MODELING THE DYNAMICS OF COVID-19 AND ALTERNATIVE POLICIES IN TURKEY

Ekin Karamalak (ekinkaramalak@gmail.com),

Elif Bayazıt (elif.bayazit98@gmail.com)

Industrial Engineering Department, Boğaziçi University

Bebek, Istanbul 34342, Turkey

We analyze the dynamics of Covid-19 in Turkey through a System Dynamics modeling approach and by conducting simulation experiments, we aim to elucidate the effectiveness of different policies and measures in mitigation of the pandemic and explore the impacts of various social factors in order to both understand the future of the outbreak and facilitate the decision-making process of the policymakers. We hope that the results will be useful not just for Turkey, but in the global extent.

The model is based on a classical SEIR model. However, it is age-specified and extended in a way to serve our policy evaluation purposes. Three age groups, namely, Children (0-20), Adults (20-65), Elderly (65+), progress through a subset of the following stocks: Susceptible, Vaccinated, Exposed, Asymptomatic Infected, Symptomatic Infected, Hospitalized, Critical, Excess Patients, Recovered, Death, Immune, Vaccinated Exposed, Vaccinated Infected, Vaccinated Recovered. (See the simplified stock-flow diagram in Figure 1). As susceptibles contact with infected people they become exposed if the disease is transmitted. After the incubation period passes, exposed people either become asymptomatic or symptomatic infected. Asymptomatic individuals get recovered after the recovery period whereas symptomatics may get hospitalized, recover, or die. Symptomatic people who get hospitalized either recover, need critical care or die. The ones that require critical care flow into critical stock only if there is enough capacity. If there is not enough capacity, then they enter into excess patient stock. Both the patients from critical and excess stocks can either die or recover but according to different rates. Recovered patients gain immunity and move into immune stock and after a immunity delay period of 6 months, they again become susceptible. This simple overview of the model holds for 20-65 and 65+ age groups since children (0-20) assumed to show only mild symptoms they recover at the end without getting hospitalized.

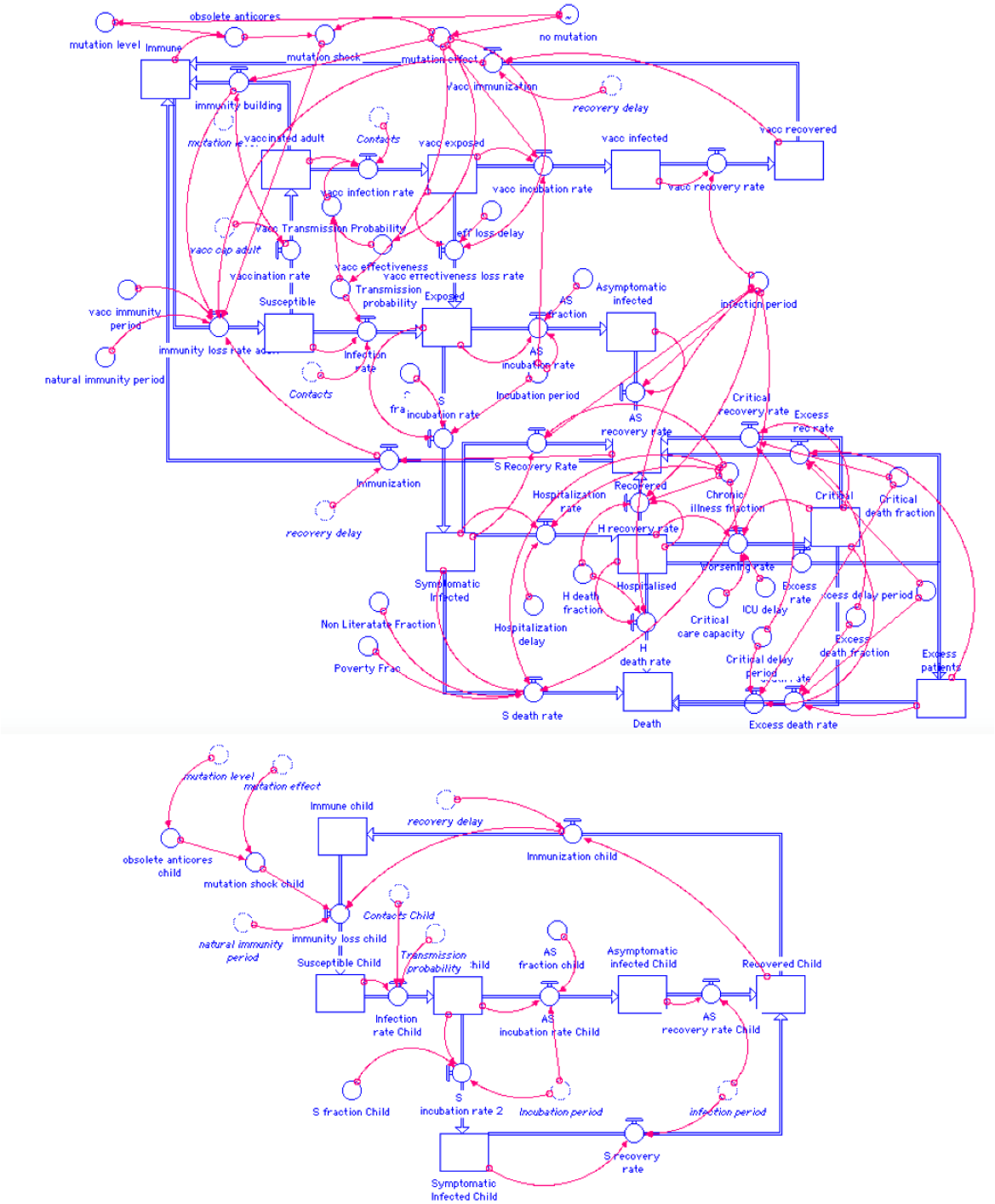

Figure 1: Simplified version of stock-flow diagram for age groups 20-65 & 65+ and for 0-20

The following factors have also been incorporated in the model:

- Testing and Quarantining
- Control Measures and Human Response
- Vaccination & Immunity

The model displays the main trends and peak points of the active cases in Turkey when provided with applied policies by government.

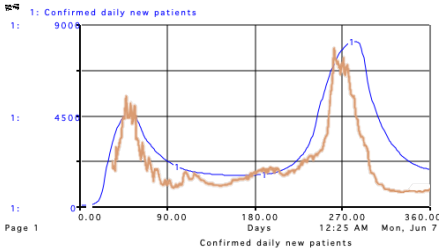

Figure 2.1: Confirmed Daily New Patients

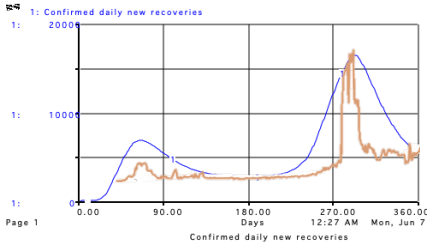

Figure 2.2: Confirmed Daily Recoveries

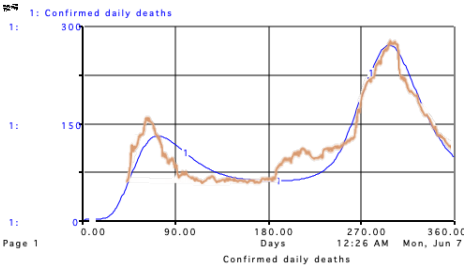

Figure 2.3: Confirmed Daily Deaths

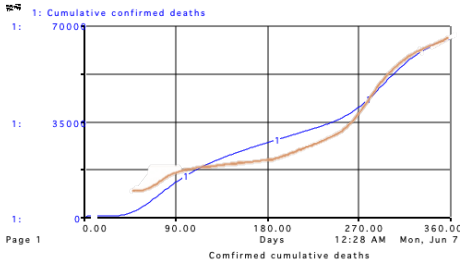

Figure 2.4: Confirmed Cumulative Deaths

By analyzing the status quo dynamics of Covid-19 in Turkey, a base scenario is determined. In the business as usual scenario, a fourth wave was estimated to take place around day 600 which peaks just above 100000 total active cases and daily new case numbers high as 5000. Immunity level of the population was estimated to stabilize at 40%, of which more than 95% were achieved through vaccination.

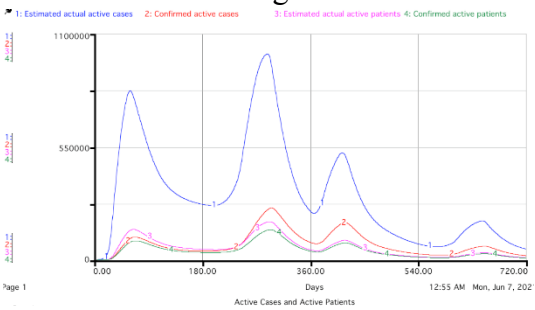

Figure 3.1: Active cases and patients

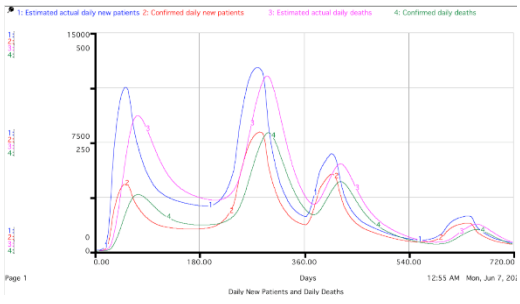

Figure 3.2: Daily new patients and deaths

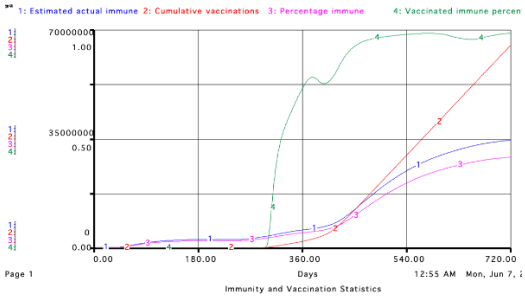

Figure 3.3: Immunity and vaccination statistics

Scenario analysis with different mutation levels, durations and start times were made. It is assumed that mutation causes effectiveness of the vaccination to decrease, transmission probability of virus to increase and a proportion of vaccinated and recovered individuals to lose their immunity.

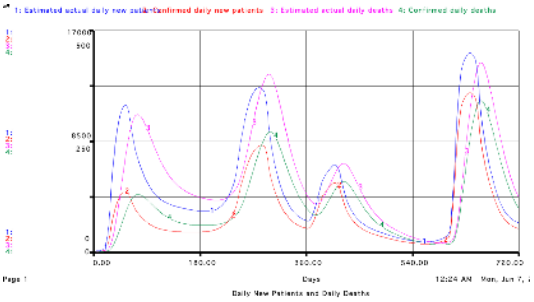

Figure 4.1 Daily statistics under high-mutation

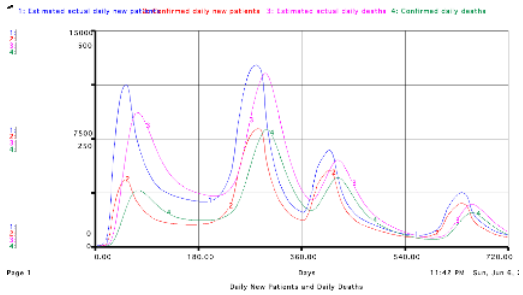

Figure 4.2: Immunity statistics under low-mutation

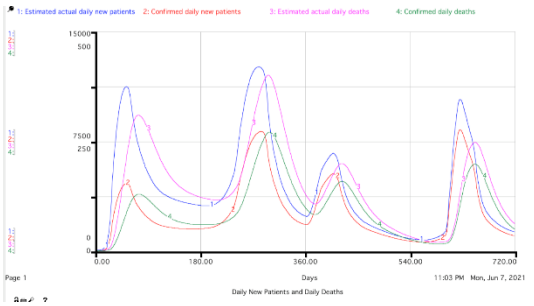

Figure 4.3 Daily statistics under short high-mutation

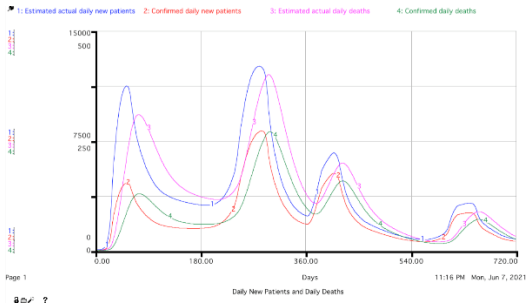

Figure 4.4: Daily statistics under short high-mutation

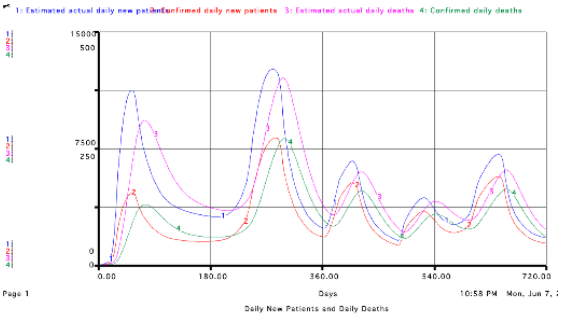

Figure 4.5 Daily statistics under early high-mutation

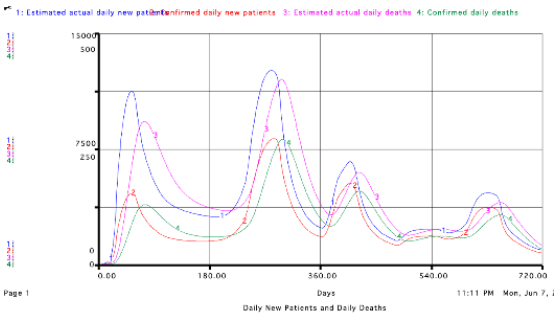

Figure 4.6: Daily statistics under early short mid-mutation

Simulation runs with low, medium and high immunity periods for vaccines and with different vaccination capacities were made.

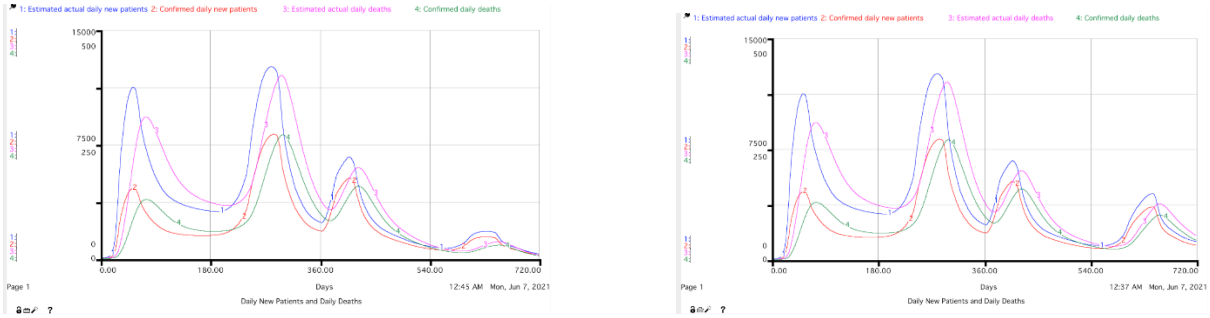

Figure 5.1 : Daily patient and death statistics with high vs. low vaccine immunity period

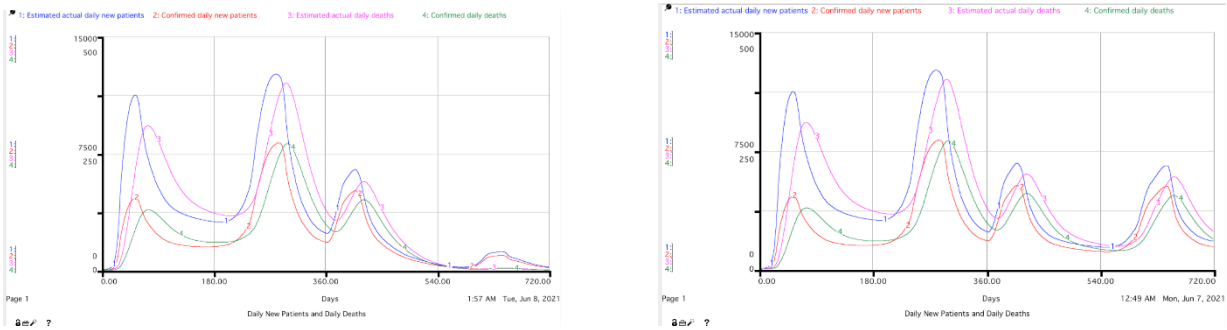

Figure 5.2: Daily patient and death statistics with high vs. low vaccine capacity

Adherence fatigue shows the people's willingness to comply with the policies imposed by the government and general social distancing and hygiene rules. High adherence fatigue increases the contacts, thus the people getting infected so in this scenario the percentage of people getting naturally immune is higher than the low adherence scenario.

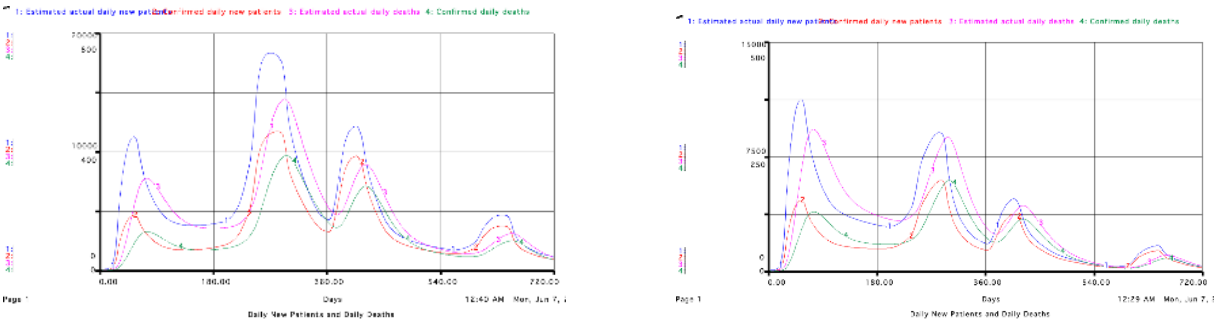

Figure 6 : Daily patient and death statistics with high vs. low adherence fatigue

The validation analysis has shown that the model is successful in capturing the main dynamics of the COVID-19 pandemic in Turkey and the model was able to reveal reasonable estimates of the key variables for policy evaluation and scenario analysis which are currently unknown in the existing database of the decision-making bodies.

Results of simulation runs of main scenario experiments and their interactions showed that adherence is a key factor that determines the future of pandemic. When the vaccination related scenario experiments are analyzed, it is seen that a high vaccination capacity is more effective than a high immunity period in reducing the cumulative cases and deaths in the end. Finally, on the mutation side mutation level turned out to be a more important determinant than its duration and starting time.

7. REFERENCES

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APPENDIX A: THE MODEL VARIABLES

Stock/Flow	Brief Description	Unit
Susceptible	Population of age group i who are susceptible to virus	People
Exposed	Population of age group i who are exposed to virus but not determined to develop symptoms or not	People
Asymptomatic Infected	Population of age group i who are infected but don't show symptoms	People
Symptomatic Infected	Population of age group i who are infected and show symptoms	People
Hospitalised	Population of age group i whose symptoms get serious and require hospitalization	People
Critical	Population of age group i whose symptoms get fatal and require ICU	People
Excess Patients	Population of age group i who require ICU but don't have the access due to limited capacity	People
Recovered	Population of age group i who have just recovered	People
Death	Cumulative population of age group i who are dead due to virus	People
Vaccinated	Population of age group i who have just been vaccinated	People
Immune	Population of age group i who develop immunity to virus either naturally by being infected or through vaccination	People
Vaccinated Exposed	Population of age group i who are vaccinated but are exposed to virus before developing immunity	People
Vaccinated Infected	Population of age group i who are infected but show only mild symptoms due to being vaccinated	People
Vaccinated Recovered	Population of age group i who are vaccinated and have just recovered from infection	People
Infection Rate	Rate at which susceptible population of age group i get infected	Person/Day
AS Incubation Rate	Rate at which exposed individuals of age group i get asymptomatically infected	Person/Day
S Incubation Rate	Rate at which exposed individuals of age group i start showing symptoms	Person/Day
Hospitalization Rate	Rate at which symptomatic individuals of age group i become serious and move to hospital	Person/Day
Worsening Rate	Rate at which hospitalized individuals of age group i get worse and need intensive care	Person/Day

Excess Rate	Rate at which hospitalized patients of age group i that could not find enough capacity in critical care units move to excess stock	Person/Day
S Death Rate	Rate at which symptomatic individuals of age group i that could not reach to hospital die	Person/Day
H Death Rate	Rate at which patients of age group i that are hospitalized die	Person/Day
C Death Rate	Rate at which patients of age group i in critical care units die	Person/Day
Excess Death Rate	Rate at which patients of age group i in excess stock die since they could not enter into critical care units	Person/Day
AS Recovery Rate	Rate of recovery of asymptomatic individuals in age group i	Person/Day
S Recovery Rate	Rate of recovery of symptomatic individuals in age group i	Person/Day
H Recovery Rate	Rate of recovery of hospitalized patients in age group i	Person/Day
Critical Recovery Rate	Rate of recovery of patients in critical care units in age group i	Person/Day
Excess Recovery Rate	Rate of recovery of patients in excess stock of age group i	Person/Day
Vaccination Rate	Rate at which susceptible individuals of age group i get vaccinated	Person/Day
Vaccinated Infection Rate	Rate at which vaccinated individuals from age group i get infected	Person/Day
Vaccinated Incubation Rate	Rate at which vaccinated exposed individuals from age group i start showing mild symptoms	Person/Day
Vaccinated Recovery Rate	Rate at which vaccinated infected individuals from age group i recover from infection	Person/Day
Vaccinated Immunization	Rate at which vaccinated recovered individuals from age group i build immunity after experiencing the disease	Person/Day
Immunity Building	Rate at which vaccinated individuals from age group i develop antibodies to virus	Person/Day
Immunity Loss	Rate at which immune individuals from age group i lose their immunities after a certain immunity period	Person/Day
Vaccine Effectiveness Loss	Rate at which vaccinated exposed individuals from age group i become exposed as vaccine loses its effectiveness	Person/Day

Immunization	Rate at which recovered individuals from age group i build immunity after experiencing the disease	Person/Day

APPENDIX B: SCENARIO RUNS

Trials	Adherence Fatigue	Vaccine Immunity Period	Daily Vaccine Capacity	Mutation			Cumulative Cases	Cumulative Deaths
	Level	Level	Level	Level	Start	Duration		
1	Base	Base	Base	Base	Day 600	120 days	10.8M	95.9k
2	Base	High	Base	Base	Day 600	120 days	10.6M	93.6K
3	Base	Low	Base	Base	Day 600	120 days	11.5M	102.2K
4	Base	Base	High	Base	Day 600	120 days	10.1M	88.3k
5	Base	Base	Low	Base	Day 600	120 days	12.3M	109.8K
6	High	Base	Base	Base	Day 600	120 days	16.1M	139.6k
7	Low	Base	Base	Base	Day 600	120 days	8.8M	78.2k
8	Base	Base	Base	High	Day 600	120 days	13.8M	120.2k
9	Base	Base	Base	Medium	Day 600	120 days	11.9M	104.9k
10	Base	Base	Base	Low	Day 600	120 days	11.1M	98.4k
11	Base	High	High	Base	Day 600	120 days	10M	87.8k
12	Base	High	Low	Base	Day 600	120 days	12.2M	108.6k
13	Base	Low	High	Base	Day 600	120 days	10.7M	94.4k
14	Base	Low	Low	Base	Day 600	120 days	12.6M	112k
15	High	High	Base	Base	Day 600	120 days	15.6M	135.1k
16	High	Low	Base	Base	Day 600	120 days	17.5M	151.7k
17	Low	High	Base	Base	Day 600	120 days	8.6M	76.8k
18	Low	Low	Base	Base	Day 600	120 days	9.3M	82.7k
19	Base	High	Base	High	Day 600	120 days	13.7M	119.3k
20	Base	High	Base	Medium	Day 600	120 days	11.5M	101.3k
21	Base	High	Base	Low	Day 600	120 days	10.8M	95.7k
22	Base	Low	Base	High	Day 600	120 days	14M	122.7k

23	Base	Low	Base	Medium	Day 600	120 days	12.8M	112.4k
24	Base	Low	Base	Low	Day 600	120 days	11.9M	105.3k
25	High	Base	Base	High	Day 600	120 days	19.8M	168.7k
26	High	Base	Base	Medium	Day 600	120 days	18.1M	154.6k
27	High	Base	Base	Low	Day 600	120 days	16.8M	145.2k
28	Low	Base	Base	High	Day 600	120 days	11.1M	98.3k
29	Low	Base	Base	Medium	Day 600	120 days	9.5M	84.2k
30	Low	Base	Base	Low	Day 600	120 days	9M	80k
31	High	Base	High	Base	Day 600	120 days	14.7M	124.1K
32	High	Base	Low	Base	Day 600	120 days	18.8M	162.8K
33	Low	Base	High	Base	Day 600	120 days	8.2M	73.9K
34	Low	Base	Low	Base	Day 600	120 days	9.9M	88.2K
35	Base	Base	High	High	Day 600	120 days	13.2M	114.3K
36	Base	Base	High	Medium	Day 600	120 days	10.7M	93.9K
37	High	Base	High	Low	Day 600	120 days	10.2M	89.4K
38	Base	Base	Low	High	Day 600	120 days	14.4M	126.9K
39	Base	Base	Low	Medium	Day 600	120 days	13.5M	119K
40	High	Base	Low	Low	Day 600	120 days	12.8M	113.4K
41	Base	Base	Base	Low	Day 480	120 days	11.1M	98.6k
42	Base	Base	Base	High	Day 480	120 days	13.2M	116.4k
43	Base	Base	Base	Low	Day 600	60 days	11M	97.9k
44	Base	Base	Base	High	Day 600	60 days	12.6M	110.5k
45	Base	Base	Base	Medium	Day 480	180 days	12M	106.5k
46	High	Base	Base	Medium	Day 480	180 days	18.4M	157.7k
47	High	Base	Low	Medium	Day 480	180 days	20.2M	174.9k
48	High	High	High	Medium	Day 480	180 days	15.8M	135.1k
49	Low	High	High	Medium	Day 480	180 days	8.8M	77.1k
50	Low	Low	Low	Medium	Day 480	180 days	10.7M	96.1k

51	Low	Low	Base	Medium	Day 480	180 days	10.2M	90.8k
52	Low	Low	Low	Low	Day 600	60 days	10.1M	91k
53	Low	High	Low	Low	Day 600	60 days	9.9M	88.8k
54	High	Low	Low	High	Day 600	60 days	20M	173.3K
55	High	Low	Low	High	Day 600	120 days	20.6M	178.3k
56	High	High	High	Low	Day 600	120 days	14.7M	123.5k
57	High	High	High	Low	Day 480	120 days	14.8M	124.6k
58	High	Low	High	Low	Day 480	120 days	16.6M	142.7k
59	High	Low	Low	Low	Day 480	120 days	19.4M	168.6k
60	Low	Low	Low	Low	Day 480	120 days	10.1M	91.2k
61	Base	Low	High	Low	Day 480	120 days	11M	97k
62	Low	High	High	Low	Day 480	120 days	8.3M	74.1M
63	Low	High	High	High	Day 480	120 days	10.3M	90.9k
64	High	High	High	High	Day 480	120 days	20.1M	170.1k
65	High	High	Low	High	Day 480	120 days	21.3M	184.6k
66	High	Low	Low	High	Day 480	120 days	21.4M	185.3k
67	Base	High	Low	High	Day 480	120 days	13.6M	121.1k
68	High	High	High	High	Day 600	60 days	15.9M	133.3k
69	High	High	Low	High	Day 600	60 days	19.6M	168.9k
70	High	Low	High	High	Day 600	60 days	18.3M	154k
71	Low	Low	High	High	Day 600	60 days	9.7M	85.7k
72	Low	High	High	Low	Day 600	60 days	8.2M	73.7k
73	Low	Low	High	Low	Day 600	60 days	8.6M	77.9k
74	High	High	High	Low	Day 600	60 days	14.6M	122.9k
75	High	Low	Low	Low	Day 600	60 days	19.3M	167.3k

**Rows that are highlighted in yellow indicates the trials that are mentioned in the discussion part.*

***Rows that are highlighted in red indicates the trials that yields the most adverse results.*