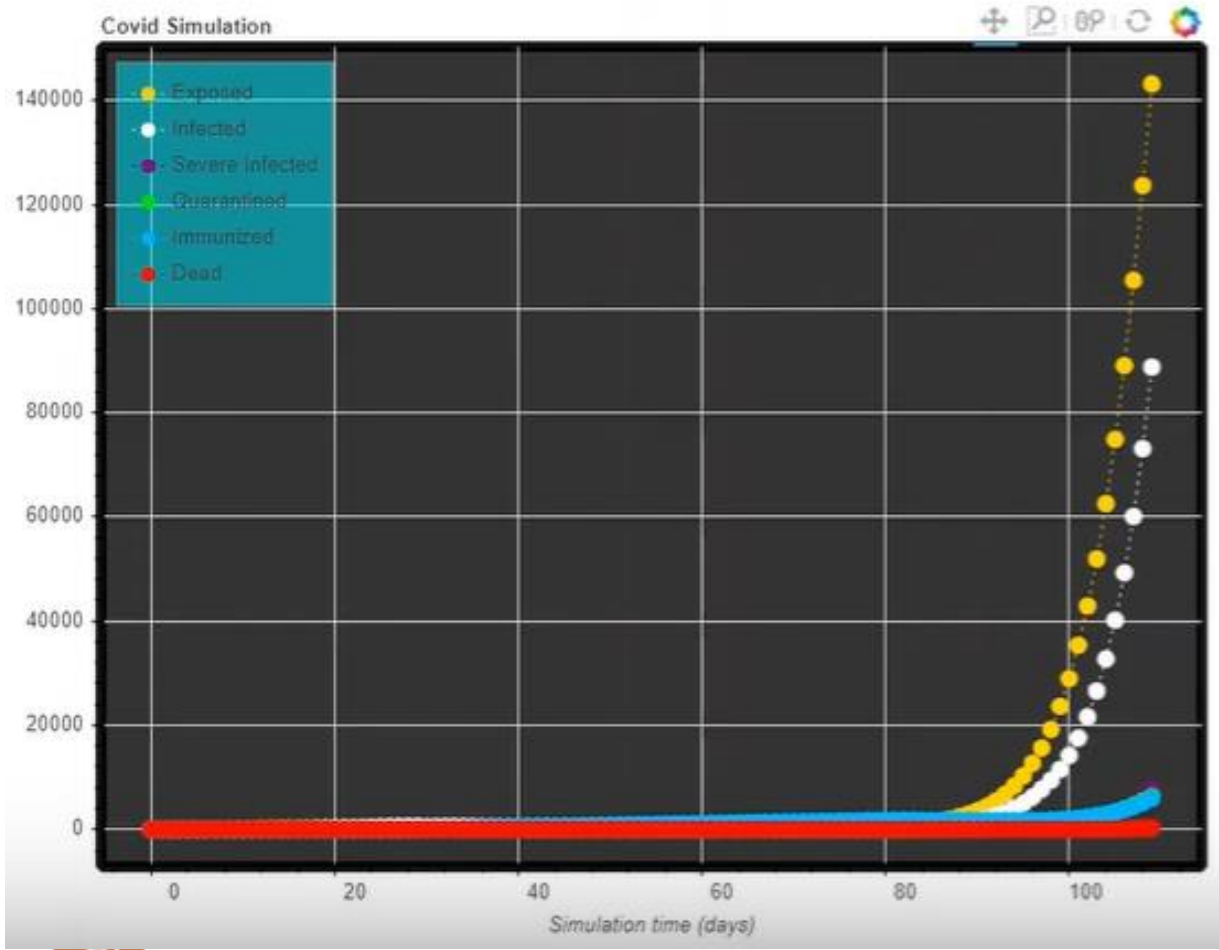
Nur-Sultan	Quarantined 7	Infected 414	Exposed 183	Severe Infected 26	Immunized 1515	Death 10	Susceptible 1076004	Start date: 2020-03-01
Kazakhstan	Quarantined 25	Infected 1536	Exposed 682	Severe Infected 124	Immunized 3543	Death 34	Susceptible 18389739	Current date: 2020-05-11

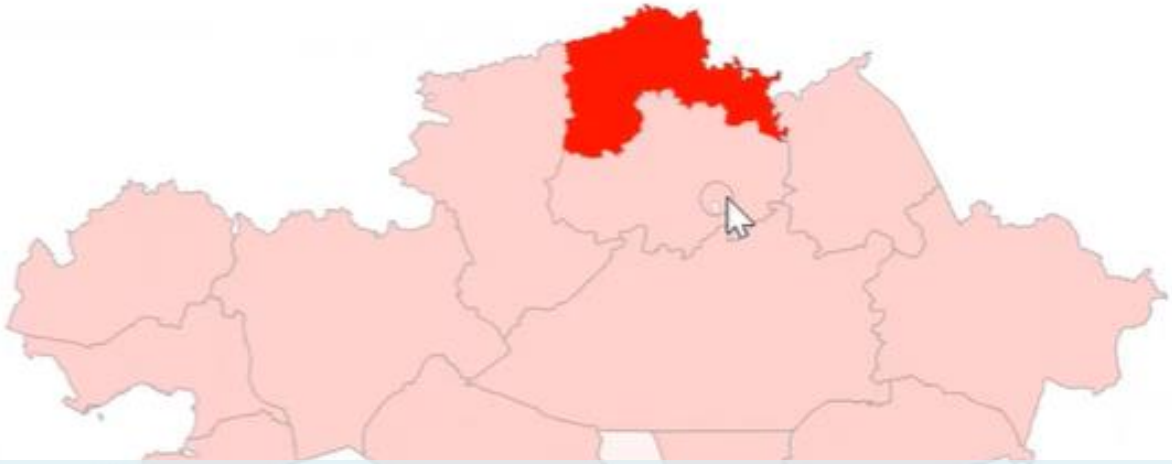


Strict measures of today continue till 10 May 2020.
→ 34 deaths on 10 May 2020.

Simulation Results – 18 June 2020

Nur-Sultan	Quarantined 6355	Infected 88800	Exposed 143175	Severe Infected 7560	Immunized 5982	Death 252	Susceptible 826682	Start date: 2020-03-01
Kazakhstan	Quarantined 45371	Infected 590713	Exposed 1050750	Severe Infected 47183	Immunized 34553	Death 1085	Susceptible 16626028	Current date: 2020-06-18





- On 20 May, measures are lifted, and people start living as they were living before the epidemic.
- Exponential rise in the number of exposed first, then infected first and then dramatic rise in deaths.

→ 1,085 deaths as of 18 June 2020 (in four weeks).

What is Next?
Simulation of Different Mitigation and Suppression Strategies