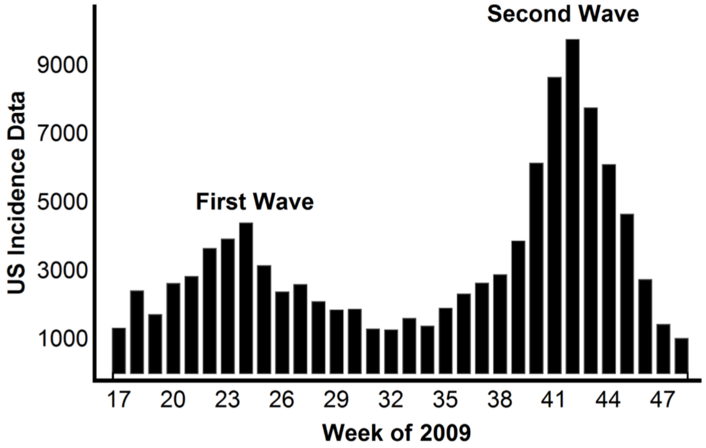
Final Presentation: H1N1 Vaccination Management

Ran Cao, Jennifer Salvatore, M.E. Shelton

Background Information:

(CDC) The H1N1 Incidence in the U.S.



In 2009, the great H1N1 Pandemic hit. This flu was unique and new, and there was no protection available from it

- H1N1 hit in two waves: one in June 2009 and one in late August 2009.
- Much of the U.S. population was infected during this outbreak.
- In total, there were 60.8 million cases, 274,304 hospitalizations, and 12,469 deaths due to H1N1 in the United States (CDC).
- Symptoms last roughly two weeks after an incubation period of two days
- A vaccine could lessen, and virtually eliminate influenza if properly treated.

Background For Our Model:

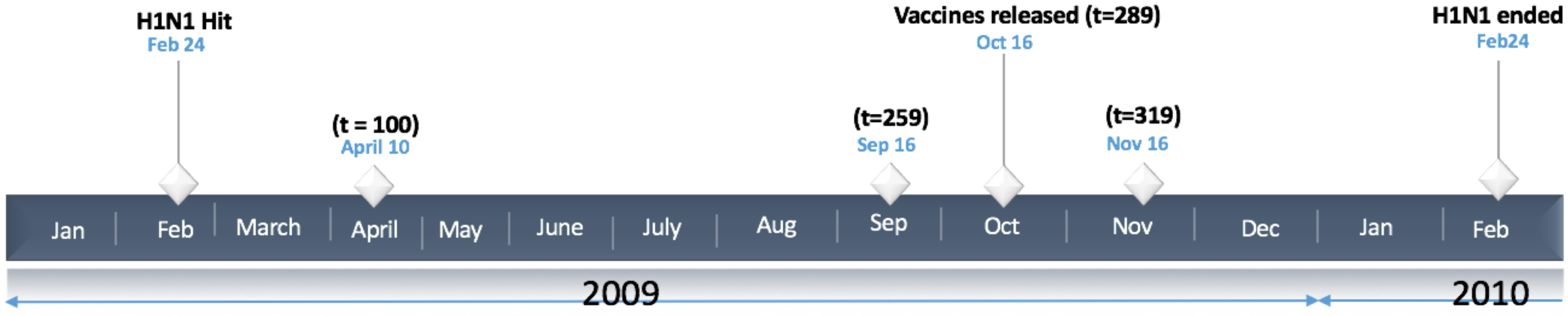
- For this study, the timeline that we used was for one year, from late February 2009 to February 2010.
- The data we have chosen is data from the H1N1 pandemic that hit America.
- We found our values from the CDC’s website. We used this data to create assumptions and as a basis for our mathematical analysis for our model.
- These assumptions allowed us to make a slightly simplified model to represent the susceptible and infected relationship.
- We created this model in Matlab.

Assumptions:

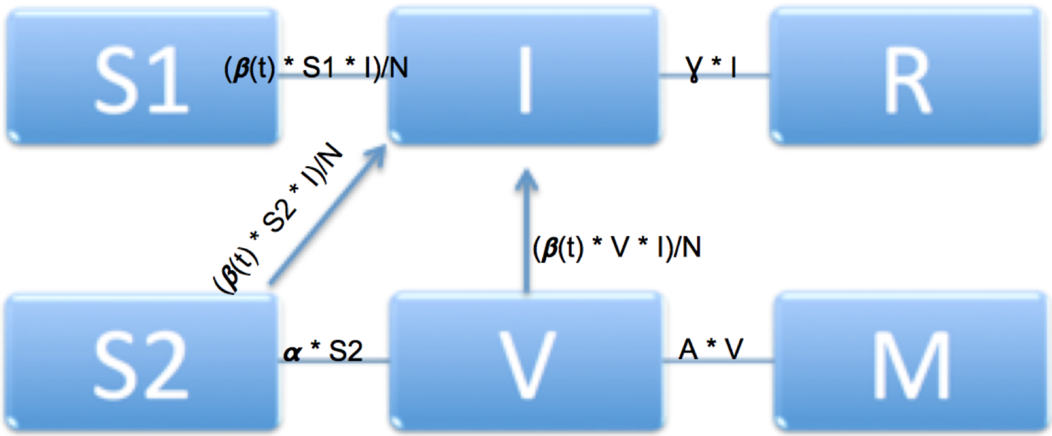
- Babies being born and people dying from old age are equal and cancel one another out.
- No one starts out immune, and that they need to be vaccinated in order to be immune.
- If someone in the model is infected with a virus, that virus is H1N1.
- The rate of becoming immune through vaccination (parameter A) and the recovery rate (parameter γ) are constants.
- Average time that it takes a vaccine to make someone immune is two weeks (after getting vaccinated).
- Our expected recovery time was 3 days (no longer infectious at 3 days).

Assumptions Cont.:

- January 1, 2009, is when t = 0
- The epidemic starts on February 24, 2009 (t = 55).
- Vaccine release date on October 16th (t = 289).
- Vaccination rate (α) is 0.0033.
- The vaccines is 89% effective for the population.
- ⅓ of the United States population got vaccinated.



Variables and Model Chart:



- S1 – People Susceptible to H1N1 but unresponsive to vaccines
- S2 - People Susceptible to H1N1 but responsive to vaccines
- I – People Infected with H1N1
- V – People who received the H1N1 Vaccination
- R – People who are Removed from the model (Recovered/dead)
- M – People who are Immune to H1N1 after vaccinated

Parameters:

- $\beta(t)$ - contact rate

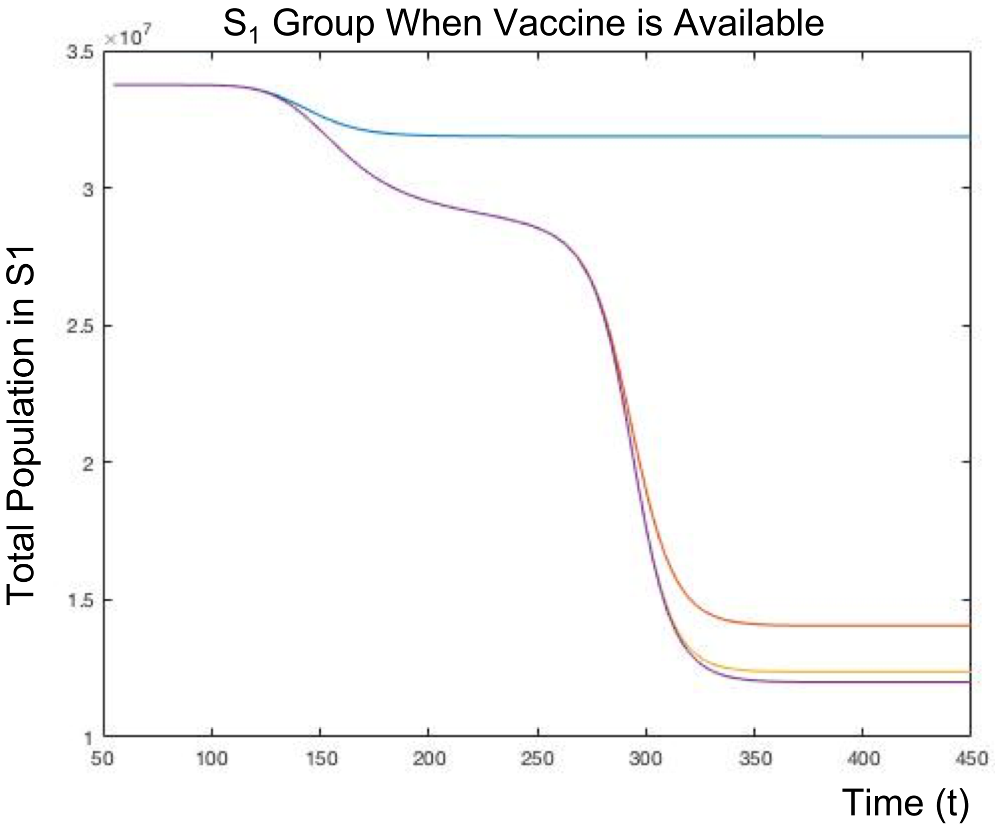
  $= 0.52(1 + 0.35 \cos(2(\pi t/365)))$
- α - vaccination rate

  (total # of vaccines produced/ # of days left until end of year) = 0.0033
- γ - recovery rate (exponential decay)

  # of people recovering every day = (1/ expected recovery time) = 1/3
- A - vaccinated people who become immune rate (exponential decay)
  - A = 1 / 2 weeks = 1/ 14
  - (-1/14)*V

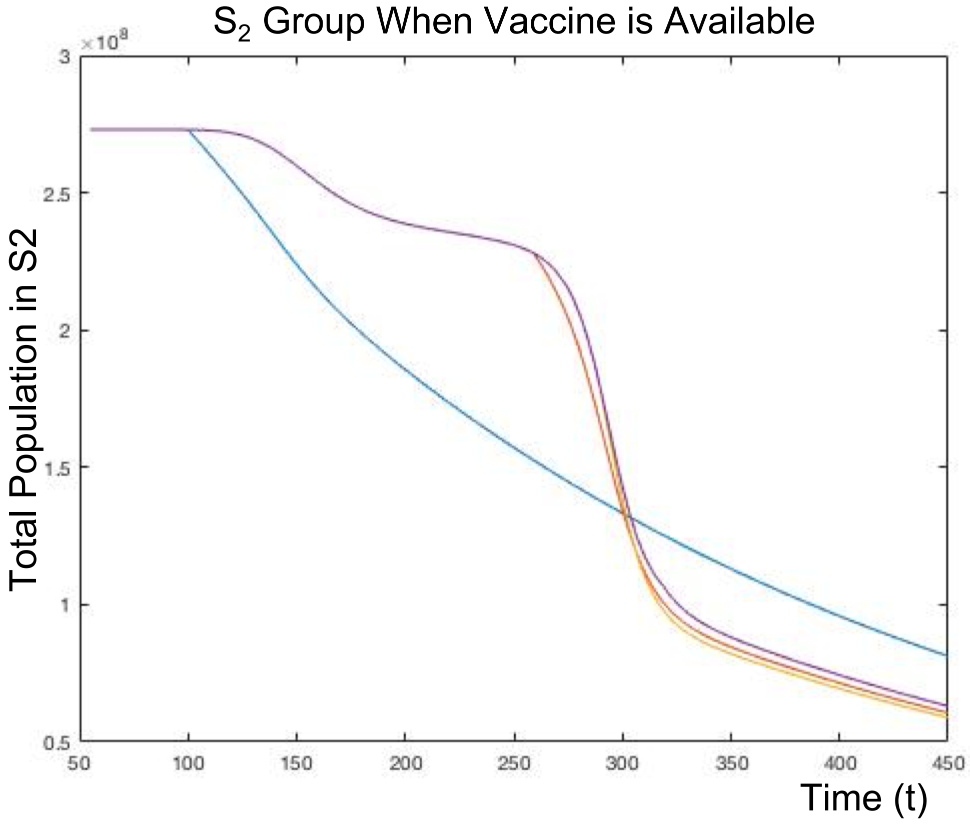
S1(Susceptible Individuals Unresponsive to Vaccines):

- t=100 (Blue)
- t=259 (Red)
- t=289 (Yellow)
- t=319 (Purple)

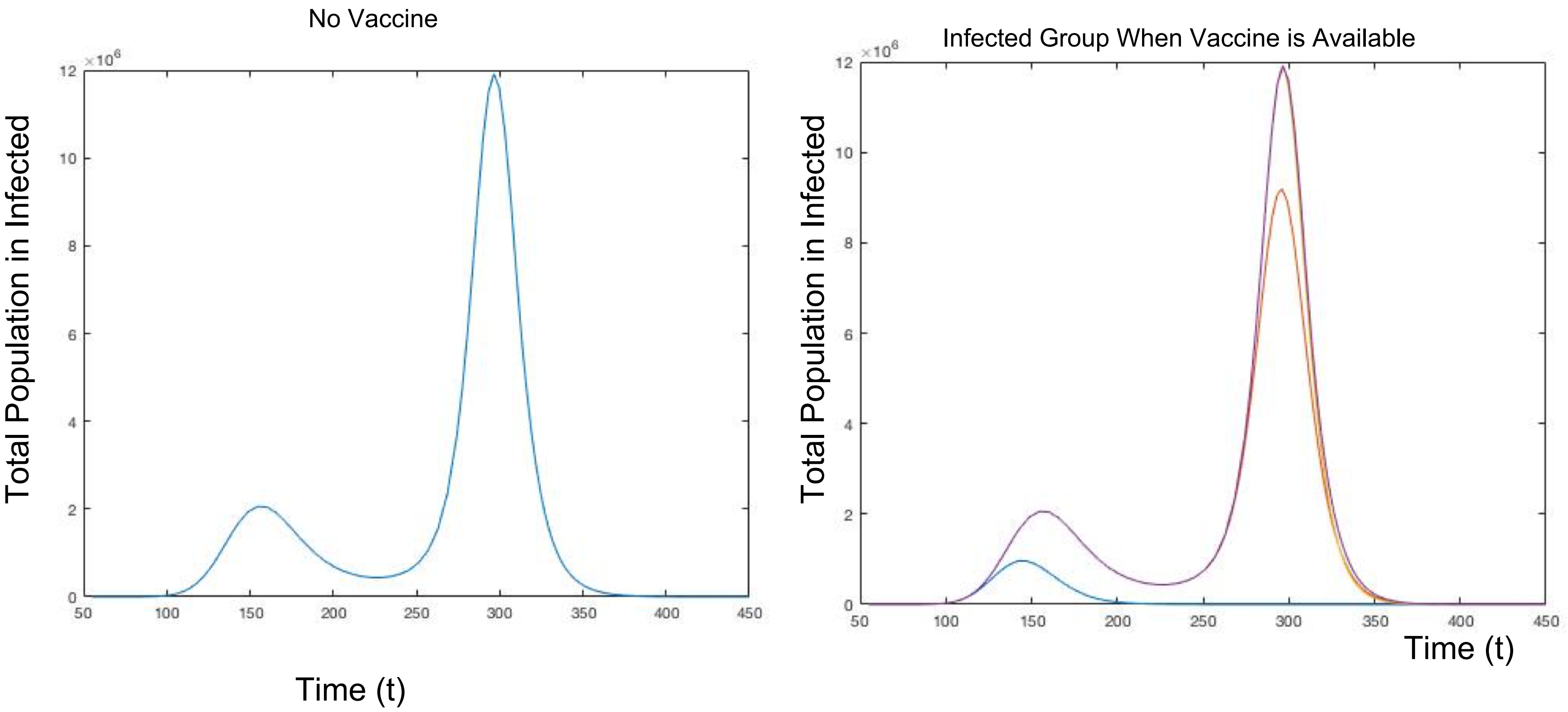


S2 (Susceptible Individuals Responsive to Vaccines):

- t=100 (Blue)
- t=259 (Red)
- t=289 (Yellow)
- t=319 (Purple)

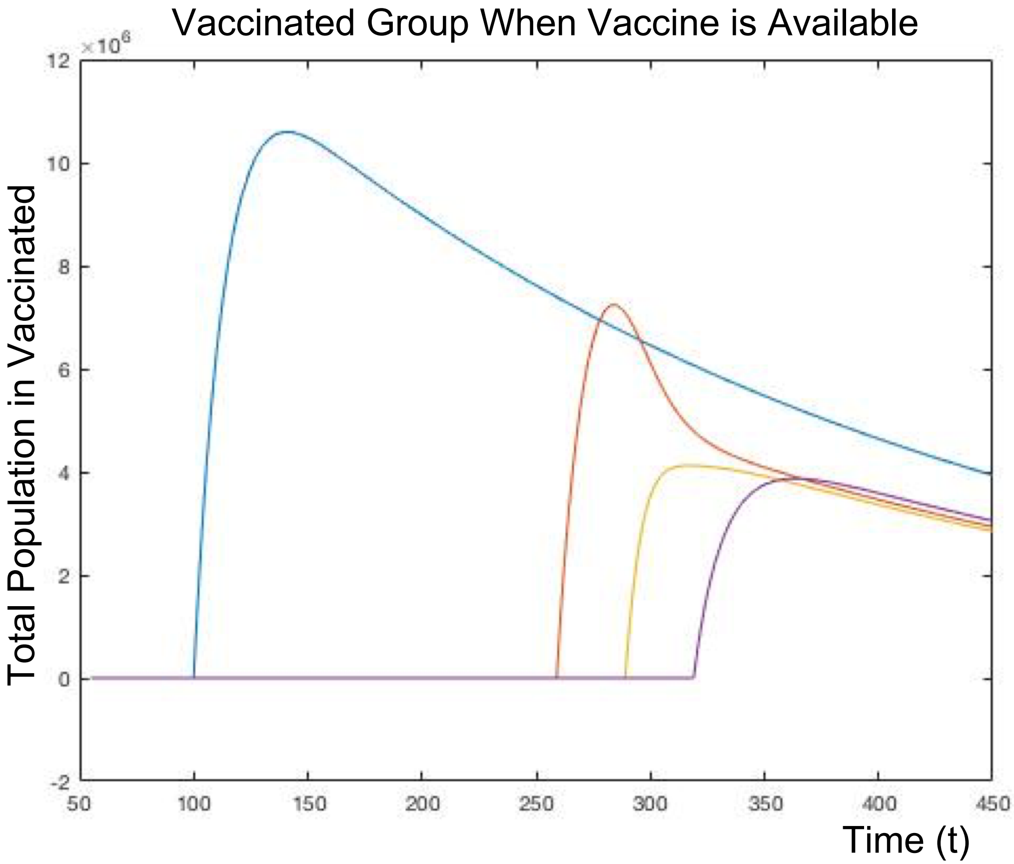


Infected Group as Vaccine Release Date Changed:



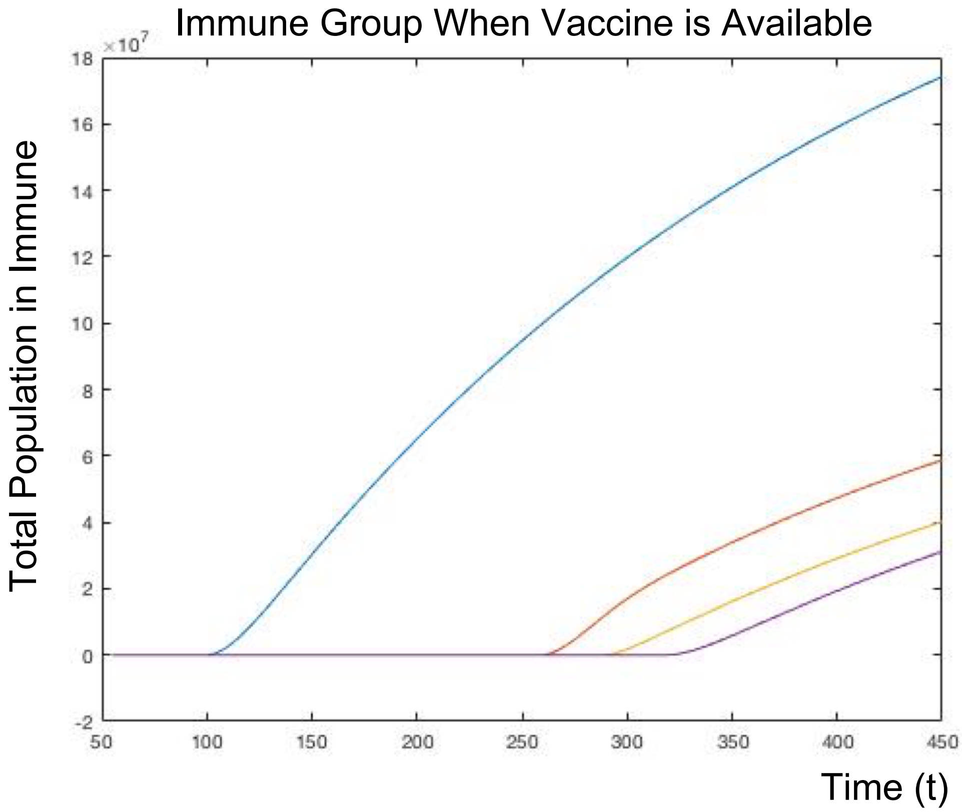
Vaccinated Group as Vaccine Release Date Changed:

- t=100 (Blue)
- t=259 (Red)
- t=289 (Yellow)
- t=319 (Purple)



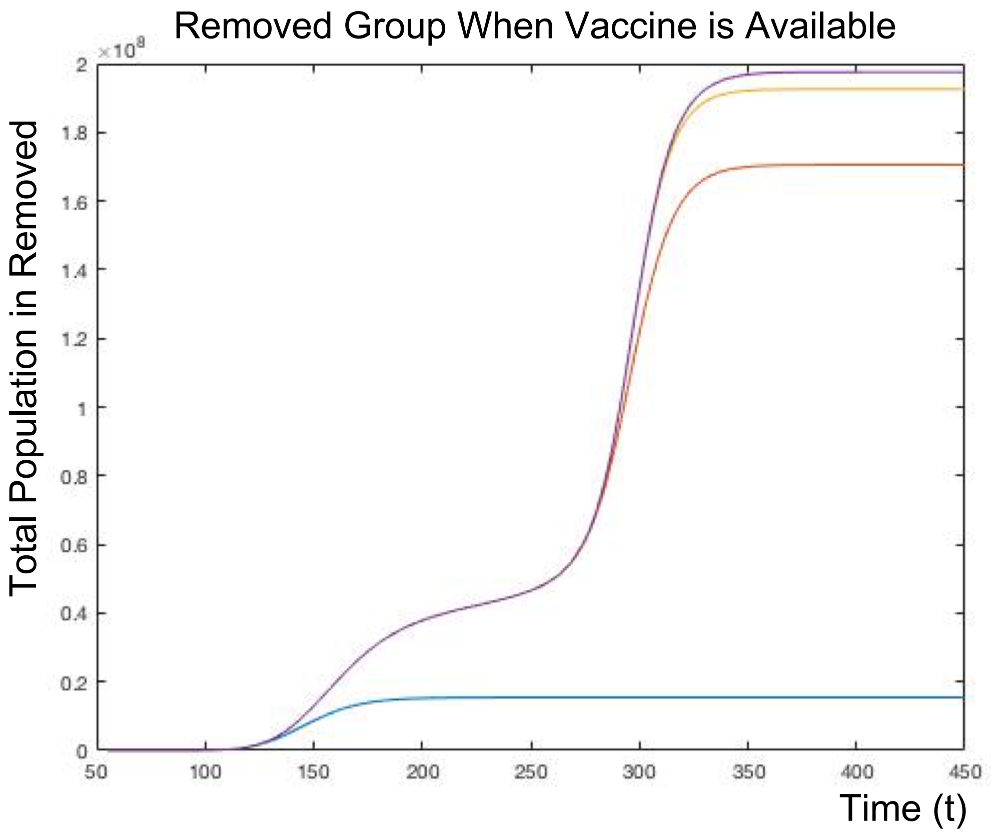
Immune Group as Vaccine Release Date Changed:

- t=100 (Blue)
- t=259 (Red)
- t=289 (Yellow)
- t=319 (Purple)



Removed Group as Vaccine Release Date Changed:

- t=100 (Blue)
- t=259 (Red)
- t=289 (Yellow)
- t=319 (Purple)



Cost Benefit Analysis:

Cost benefit analysis is defined as a systematic process for calculating and comparing benefits and costs of a decision, policy or project.

In our model, we did cost-benefit analysis because our goals are to figure out:

1. An estimation of morbidity, hospitalized population, mortality, and the economic costs when varying the vaccines distribution dates

2. The effect of changing the vaccine efficacy rate

3. Cost-benefit analysis of releasing vaccines a month earlier and a month later.

Report Rate:

- Our model showed 192.56 million people made it to the removed group.
- However, not all infected people actually got reported.
- We merge the actual data and our data together with a multiplier of 0.316 to calculate that of the 192.56 million, only 60.8 million (CDC data) were sick enough to report themselves as infected.

$$report\ rate = \frac{60.8\ million\ reported\ cases}{192.56\ million\ total\ infected\ population} = 0.316$$

Information For Vaccination Cost:

We decided the cost of our vaccination which allowed us to continue with our model and to find our end results:

- $6.15 billion spent on all of H1N1 prevention
- We decided the vaccination cost roughly half of that ($3.075 billion).
- cost per vaccination:

$$\frac{\$3.075\ billion\ vaccination\ cost}{\$118\ million\ vacciated\ population} \approx \$26\ per\ vaccination$$

Source: http://www.pbs.org/newshour/updates/health-july-dec09-flu-costs_10-08/

Assumptions for Our Cost Benefit Analysis:

Calculating the morbidity and mortality:

■ report rate is 0.316

■ US population in 2009 was 306,800,000.

Calculating the cost of lost wages:

■ Expected recovery time was 3 days.

■ US average salary is 59,039.

■ Half of the infected population is children and they don’t have salary.

Calculating the hospital cost:

■ For each patient, the average cost per inpatient day is $1,986.

Calculating the vaccination cost:

■ Vaccination cost = 26 dollar/dose

■ Ignore the vaccine production cost and cost for paying researchers’ salary. We only focused on the cost for susceptible group to get vaccinated.

Cost Benefit Analysis For Changing Vaccine Release Date:

Equations we used to come up with morbidity, hospitalized population, and mortality:

hospitalization/morbidity ratio = $$\frac{actual\ hospitalization}{actual\ cases} = \frac{274{,}304}{60{,}800{,}000}$$

mortality/morbidity ratio = $$\frac{actual\ deaths}{actual\ cases} = \frac{12{,}469}{60{,}800{,}000}$$

For our model, Matlab gave us the morbidity number. Hospitalized population and mortality were derived by:

hospitalized population = morbidity * report rate * hospitalization/morbidity ratio
mortality = morbidity * report rate * mortality/morbidity ratio

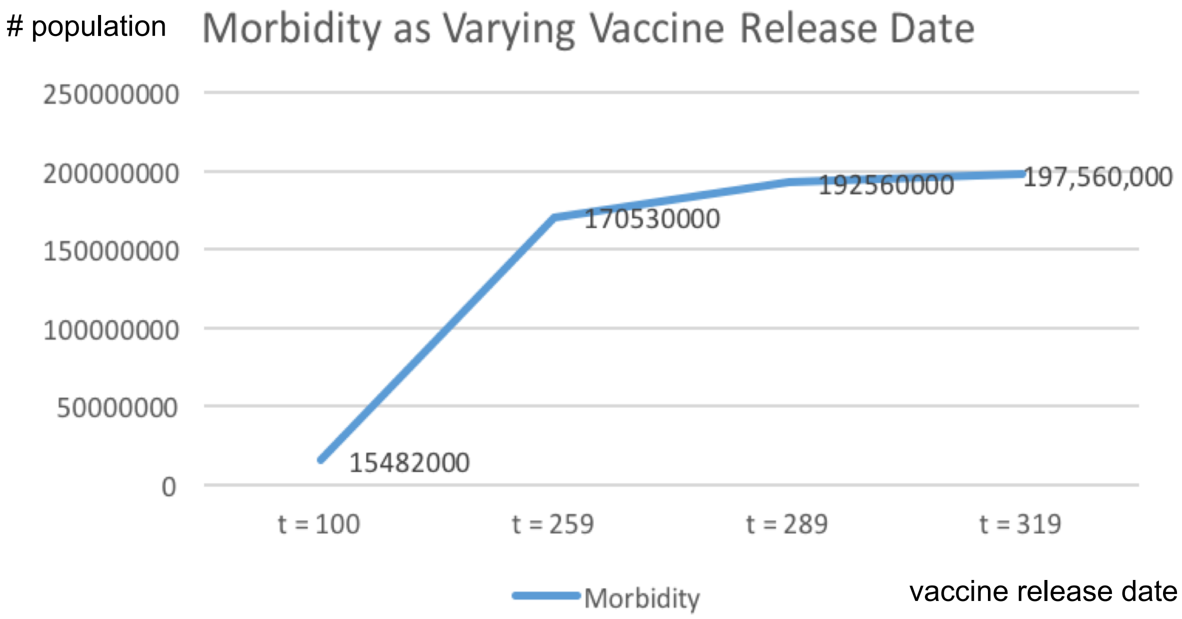
Results When Changing Vaccine Release Date:

	T = 100	T = 259	T = 289	T = 319
morbidity	15,482,000	170,530,000	192,560,000	197,560,000
hospitalized population	22,072	243,120	274,530	281,650
mortality	1,003	11,051	12,479	12,803

Trends: having a vaccine available earlier decreases the morbidity, hospitalized population, and mortality.

Changes in Morbidity as Vaccine Release Date Changes:

Vaccine Release Day	Morbidity
T = 100	15,482,000
T = 259	170,530,000
T = 289	192,560,000
T = 319	197,560,000

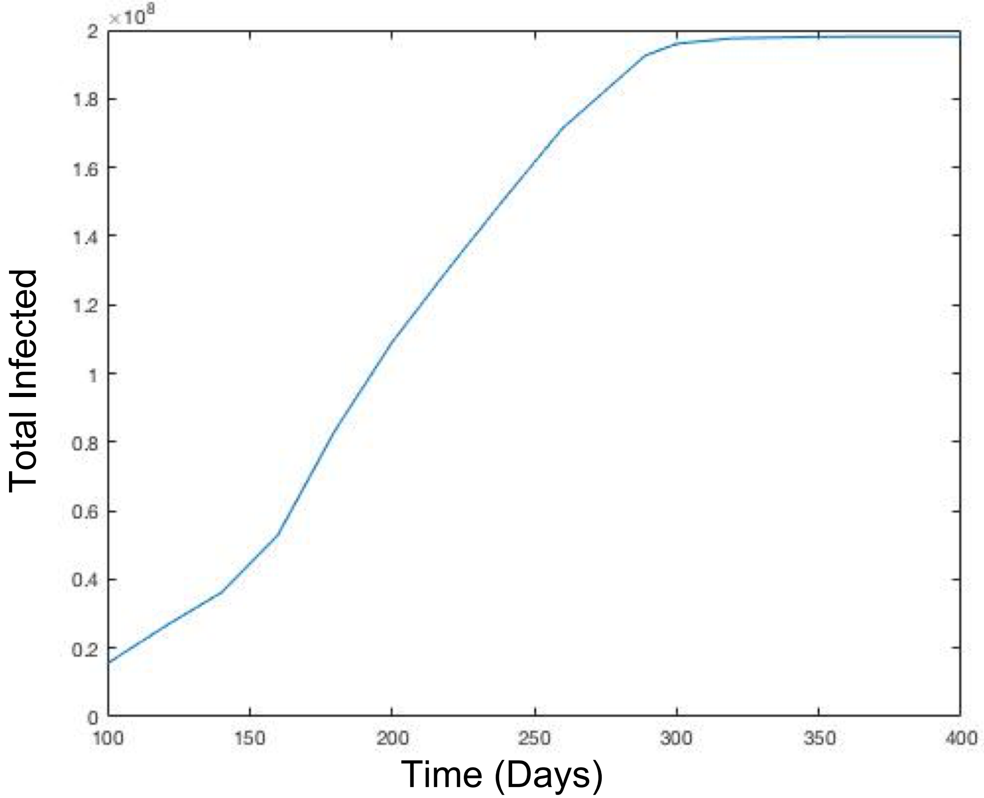


Infected Population as Vaccine Release Date Changed:

- Based on the Release Date

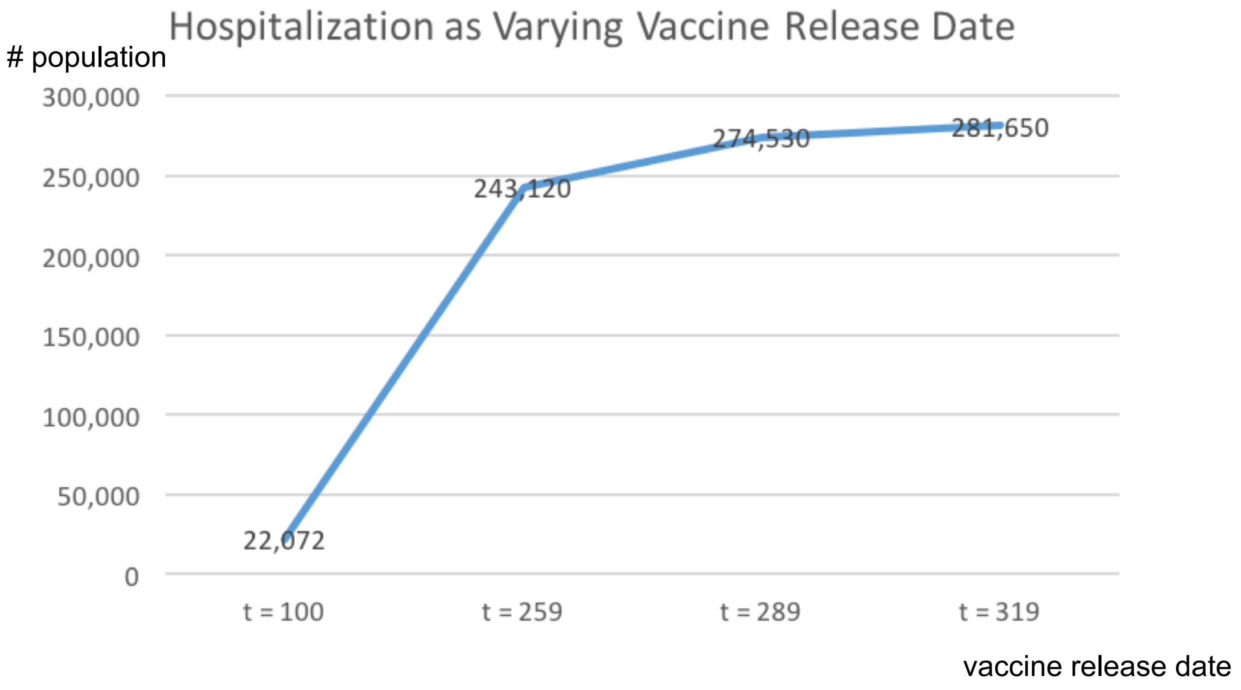
how many people get infected

- Efficacy rate is 89%



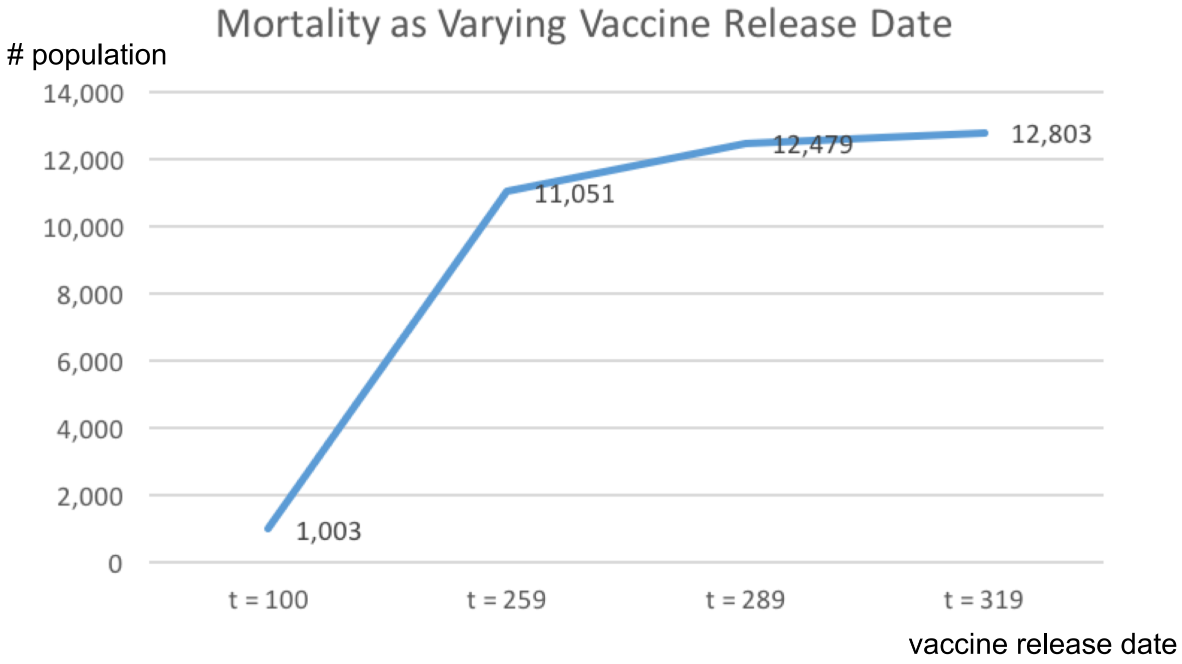
Hospitalized Population as Vaccine Release Date Changes:

Vaccine Release Day	Hospitalized Population
T = 100	22,072
T = 259	243,120
T = 289	274,530
T = 319	281,650



Changes in Mortality as Vaccine Release Date Changes:

Vaccine Release Day	Mortality
T = 100	1,003
T = 259	11,051
T = 289	12,479
T = 319	12,803



Cost Benefit Analysis Cont.:

Equations we used to calculate the costs:

- lost wages cost = US average daily salary * number of recovery days * morbidity group /2
- vaccinated cost = average cost of producing one dose * vaccinated group
- hospitalization cost = average cost per inpatient day * recovery day * hospitalized population
- total cost = lost wages cost + vaccinated cost + hospitalization cost

Vaccinated Population as Vaccine Release Date Changed:

How did we find the total vaccinated population?

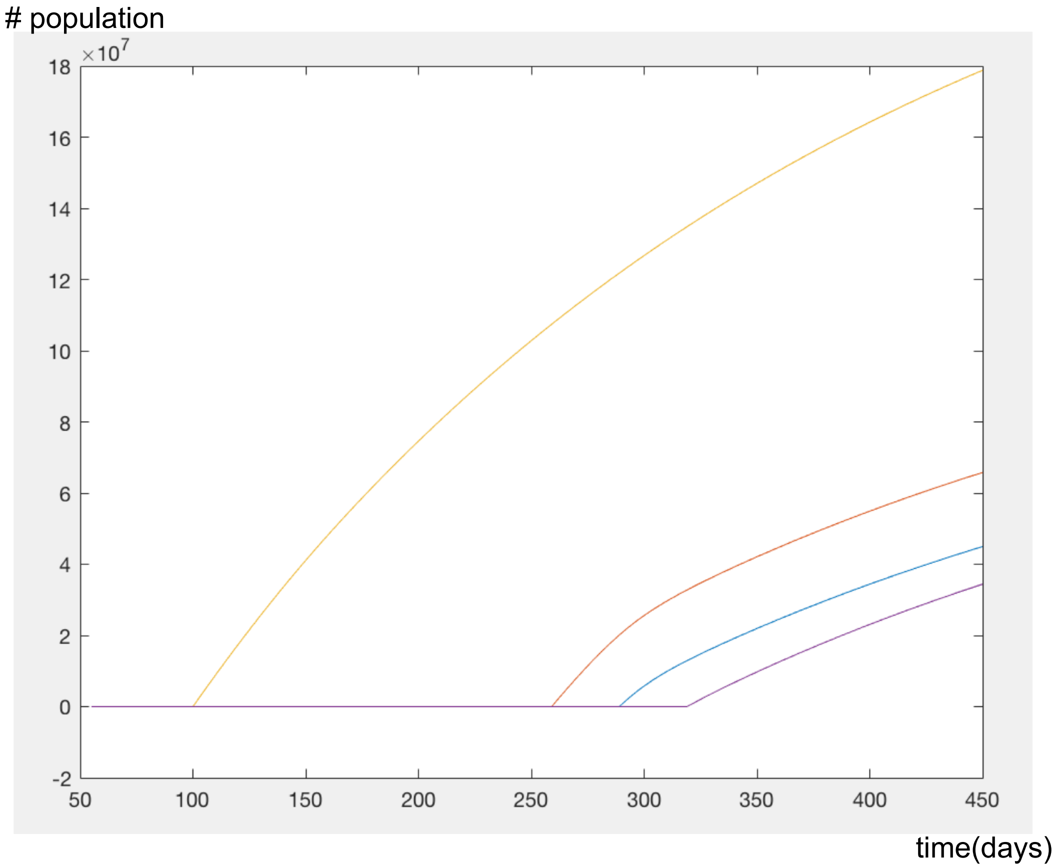
- A new variable V2
- Different from V,
  V: vaccinated group
  V2: total vaccinate population

t=100 (Yellow)

t=259 (Red)

t=289 (Blue)

t=319 (Purple)

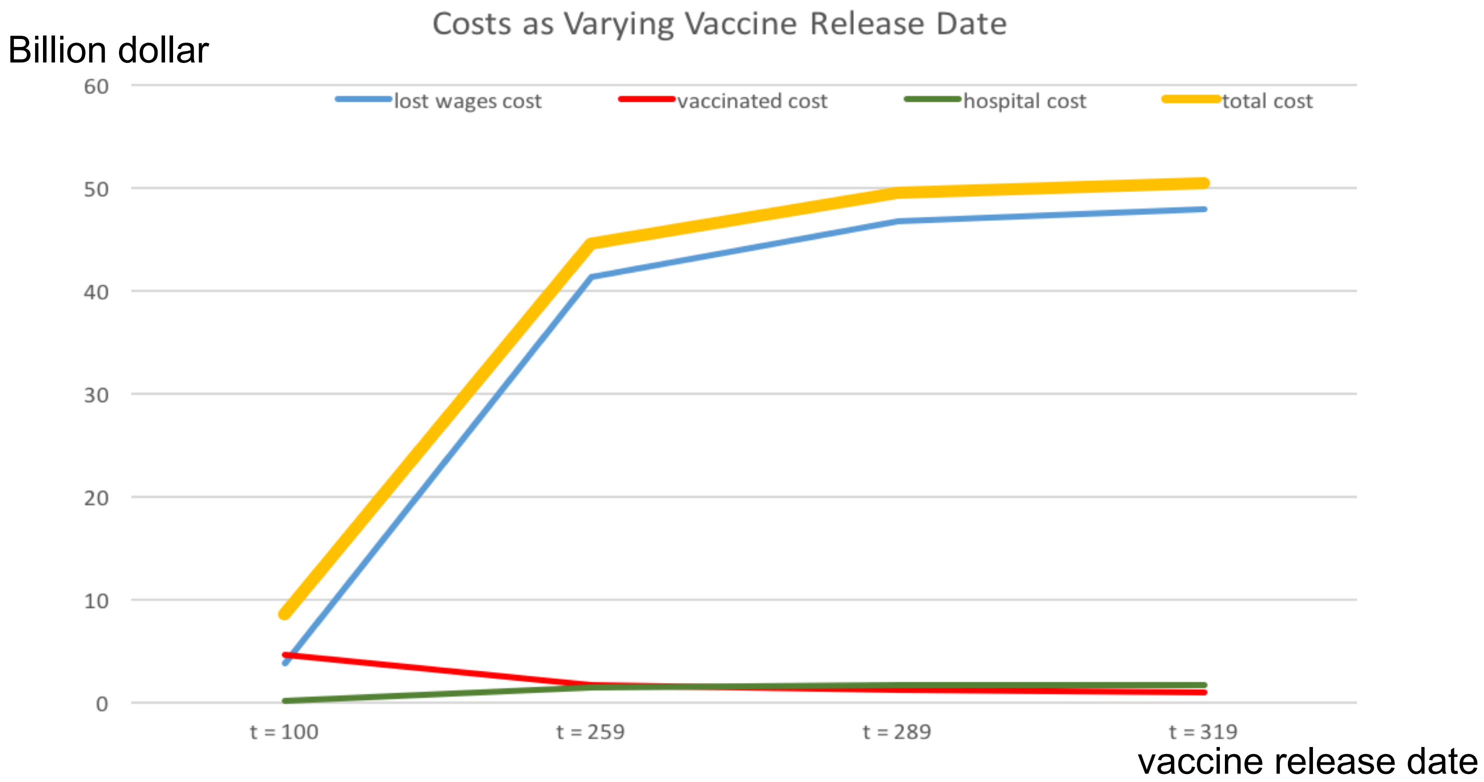


Results When Changing Vaccine Release Date:

	T = 100	T = 259	T = 289	T = 319
lost wages cost	3,756,300,000	41,375,000,000	46,720,000,000	47,933,000,000
vaccinated cost	4,648,300,000	1,710,500,000	1,169,300,000	894,560,000
hospital cost	131,500,000	1,448,500,000	1,635,600,000	1,678,100,000
total cost	8,536,100,000	44,534,000,000	49,524,900,000	50,505,660,000

Trends: Having a vaccine available earlier increases the vaccinated cost but lowers the cost of lost wages, hospital cost, and total costs.

Cost as Vaccine Release Date Changes:



CBA Comparison When Vaccine Released Date Changes:

Comparing t = 289 with t = 259 (releasing the vaccine a month apart)

- When t = 289, there are 22.03 million more people who get infected, 31410 more people who get hospitalized, and 1428 more people who would die, in comparison to when t = 259

- Releasing the vaccine at t=289 generates an increase in cost by 4.99 billion dollars compared to t=259

Comparing t = 289 with t = 319 (a month later)

- When t = 289, 5 million fewer people get infected, 7120 fewer people get hospitalized, and 324 fewer people would die, in comparison to when t = 319

- Releasing the vaccine at t=289 generates a decrease in cost by 981 million dollars compared to t = 319

Cost Benefit Analysis of Changing Vaccine Efficacy:

In the table, E stands for the vaccine efficacy.

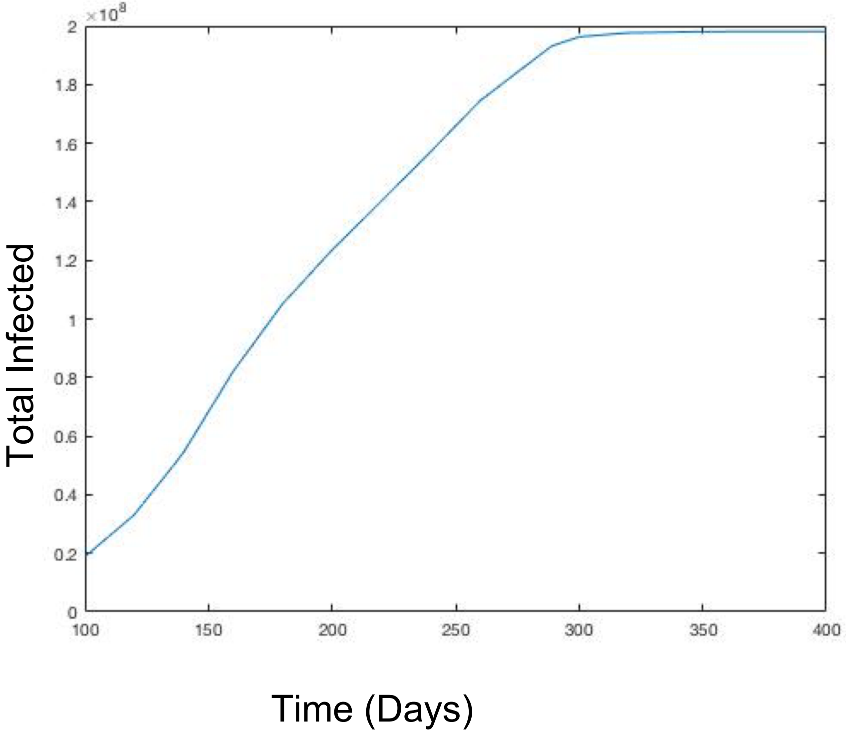
We set vaccine distribution date to be constant (t = 289, Oct 16th) and only study the effect of changing the efficacy rate.

	E = 99%	E = 89%	E = 79%
morbidity	191,970,000	192,560,000	193,170,000
hospitalization	273,680	274,530	275,390
mortality	12,441	12,479	12,519

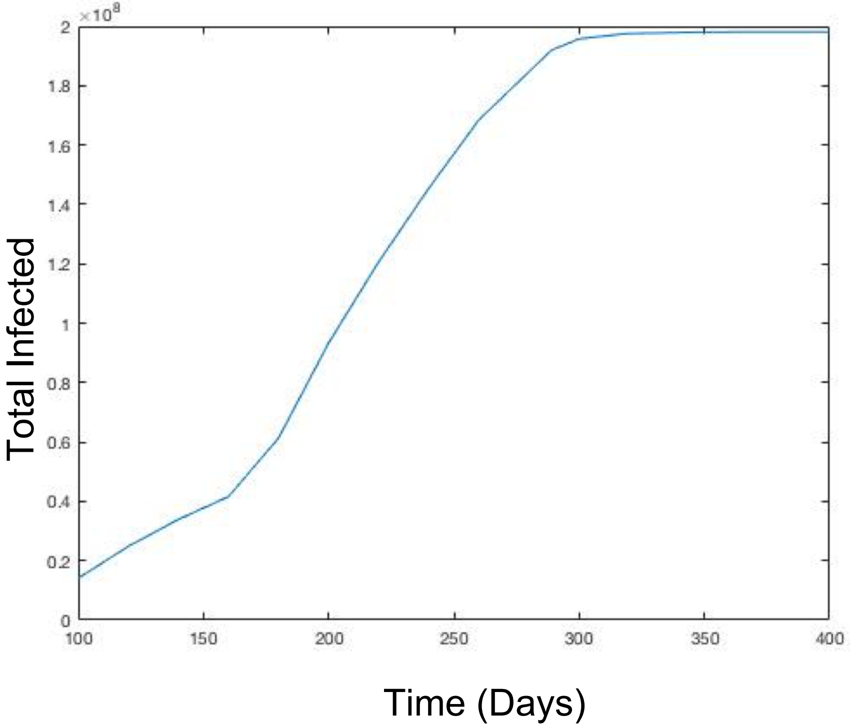
Trends: as we lowering the vaccine efficacy rate, the number of morbidity, hospitalized population and mortality increase.

Conclusion on Different Vaccine Efficacy Rates:

E=79%



E=99%



Cost Benefit Analysis Cont. On Changing Vaccine Efficacy:

	E = 99%	E = 89%	E = 79%
lost wages cost	46,576,000,000	46,720,000,000	46,868,000,000
vaccinated cost	1,304,100,000	1,169,300,000	1,035,200,000
hospital cost	1,630,600,000	1,635,600,000	1,640,800,000
total cost	49,510,700,000	49,524,900,000	49,544,000,000

Trends: as we lowering the vaccine efficacy rate, the total cost increases.

* cost of lost wages and hospital cost increase
* vaccinated cost decreases

Conclusion:

- The earlier the vaccine is released, the better for the society in the ways that:
    - Socially: less morbidity, less hospitalization, and less mortality
    - Economically: less economic cost
- However, producing vaccines is time consuming, because the H1N1 is unique and new and experiments are needed. The exact vaccine released date is uncertain, but still, the earlier, the better.
- If vaccines are distributed later, there is a smaller difference among the morbidity group.
    - Remember our data - the comparison slide, data of distributing one month earlier versus data of distributing one month later (smaller difference).
    - Remember our graph - No matter if E = 79%, 89% or 99% , the slope becomes flatter as t exceeds 300 (Oct 27th).

Sources:

https://www.cdc.gov/h1n1flu/estimates_2009_h1n1.htm
https://www.cdc.gov/h1n1flu/in_the_news/influenza_vaccination.htm
https://www.cdc.gov/flu/protect/keyfacts.htm
https://www.cdc.gov/h1n1flu/vaccination/public/vaccination_qa_pub.htm
http://wikipedia.com
https://www.ncbi.nlm.nih.gov/pubmed/22169697
https://www.theatlantic.com/health/archive/2012/01/a-cost-benefit-analysis-of-vaccines/251565/
http://www.wisebread.com/how-much-does-a-flu-shot-cost
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3302763/
https://www.census.gov/newsroom/press-releases/2017/income-povery.html
https://www.ncbi.nlm.nih.gov/pubmed/20008759
http://www.cidrap.umn.edu/news-perspective/2010/05/study-adjuvanted-h1n1-vaccine-was-very-effective
https://www.beckershospitalreview.com/finance/average-cost-per-inpatient-day-across-50-states
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0060343