An Epidemic of Antibiotics

New Mexico
SuperComputing Challenge
Final Report
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Team 50
The Down to Earth School

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Executive Summary:

Antibiotics are a medicine (such as penicillin) that inhibits the growth of or destroys microorganisms called bacteria. Bacteria can become immune to antibiotics

Methicillin-Resistant Staphylococcus aureus (MRSA) is a bacterium responsible for many difficult-to-treat infections in the body. Our project will be focusing on the transmission rates of MRSA and how they will be affected with the overuse of antibiotics. Overuse can lead to the mutation of bacteria, thus resulting in what is commonly known as superbugs or antibiotic-resistant bacteria. Some drug-resistant bacteria can transfer their immunity to other bacteria, including bacteria of different types, causing them to become immune as well. Superbugs have become an extreme health threat in our modern-day society, and the problem is getting worse.

Our model shows how antibiotic overusers affect the transmission rates of MRSA. The transmission rate is how quickly and easily the bacteria spreads throughout a population. There are different types of people in our model. The different types include different stages of MRSA and different users of antibiotics. The agents interact with and affect each other.

Introduction and Research:

Antibiotic-resistant bacteria, or superbugs, have become an extreme health threat in our modern-day society, and the problem is getting worse with the over-use of antibiotics. Superbugs are bacteria that have become immune to antibiotics and are no longer affected by them. Some drug-resistant bacteria can transfer their immunity to other bacteria, including bacteria of different types, causing them to become immune as well. Antibiotics are used to destroy, or slow down the growth of bacteria. Antibiotics do not affect viruses, only bacteria. Antibiotics were discovered in 1928 by Alexander Fleming, on accident. Penicillin was the first antibiotic discovered and is still used today. There are two ways all antibiotics work; the first way is that the antibiotic kills the bacteria, and an example of this is Penicillin; the other is the antibiotics damage the cell wall of the bacterium, disabling the bacteria to reproduce.

The specific antibiotic-resistant bacterium we are

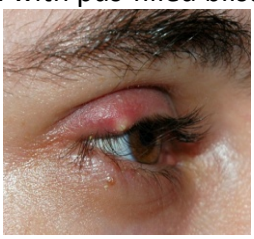
studying is Methicillin-Resistant Staphylococcus-aureus (MRSA).

MRSA is known for being antibiotic-resistant and difficult to treat. Early stages of MRSA can cause the following: Cellulitis (an infection of the skin, usually starting as small red bumps on skin with some areas resembling a bruise), puss-filled infections called boils, Abscesses, Sty (infection of an oil gland in the eyelid), a rash, Carbuncles (infections larger than abscesses, usually with several openings to the skin), Impetigo (a skin infection with pus-filled blisters).

Cellulitis

Boils

Abscesses



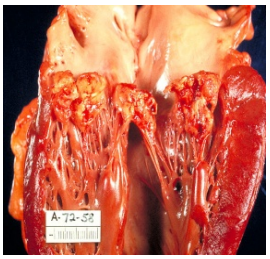
Sty

A rash

Carbuncles

Impetigo

If the bacteria spreads to and infects internal organs, it may be life threatening. If MRSA becomes severe, it may cause: Endocarditis (a heart disease), a flesh eating disease called Necrotizing Fasciitis, Osteomyelitis (a bone infection), and Sepsis (blood poisoning).



Endocarditis

Necrotizing Fasciitis

Osteomyelitis

Sepsis

There are two types of MRSA: Heath care Associated (HA-MRSA) and Community Associated (CA-MRSA). Heath care Associated MRSA was the original type of MRSA, spread throughout hospitals affecting patients and employees. Eventually the bacteria escaped from the hospitals and began infecting people in the community (CA-MRSA). The percentage of hospitalized MRSA patients who were infected by CA-MRSA is approximately 30%-37%. Thus HA-MRSA accounts for 63%-70%.

Problem Statement:

The questions we will be addressing are: how will the transmission rates of MRSA vary; and how will the over-use of antibiotics affect this variance? We predict that the rates will increase dramatically over the years and the over-use of antibiotics is causing the increase to be greater. This is because the overuse and abuse of antibiotics increases the probability of the infection or colonization. The overuse of antibiotics can, not only kill the harmful bacteria, but can rid your body of the helpful bacteria, thus causing your immune system to be more vulnerable. The abuse of antibiotics may include using antibiotics incorrectly. For example if a doctor prescribes you for an antibiotic and requires you to take all of them, and you discontinue the use once you are feeling well, the bacteria may be damaged, due to the antibiotics, but can become immune to the antibiotic. Thus the bacterium now has become stronger and can no longer be treated with that antibiotic. The example mentioned is one way that the abuse of antibiotics can increase the chance of infection or colonization not just for the over user, or the abuser, but for everyone around them.

Physical Problem/Method

Community-Associated MRSA originated form Health-care Associated MRSA and is commonly found in densely populated areas such as mass populated cities and high schools.

MRSA is transmitted by skin-to-skin contact or by contact to a contaminated surface. There have been cases in MRSA in high schools, especially infecting teens who play sports, or use the locker rooms and share equipment, and cheerleaders. The reason for this is because playing sports and cheerleading involves a lot of skin-to-skin contact. Using the locker rooms involves contact with surfaces and shared items.

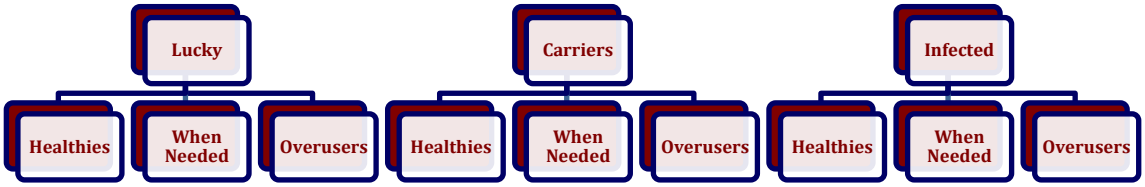
We will also being observing the influence of the agents on each other. When you have a conversation with another person about one's opinion, the other person has a chance of influencing you into their opinion or into a different opinion than yours was. The topic can be anything that can have different opinions and different sides to each opinion.

We are observing how the students, in high school, who overuse antibiotics, affect the students around them and the transmission rates of MRSA in that high school. We have chosen to observe the activity in high schools due to the fact that we are both high school students.

Computational Model

Our model depicts a high school with each of the grades as different colors.

There are nine breeds in our model.



- LuckyH (LH) - People who are not colonized and are **H**ealthies (never use antibiotics).
- LuckyWN (LWN) - People who are not colonized or infected and use antibiotics correctly and only **W**hen **N**eeded.
- LuckyOU (LOU) - People who are not colonized or infected and **O**ver**U**se, abuse, or use antibiotics incorrectly.
- CarriersH (CH) - People who are colonized but not infected and are **H**ealthies.
- CarriersWN (CWN) - People who are colonized and use antibiotics **W**hen **N**eeded.
- CarrersOU (COU) - People who are carriers and **O**ver**U**se antibiotics
- InfectedH (IH) - People who are infected and are **H**ealthies.
- InfectedWN (IWN) - People who are infected and use antibiotics **W**hen **N**eeded.
- InfectedOU (IOU) - People who are infected and **O**ver**U**se antibiotics.

The number of each breed is a variable that can be changed with sliders on the interface of the model. The agents are randomly scattered throughout the school and the color they begin on determines the grade they are in. Once their grade is chosen, randomly, they cannot change grades during that run. The model contains two global variables called "time" and "days". When the model is started, the time is set to eight, resembling eight

‘o’clock a.m. When the time reaches fifteen, resembling three ‘o’clock, the days increase by one and the time resets back to eight, thus our model shows the activity during school days.

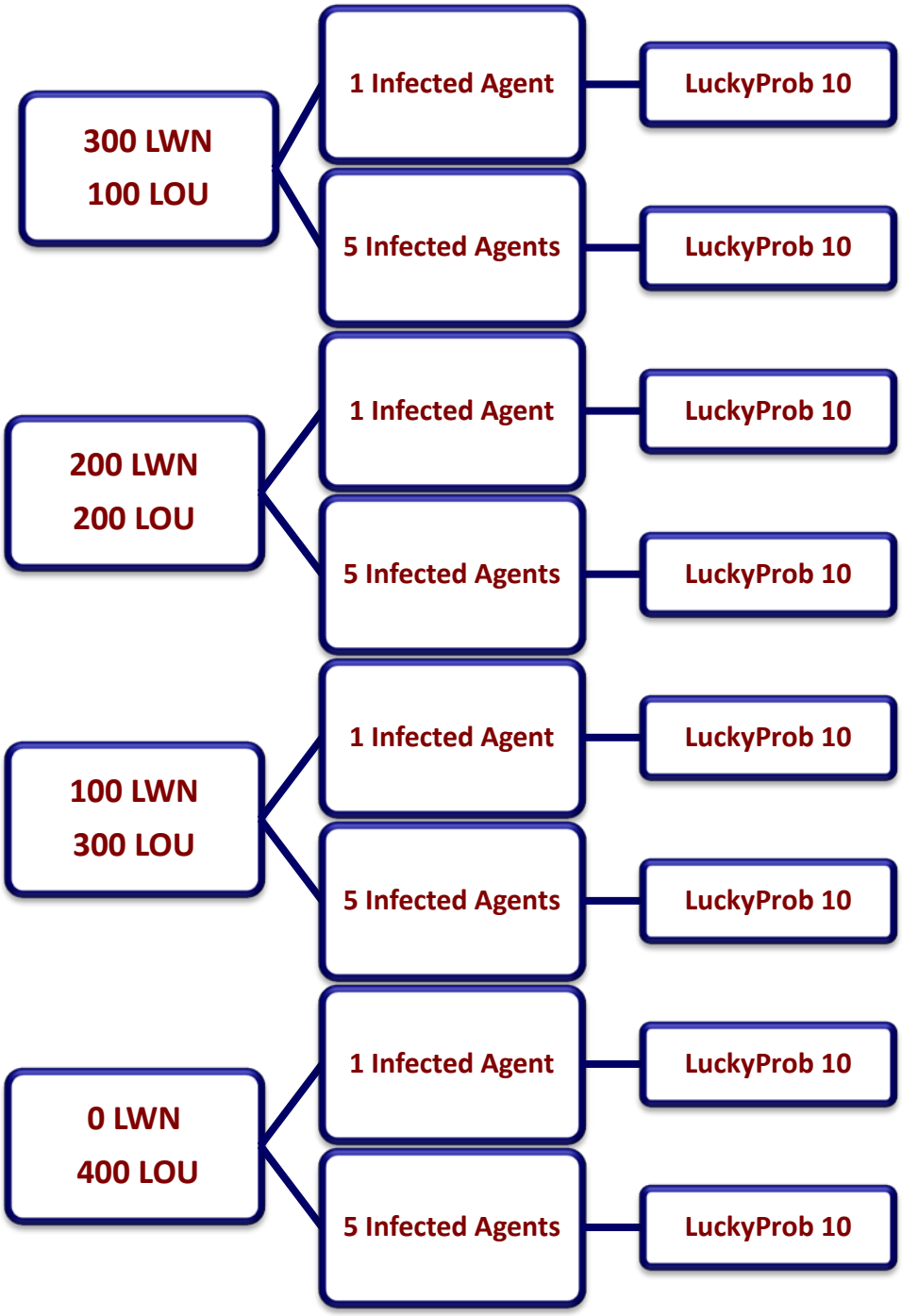
The agents move about the school and interact with one another. When two agents are on the same patch, they both have a chance of affecting each other, unless they are the exact same breed (i.e., a LuckyWN and a LuckyWN). There is a slider, called LuckyProb, on the interface that controls the probability of these agents being influenced, infected, or colonized. Each agent in the interaction then chooses a number between one and the number on the slider labeled LuckyProb.

As in reality, the agents have a chance to influence the other agents on the use of antibiotics. If one agent is an overuser and the other agent is a person who uses antibiotics correctly and when needed, the overuser has a chance of influencing the when needed agent to overuse antibiotics and vice versa.

They have an equal chance of being colonized, infected or influenced but a much greater chance to not be affected. The overusers have a smaller chance of not being affected and staying the same, than the other users do. The Healthies and the people who use antibiotics correctly and when needed have the same chance of being affected.

After a certain amount of time, the colonized agents have a chance of becoming decolonized. The infected agents have a chance of becoming a lucky agent or a colonized agent. The amount of time that is depends on their use of antibiotics. The bacteria are stronger when the person is an overuser or abuser of antibiotics, thus the time for an overuser to get the chance to change is longer than an agent that uses antibiotics correctly and when needed.

In the trials we conducted, the data we were collecting was how long it takes for all the lucky agents to become colonized or infected.



Lucky Agents Infected agents in each grade Value of "LuckyProb"

We had the school start out with 400 lucky agents. The numbers of LuckyWN and LuckyOU are shown above. In half of our trials we had one, and only one, infected agent in each grade, and in the other half we had five infected agents in each grade. The value of the slider "LuckyProb" was either 10 or 45 in all our trials. The value was 10 in half and 45 in the other half. We did 10 runs for each trial and averaged the results from the ten runs.

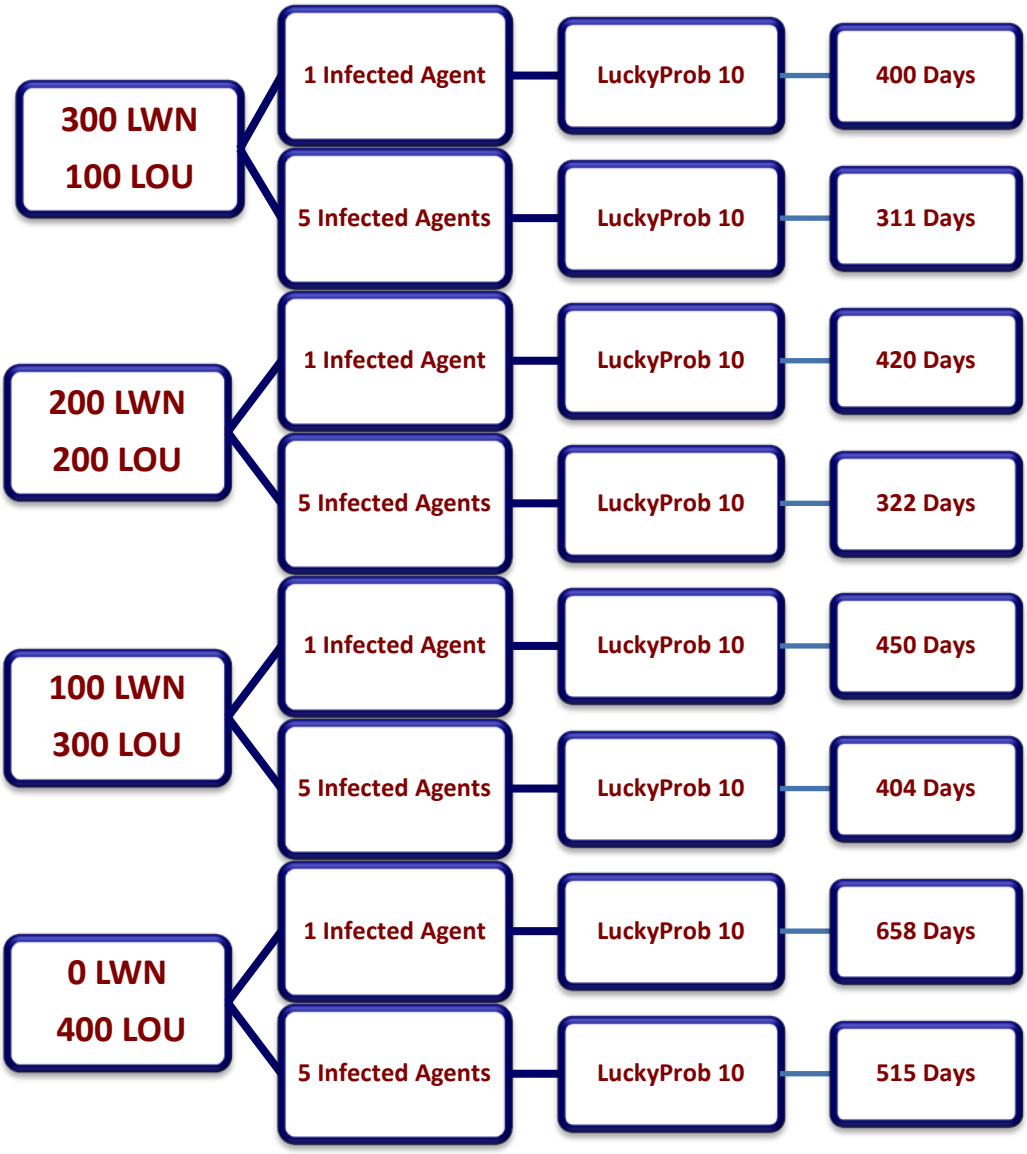
Verification and Validation

Our model has factors that are realistic but things that need to be changed for it to match reality and able to be used for other bacteria or diseases. We have many things that can be changed by sliders including the amount of people of each breed and the set probability. The things that would need to be turned into sliders if we continue this project will be the added probability for influence, colonization or infection for each breed and the probability that they will become uninfected or decolonized. We would also need a probability that the infected agents could eventually die, and that would have to be made a slider as well.

The factors in our model that we used to validate it include, the grades and space for each grade, the hours only set for the hours during a school day, the days representing school days, the probability that they will be influenced, colonized, or infected, the interaction between students, and the breeds allowing them different characteristics.

Results and Conclusion

For each set of trials we conducted at least ten runs, then averaged the days it took to colonize or infect all of the uncolonized agents. In the trials that had five infected agents in each grade, the days it took to colonize or infect everyone, were much less than the trials that consisted of only one infected agent in each grade.



The output we got did not support our hypothesis. We thought that the trials that consisted of more overusers than when needed would be shorter in the number of days it took.

However we did expect that in the trials that contained five infected agents in each grade, it would take fewer days than those with one infected agent in each grade, which, as shown in the graphic above, was true.

We began running trials in which the value for the LuckyProb was 45 instead of ten. If we were to continue this project we would run the same trials as the ones with the LuckyProb at ten, but with the LuckyProb at 45 to see if the probability affected the outcome.

The percentage difference between the probability of the when needed and the probability of the overusers was only around a 5% difference. We believe that is the reason that the model did not output the data we were expecting. If we were to do this again or continue on this, we would need to increase the difference between the probabilities and see if the data would be how we expected.

Teamwork

Our team is a team of two, Simone Hill the programmer and Analyse Waldron the researcher. Simone was also given the jobs of being the team leader, and the lead presenter.

Analyse is responsible for being the lead power point designer and poster designer. We split the responsibilities of the technical writer and graphic designer.

Significant Achievement

Our significant achievement was successfully getting the model to run smoothly and correctly. We also got the model to produce data for our results. Through the research we conducted, we learned the importance proper use of antibiotics and the danger of overusing and abusing antibiotics.

Acknowledgements

Team 50 would like to thank everyone who has helped us with our challenge. Thank you to Betsy, Celia, David and, Patty, the Supercomputing consult team. We do enjoy our Monday morning messages. To Christopher Koch and Dorian Arnold who reviewed our project and gave us very helpful feedback we thank you. To all of the volunteers who reviewed the interim reports we thank you for all of your effort. For the two judges, Erick Chaves and Rocky Navamete who evaluated our presentation at NMSU, your feedback was very useful. Thank you to Daniel Jacobs and Michael Landon from the New Mexico Department of Health (NMDOH). To Jennifer Bryant, Analyst at Health Insite New Mexico, thank you. We would like to give a special thanks to our amazing mentors Maia Chaney and Shanon Muehlhausen.

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Appendix A – Code:

```
Globals[
  time
  prob-lh
  prob-LWN
  prob-LOU
  prob-CH
  Prob-CWN
  Prob-COU
  Prob-IH
  Prob-IWN
  Prob-IOU
  Days
  num-lh
  num-lwn
  num-lou
  num-ch
  num-cwn
  num-cou
  num-ih
  num-iwn
  num-iou]
turtles-own[
  gcolor
  grade
  pcolour
  StartDay
  RanProb]
Breed[luckyou]
Breed[carriersou]
Breed[infectedou]
Breed[luckywn]
Breed[carrierswn]
Breed[infectedwn]
Breed[luckyh]
Breed[carriersh]
Breed[infectedh]


To Setup
  Clear-All
  Set time 8
  Set days 0
```

```
ask patches with [pycor >= 45]
[
  set pcolor cyan + 1
]
ask patches with [pycor >= 0 and pycor < 45]
[
  set pcolor grey + 2
]
ask patches with [pycor < 0 and pycor >= -45]
[
  set pcolor yellow + 2
]
ask patches with [pycor < -45]
[
  set pcolor magenta + 3
]

   Set-default-shape LuckyH "Hippie"
   Set-default-shape CarriersH "HippieCarrier"
   Set-default-shape InfectedH "InfectedHippie"
    Set-default-shape LuckyWn "Person"
   Set-default-shape CarriersWN "Carriers"
   Set-default-shape InfectedWn "Infected"
    Set-default-shape LuckyOu "OverUser"
   Set-default-shape CarriersOu "Overusingcarriers"
   Set-default-shape InfectedOu "Overusinginfected"
Create-LuckyOU PeopleWhoAreLuckyOU
[
  Setxy Random-Xcor Random-Ycor
  set size xy
]
Create-CarriersOU PeopleWhoAreCarriersOfTheSuperbugOU
[
  Setxy Random-Xcor Random-Ycor
  set size xy
]
Create-InfectedOU  PeopleWhoAreInfectedByTheSuperbugOU
[
  move-to one-of patches with [pcolor = cyan + 1]
  set size xy
]
Create-InfectedOU  PeopleWhoAreInfectedByTheSuperbugOU
[
  move-to one-of patches with [pcolor = yellow + 2]
```

```
  set size xy
]
Create-InfectedOU  PeopleWhoAreInfectedByTheSuperbugOU
[
  move-to one-of patches with [pcolor = grey + 2]
  set size xy
]
Create-InfectedOU  PeopleWhoAreInfectedByTheSuperbugOU
[
  move-to one-of patches with [pcolor = magenta + 3]
  set size xy
]
  Create-LuckyWN PeopleWhoAreLuckyWN
[
  Setxy Random-Xcor Random-Ycor
  set size xy
]
Create-CarriersWn PeopleWhoAreCarriersOfTheSuperbugWN
[
  Setxy Random-Xcor Random-Ycor
  set size xy
]
Create-InfectedWN  PeopleWhoAreInfectedByTheSuperbugWN
[
  Setxy Random-Xcor Random-Ycor
  set size xy
]
  Create-LuckyH PeopleWhoAreLuckyH
[
  Setxy Random-Xcor Random-Ycor
  set size xy
]
Create-CarriersH PeopleWhoAreCarriersOfTheSuperbugH
[
  Setxy Random-Xcor Random-Ycor
  set size xy
]
Create-InfectedH  PeopleWhoAreInfectedByTheSuperbugH
[
  Setxy Random-Xcor Random-Ycor
  set size xy
]
ask turtles
[
```

```
    if pcolor = cyan + 1
   [set gcolor one-of patches with [pcolor = cyan + 1]
    set grade "freshman"
    set pcolour cyan + 1]
    if pcolor = yellow + 2
   [set gcolor one-of patches with [pcolor = yellow + 2]
    set grade "sophomore"
    set pcolour yellow + 2]
    if pcolor = grey + 2
   [set gcolor one-of patches with [pcolor = grey + 2]
    set grade "junior"
    set pcolour grey + 2]
    if pcolor = magenta + 3
   [set gcolor one-of patches with [pcolor = magenta + 3]
    set grade "senior"
    set pcolour magenta + 3]
  set startday 0
   ]

End


To go
  ask turtles[

   set num-lh count turtles with [breed = luckyh]
   set num-lwn count turtles with [breed = luckywn]
   set num-lou count turtles with [breed = luckyou]
   set num-ch count turtles with [breed = carriersh]
   set num-cwn count turtles with [breed = carrierswn]
   set num-cou count turtles with [breed = carriersou]
   set num-ih count turtles with [breed = infectedh]
   set num-iwn count turtles with [breed = infectedwn]
   set num-iou count turtles with [breed = infectedou]
   if grade = "freshman"
   [
    set gcolor one-of patches with [pcolor = cyan + 1]
   ]
   if grade = "sophomore"
   [
    set gcolor one-of patches with [pcolor = yellow + 2]
   ]
   if grade = "junior"
   [
```

```
    set gcolor one-of patches with [pcolor = grey + 2]
   ]
   if grade = "senior"
   [
    set gcolor one-of patches with [pcolor = magenta + 3]
   ]
  if time >= 8
  [
   fd random 5
   rt random 25
   lt random 25
   if pcolor != pcolour
   [
    move-to gcolor
   ]
   interact
   set time time + 0.0001
  ]
  if time >= 15
  [
   set days days + 1
   set time 8
   Set startday startday + 1
  ]

  ]
 if  num-lh + num-lwn + num-lou = 0
 [output-print time - 8
  output-print days + 1
  again
  ]
end

to again
  setup
  go
end

to interact
   if breed = LuckyH
     [
      If any? turtles-here with [breed = LuckyWN]
      [
       Set Prob-LH random 2
```

```
  if Prob-LH = 1
  [set breed LuckyH]
  if Prob-LH = 2
  [set breed LuckyWN]
]
If any? turtles-here with [breed = LuckyOU]
[
  Set Prob-LH random 2
  If Prob-LH = 1
  [Set breed LuckyH]
  If Prob-LH = 2
  [Set breed LuckyOU]
]
If any? turtles-here with [breed = CarriersH]
[
  Set Prob-LH random Luckyprob + 2
  If Prob-LH <= Luckyprob
  [set breed LuckyH]
  If Prob-LH = luckyprob + 1
  [set breed CarriersH]
  If Prob-LH = luckyprob + 2
  [set breed InfectedH]
]
If any? turtles-here with [breed =  CarriersWN]
[
  set Prob-LH random Luckyprob + 5
  if Prob-LH <= luckyprob
  [set breed LuckyH]
  If Prob-LH = luckyprob + 1
  [set breed LuckyWN]
  If Prob-LH = luckyprob + 2
  [set breed CarriersH]
  If Prob-LH = luckyprob + 3
  [set breed CarriersWN]
  If Prob-LH = luckyprob + 4
  [set breed InfectedH]
  If Prob-LH = luckyprob + 5
  [set breed InfectedWN]
]
If any? turtles-here with [breed =  CarriersOU]
[
  set Prob-LH random luckyprob + 5
  if Prob-LH <= luckyprob
  [set breed LuckyH]
```

```
  If Prob-LH = luckyprob + 1
  [set breed LuckyOU]
  If Prob-LH = luckyprob + 2
  [set breed CarriersH]
  If Prob-LH = luckyprob + 3
  [set breed CarriersOU]
  If Prob-LH = luckyprob + 4
  [set breed InfectedH]
  If Prob-LH = luckyprob + 5
  [set breed InfectedOU]
]
If any? turtles-here with [breed = InfectedH]
[
  Set Prob-LH random luckyprob + 2
  If Prob-LH <= luckyprob
  [set breed LuckyH]
  If Prob-LH = luckyprob + 1
  [set breed CarriersH]
  If Prob-LH = luckyprob + 2
  [set breed InfectedH]
]
If any? turtles-here with [breed =  InfectedWN]
[
  set Prob-LH random luckyprob + 5
  if Prob-LH <= luckyprob
  [set breed LuckyH]
  If Prob-LH = luckyprob + 1
  [set breed LuckyWN]
  If Prob-LH = luckyprob + 2
  [set breed CarriersH]
  If Prob-LH = luckyprob + 3
  [set breed CarriersWN]
  If Prob-LH = luckyprob + 4
  [set breed InfectedH]
  If Prob-LH = luckyprob + 5
  [set breed InfectedWN]
]
If any? turtles-here with [breed =  InfectedOU]
[
  set Prob-LH random luckyprob + 5
  if Prob-LH <= luckyprob
  [set breed LuckyH]
  If Prob-LH = luckyprob + 1
  [set breed LuckyOU]
```

```
    If Prob-LH = luckyprob + 2
    [set breed CarriersH]
    If Prob-LH = luckyprob + 3
    [set breed CarriersOU]
    If Prob-LH = luckyprob + 4
    [set breed InfectedH]
    If Prob-LH = luckyprob + 5
    [set breed InfectedOU]
  ]]
   if breed = LuckyWN
[
 If any? turtles-here with [breed = LuckyH]
 [
  Set prob-LWN random 2
  If prob-LWN = 1
  [set breed LuckyWN]
  If prob-LWN = 2
  [set breed LuckyH]
 ]
 If any? turtles-here with [breed = LuckyOU]
 [
  set prob-LWN random 2
  if prob-LWN = 1
  [set breed LuckyWN]
  if Prob-LWN = 2
  [set breed LuckyOU]
 ]
 If any? turtles-here with [breed = CarriersH]
 [
  Set prob-LWN random luckyprob + 5
  If prob-LWN <= luckyprob
  [set breed LuckyWN]
  If prob-LWN = luckyprob + 1
  [set breed LuckyH]
  If prob-LWN = luckyprob + 2
  [set breed CarriersWN]
  If Prob-LWN = luckyprob + 3
  [Set breed CarriersH]
  If prob-LWN = luckyprob + 4
  [set breed InfectedWN]
  If Prob-LWN = luckyprob + 5
  [set breed InfectedH]
 ]
 If any? turtles-here with [breed = CarriersWN]
```

```
[
 set prob-LWN random luckyprob + 2
 if prob-LWN <= luckyprob
 [set breed LuckyWN]
 if Prob-LWN = luckyprob + 1
 [set breed CarriersWN]
 if Prob-LWN = luckyprob + 2
 [set breed infectedWN]
]
If any? turtles-here with [breed = CarriersOU]
[
 Set prob-LWN random luckyprob + 5
 If prob-LWN <= luckyprob
 [set breed LuckyWN]
 If prob-LWN = luckyprob + 1
 [set breed LuckyOU]
 If prob-LWN = luckyprob + 2
 [set breed CarriersWN]
 If Prob-LWN = luckyprob + 3
 [Set breed CarriersOU]
 If prob-LWN = luckyprob + 4
 [set breed InfectedWN]
 If Prob-LWN = luckyprob + 5
 [set breed InfectedOU]
]
If any? turtles-here with [breed = InfectedH]
[
 Set prob-LWN random luckyprob + 5
 If prob-LWN <= luckyprob
 [set breed LuckyWN]
 If prob-LWN = luckyprob + 1
 [set breed LuckyH]
 If prob-LWN = luckyprob + 2
 [set breed CarriersWN]
 If Prob-LWN = luckyprob + 3
 [Set breed CarriersH]
 If prob-LWN = luckyprob + 4
 [set breed InfectedWN]
 If Prob-LWN = luckyprob + 5
 [set breed InfectedH]
]
If any? turtles-here with [breed = InfectedWN]
[
 set prob-LWN random luckyprob + 2
```

```
    if prob-LWN = luckyprob
    [set breed LuckyWN]
    if Prob-LWN = luckyprob + 1
    [set breed CarriersWN]
    if Prob-LWN = luckyprob + 2
    [set breed infectedWN]
  ]
  If any? turtles-here with [breed = InfectedOU]
  [
    Set prob-LWN random luckyprob + 5
    If prob-LWN <= luckyprob
    [set breed LuckyWN]
    If prob-LWN = luckyprob + 1
    [set breed LuckyOU]
    If prob-LWN = luckyprob + 2
    [set breed CarriersWN]
    If Prob-LWN = luckyprob + 3
    [Set breed CarriersOU]
    If prob-LWN = luckyprob + 4
    [set breed InfectedWN]
    If Prob-LWN = luckyprob + 5
    [set breed InfectedOU]
  ]]
If breed = LuckyOU
[
  If any? turtles-here with [breed = LuckyH]
  [
    Set prob-LOU random 2
    If prob-LOU = 1
    [set breed LuckyOU]
    If prob-LOU = 2
    [set breed LuckyH]
  ]
  If any? turtles-here with [breed = LuckyWN]
  [
    set prob-LOU random 2
    if prob-LOU = 1
    [set breed LuckyOU]
    if Prob-LOU = 2
    [set breed LuckyWN]
  ]
  If any? turtles-here with [breed = CarriersH]
  [
    Set prob-LOU random luckyprob + 1
```

```
  If prob-LOU <= luckyprob - 4
  [set breed LuckyOU]
  If prob-LOU = luckyprob - 3
  [set breed LuckyH]
  If prob-LOU = luckyprob - 2
  [set breed CarriersOU]
  If Prob-LOU = luckyprob - 1
  [Set breed CarriersH]
  If prob-LOU = luckyprob
  [set breed InfectedOU]
  If Prob-LOU = luckyprob + 1
  [set breed InfectedH]
]
If any? turtles-here with [breed = CarriersWN]
[
  Set prob-LOU random luckyprob + 1
  If prob-LOU <= luckyprob - 4
  [set breed LuckyOU]
  If prob-LOU = luckyprob - 3
  [set breed LuckyWN]
  If prob-LOU = luckyprob - 2
  [set breed CarriersOU]
  If Prob-LOU = luckyprob - 1
  [Set breed CarriersWN]
  If prob-LOU = luckyprob
  [set breed InfectedOU]
  If Prob-LOU = luckyprob + 1
  [set breed InfectedWN]
]
If any? turtles-here with [breed = CarriersOU]
[
  set prob-LOU random luckyprob
  if prob-LOU <= luckyprob - 2
  [set breed LuckyOU]
  if Prob-LOU = luckyprob - 1
  [set breed CarriersOU]
  if Prob-LOU = luckyprob
  [set breed infectedOU]
]
If any? turtles-here with [breed = InfectedH]
[
  Set prob-LOU random luckyprob + 1
  If prob-LOU <= luckyprob - 4
  [set breed LuckyOU]
```

```
    If prob-LOU = luckyprob - 3
    [set breed LuckyH]
    If prob-LOU = luckyprob - 2
    [set breed CarriersOU]
    If Prob-LOU = luckyprob - 1
    [Set breed CarriersH]
    If prob-LOU = luckyprob
    [set breed InfectedOU]
    If Prob-LOU = luckyprob + 1
    [set breed InfectedH]
   ]
   If any? turtles-here with [breed = InfectedWN]
   [
    Set prob-LOU random luckyprob + 1
    If prob-LOU <= luckyprob - 4
    [set breed LuckyOU]
    If prob-LOU = luckyprob - 3
    [set breed LuckyWN]
    If prob-LOU = luckyprob - 2
    [set breed CarriersOU]
    If Prob-LOU = luckyprob - 1
    [Set breed CarriersWN]
    If prob-LOU = luckyprob
    [set breed InfectedOU]
    If Prob-LOU = luckyprob + 1
    [set breed InfectedWN]
   ]
   If any? turtles-here with [breed = InfectedOU]
   [
    set prob-LOU random luckyprob
    if prob-LOU <= luckyprob - 2
    [set breed LuckyOU]
    if Prob-LOU = luckyprob - 1
    [set breed CarriersOU]
    if Prob-LOU = luckyprob
    [set breed infectedOU]
   ]]
If breed = CarriersH
[
 if any? turtles-here with [breed = LuckyWN]
 [
  set prob-CH random 4
  if Prob-CH <= 3
  [set breed CarriersH]
```

```
  if Prob-CH = 4
  [set breed CarriersWN]
 ]
 if any? turtles-here with [breed = LuckyOU]
 [
  set Prob-CH random 4
  if Prob-CH <= 3
  [set breed CarriersH]
  if Prob-CH = 4
  [set breed CarriersOU]
 ]
 if any? turtles-here with [Breed = CarriersWN]
 [
  set prob-Ch random 4
  if Prob-CH <= 3
  [set breed CarriersH]
  if Prob-Ch = 4
  [set breed CarriersWN]
 ]
 if any? turtles-here with [breed = CarriersOU]
 [
  Set prob-ch random 4
  if prob-ch <= 3
  [set breed carriersh]
  if prob-ch = 4
  [set breed carriersOU]
 ]
 if any? turtles-here with [breed = InfectedWN]
 [
  Set prob-ch random 4
  if prob-ch <= 3
  [set breed CarriersH]
  if prob-ch = 4
  [set breed CarriersWN]
 ]
 if any? turtles-here with [breed = InfectedOU]
 [
  set prob-ch random 4
  if prob-ch <= 3
  [set breed CarriersH]
  if prob-ch = 4
  [set breed CarriersOU]
 ]]
if breed = CarriersWN
```

```
[
 if any? turtles-here with [breed = LuckyH]
 [
  set prob-cWN random 2
  if prob-cWN = 1
  [set breed CarriersWN]
  if Prob-cWN = 2
  [set breed CarriersH]
 ]
 if any? turtles-here with [breed = LuckyOU]
 [
  set prob-cwn random 2
  if prob-cwn = 1
  [set breed CarriersWN]
  if prob-CWN = 2
  [set breed CarriersOU]
 ]
 if any? turtles-here with [breed = CarriersH]
 [
  set prob-CWN random 2
  if Prob-CWN = 1
  [set breed CarriersWN]
  if prob-cWN = 2
  [set breed CarriersH]
 ]
 if any? turtles-here with [breed = CarriersOU]
 [
  set Prob-CWN random 2
  if Prob-CWN = 1
  [set breed CarriersWN]
  If Prob-CWN = 2
  [set breed CarriersOU]
 ]
 if any? turtles-here with [breed = InfectedOU]
 [
  set Prob-CWN random 2
  if prob-cwn = 1
  [set breed carrierswn]
  if prob-cwn = 2
  [set breed carriersou]
 ]
 if any? turtles-here with [breed = infectedh]
 [
  set prob-cwn random 2
```

```
    if prob-cwn = 1
    [set breed carrierswn]
    if prob-cwn = 2
    [set breed carriersh]
  ]]
 if breed = CarriersOU
 [
  if any? turtles-here with [breed = LuckyH]
  [
    set prob-COU random 2
    if prob-cou = 1
    [set breed CarriersOU]
    if prob-cou = 2
    [set breed CarriersH]
  ]
  if any? turtles-here with [breed = LuckyWN]
  [
    set prob-cou random 2
    if prob-cou = 1
    [set breed carriersou]
    if prob-cou = 2
    [set breed carrierswn]
  ]
  if any? turtles-here with [breed = carriersh]
  [
    set prob-cou random 2
    if prob-cou = 1
    [set breed carriersou]
    if prob-cou = 2
    [set breed carriersh]
  ]
  if any? turtles-here with [breed = carrierswn]
  [
    set prob-cou random 2
    if prob-cou = 1
    [set breed carriersou]
    if prob-cou = 2
    [set breed carrierswn]
  ]
  if any? turtles-here with [breed = infectedh]
  [
    set prob-cou random 2
    if prob-cou = 1
    [set breed carriersou]
```

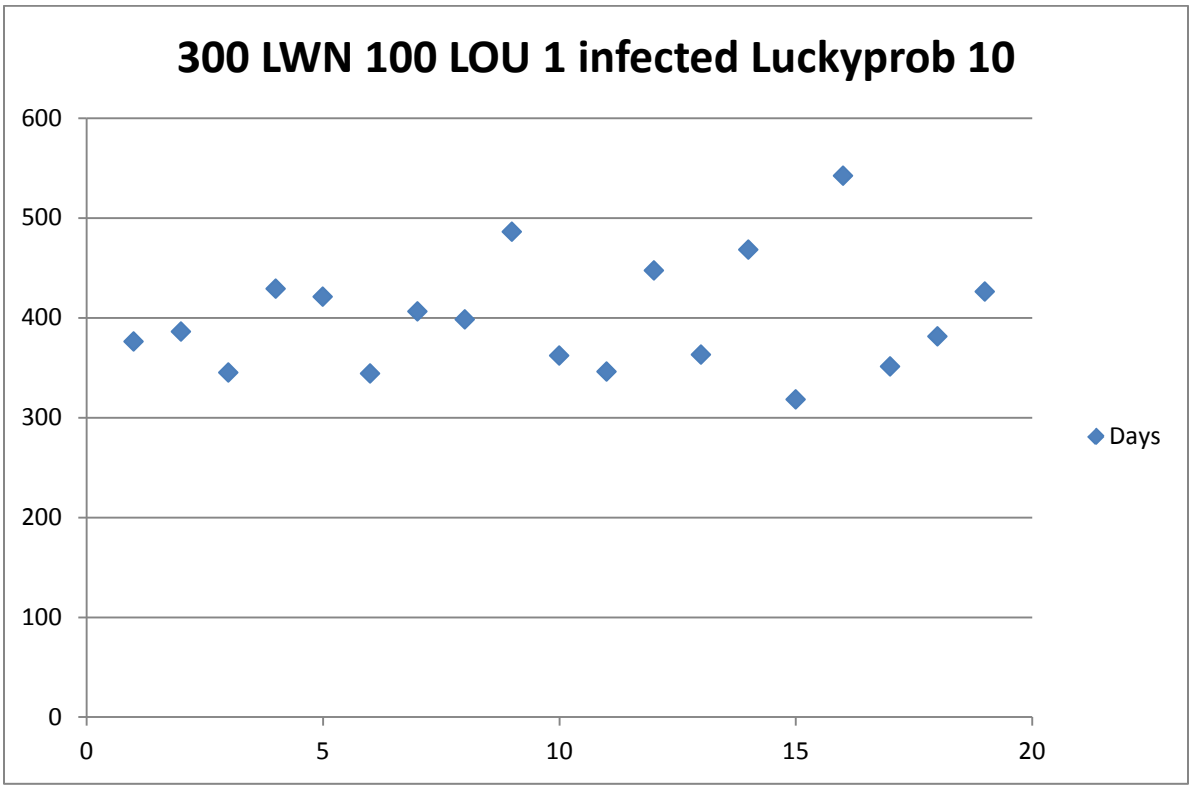
```
    if prob-cou = 2
    [set breed carriersh]
  ]
  if any? turtles-here with [breed = infectedwn]
  [
    set prob-cou random 2
    if prob-cou = 1
    [set breed carriersou]
    if prob-cou = 2
    [set breed carrierswn]
  ]]
if breed = infectedh
[
  if any? turtles-here with [breed = luckywn]
  [
    set prob-ih random 2
    if prob-ih = 1
    [set breed infectedh]
    if prob-ih = 2
    [set breed infectedwn]
  ]
  if any? turtles-here with [breed = luckyou]
  [
    set prob-ih random 2
    if prob-ih = 1
    [set breed infectedh]
    if prob-ih = 2
    [set breed infectedou]
  ]
  if any? turtles-here with [breed = carrierswn]
  [
    set prob-ih random 2
    if prob-ih = 1
    [set breed infectedh]
    if prob-ih = 2
    [set breed infectedwn]
  ]
  if any? turtles-here with [breed = carriersou]
  [
    set prob-ih random 2
    if prob-ih = 1
    [set breed infectedh]
    if prob-ih = 2
    [set breed infectedou]
```

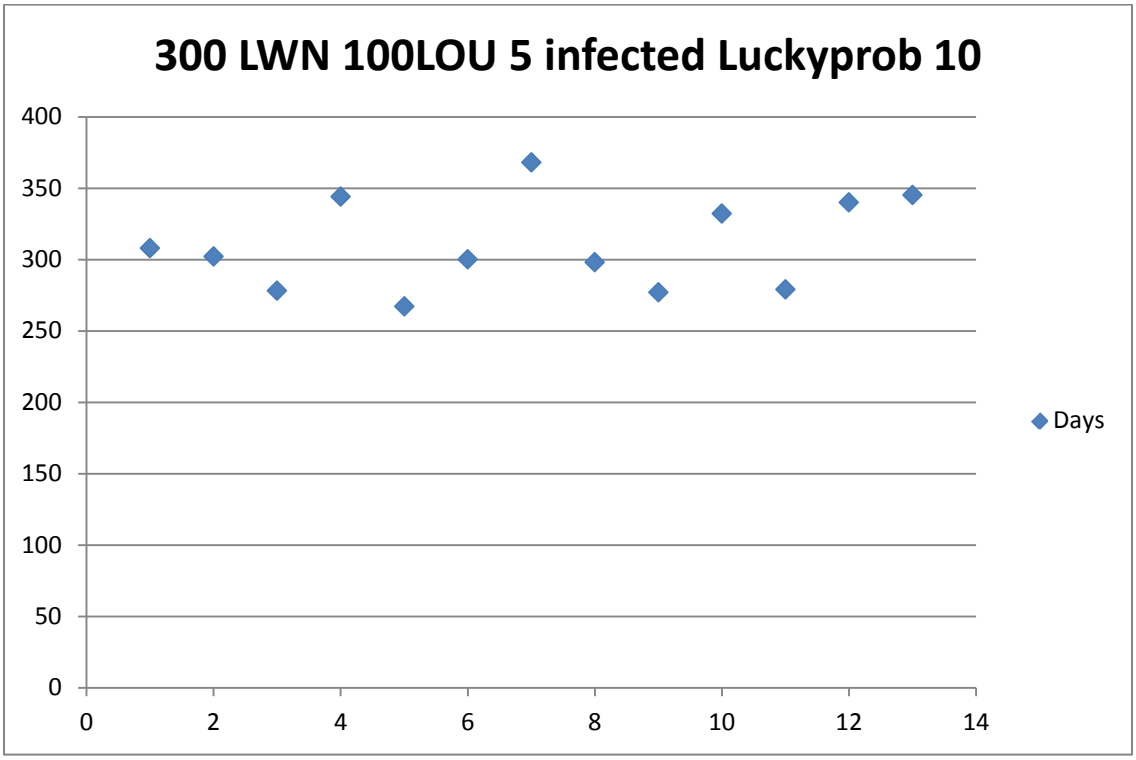
```
  ]
  if any? turtles-here with [breed = infectedwn]
  [
    set prob-ih random 2
    if prob-ih = 1
    [set breed infectedh]
    if prob-ih = 2
    [set breed infectedwn]
  ]
  if any? turtles-here with [breed = infectedou]
  [
    set prob-ih random 2
    if prob-ih = 1
    [set breed infectedh]
    if prob-ih = 2
    [set breed infectedou]
  ]]
if breed = infectedwn
[
  if any? turtles-here with [breed = luckyh]
  [
    set prob-iwn random 2
    if prob-iwn = 1
    [set breed infectedwn]
    if prob-iwn = 2
    [set breed infectedh]
  ]
  if any? turtles-here with [breed = luckyou]
  [
    set prob-iwn random 2
    if prob-iwn = 1
    [set breed infectedwn]
    if prob-iwn = 2
    [set breed infectedou]
  ]
  if any? turtles-here with [breed = carriersh]
  [
    set prob-iwn random 2
    if prob-iwn = 1
    [set breed infectedwn]
    if prob-iwn = 2
    [set breed infectedou]
  ]
  if any? turtles-here with [breed = carriersou]
```

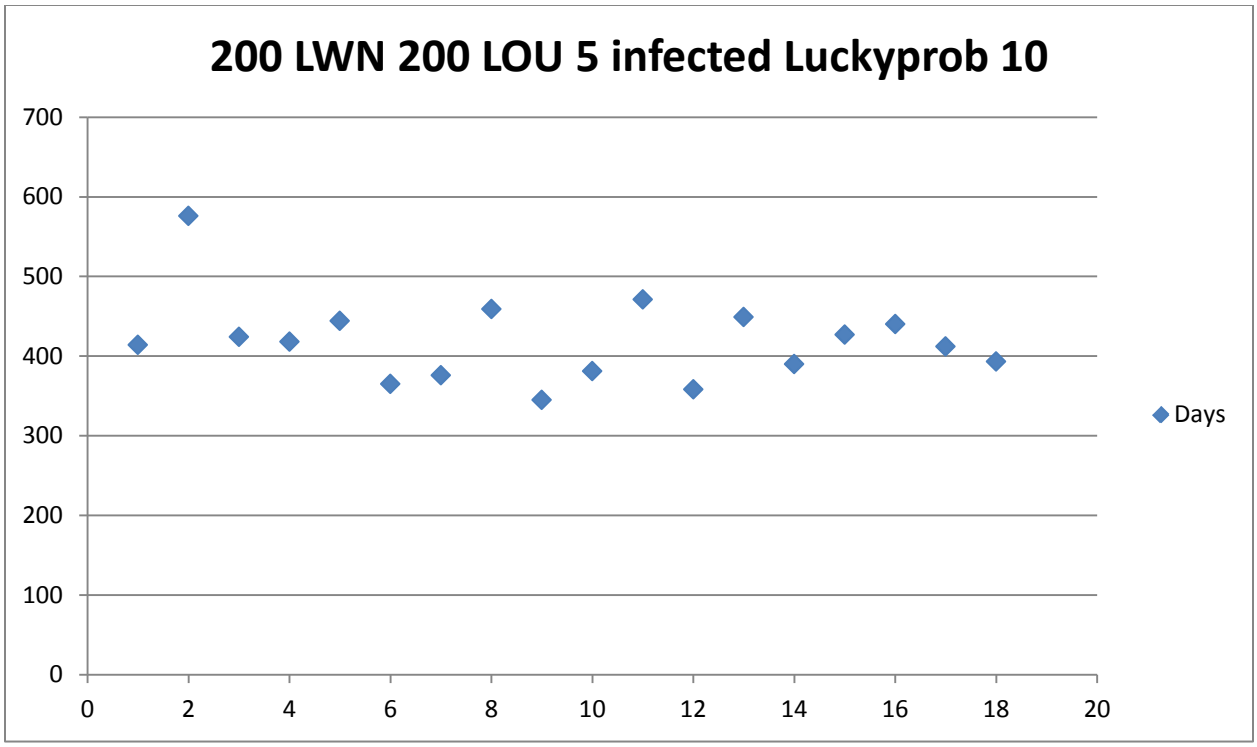
```
  [
    set prob-iwn random 2
    if prob-iwn = 1
    [set breed infectedwn]
    if prob-iwn = 2
    [set breed infectedou]
  ]
  if any? turtles-here with [breed = infectedh]
  [
    set prob-iwn random 2
    if prob-iwn = 1
    [set breed infectedwn]
    if prob-iwn = 2
    [set breed infectedh]
  ]
  if any? turtles-here with [breed = infectedou]
  [
    set prob-iwn random 2
    if prob-iwn = 1
    [set breed infectedwn]
    if prob-iwn = 2
    [set breed infectedou]
  ]]
if breed = infectedou
[
  if any? turtles-here with [breed = luckyh]
  [
    set prob-iou random 2
    if prob-iou = 1
    [set breed infectedou]
    if prob-iou = 2
    [set breed infectedh]
  ]
  if any? turtles-here with [breed = luckywn]
  [
    set prob-iou random 2
    if prob-iou = 1
    [set breed infectedou]
    if prob-iou = 2
    [set breed infectedwn]
  ]
  if any? turtles-here with [breed = carriersh]
  [
    set prob-iou random 2
```

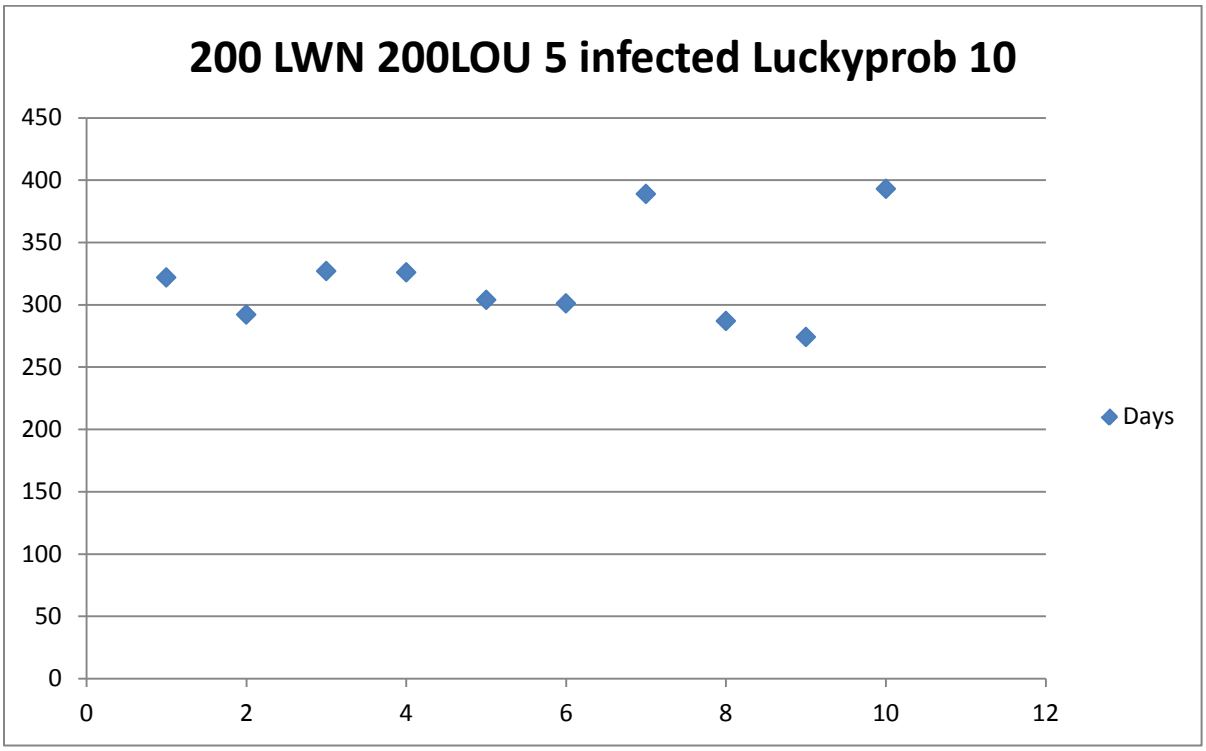
```
      if prob-iou = 1
      [set breed infectedou]
      if prob-iou = 2
      [set breed infectedh]
    ]
    if any? turtles-here with [breed = carrierswn]
    [
      set prob-iou random 2
      if prob-iou = 1
      [set breed infectedou]
      if prob-iou = 2
      [set breed infectedwn]
    ]
    if any? turtles-here with [breed = infectedh]
    [
      set prob-iou random 2
      if prob-iou = 1
      [set breed infectedou]
      if prob-iou = 2
      [set breed infectedh]
    ]
    if any? turtles-here with [breed = infectedwn]
    [
      set prob-iou random 2
      if prob-iou = 1
      [set breed infectedou]
      if prob-iou = 2
      [set breed infectedwn]
    ]]
  set time time + 0.001
end
```

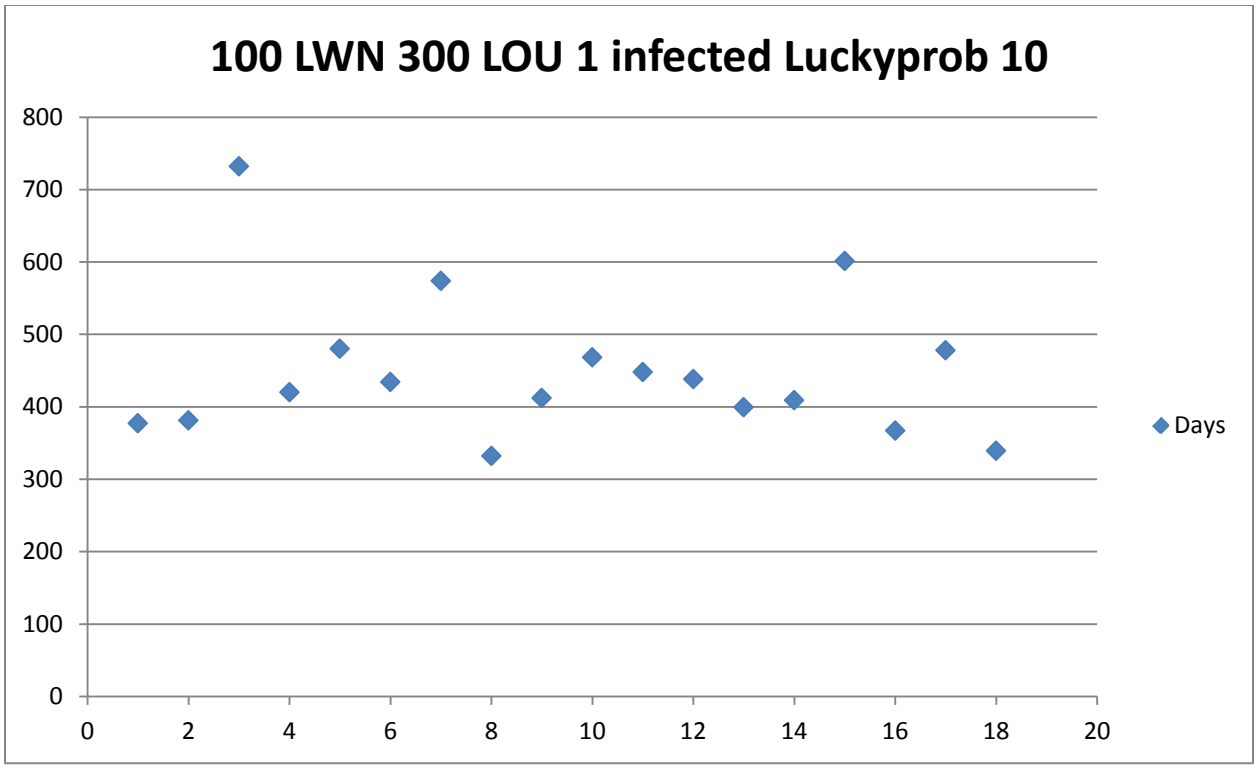
Appendix B – Data

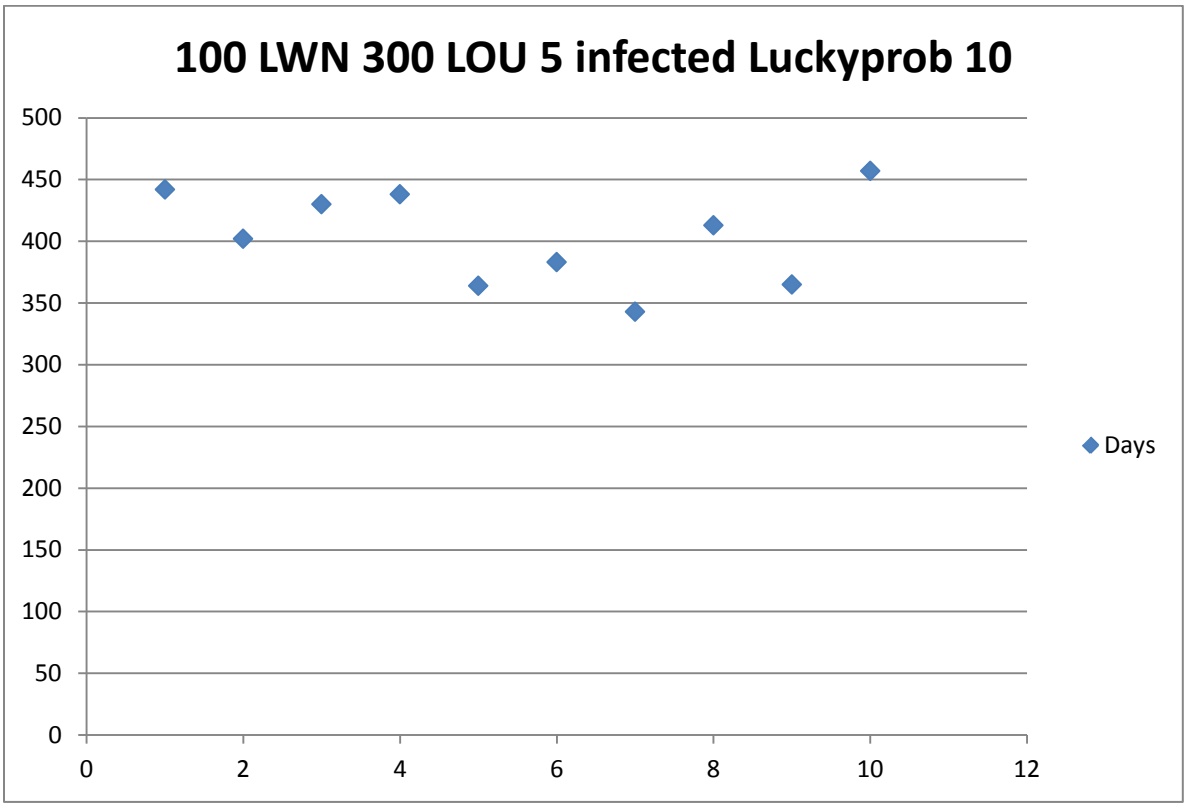


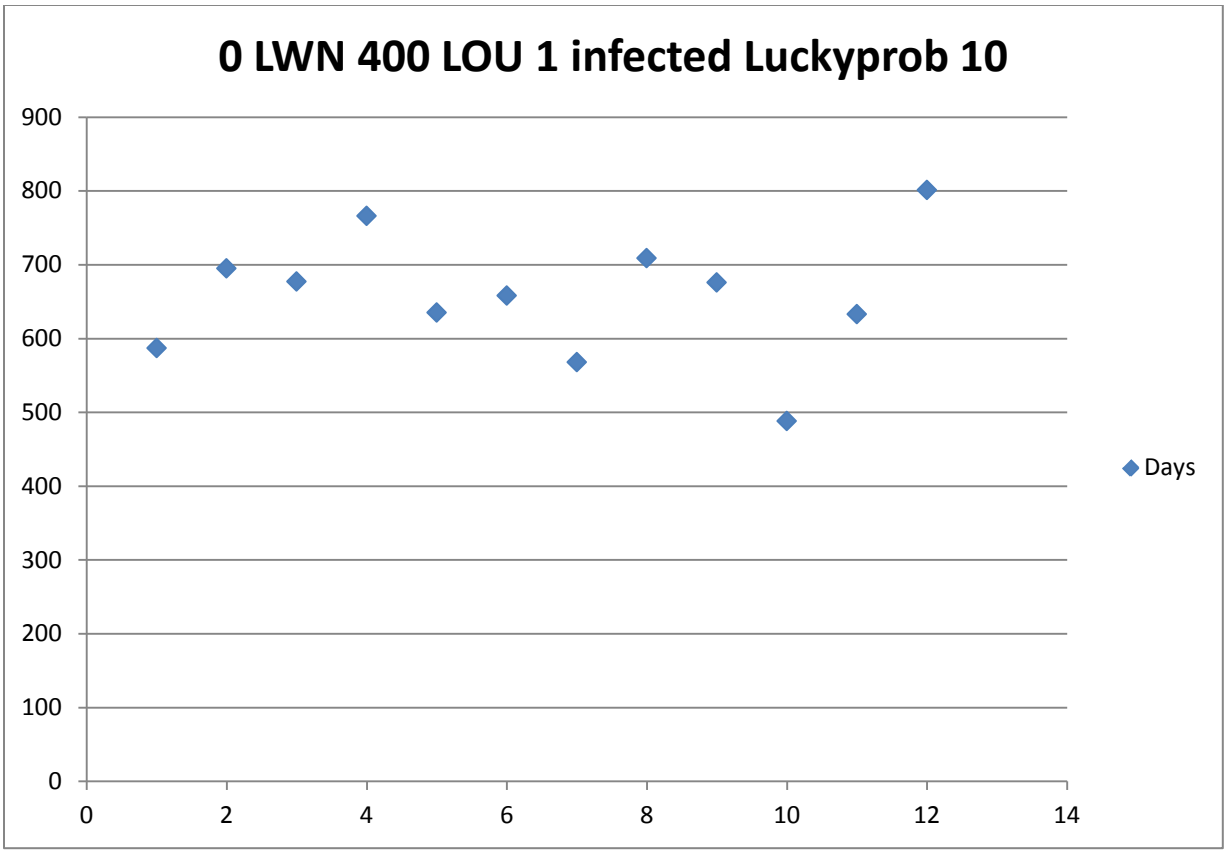


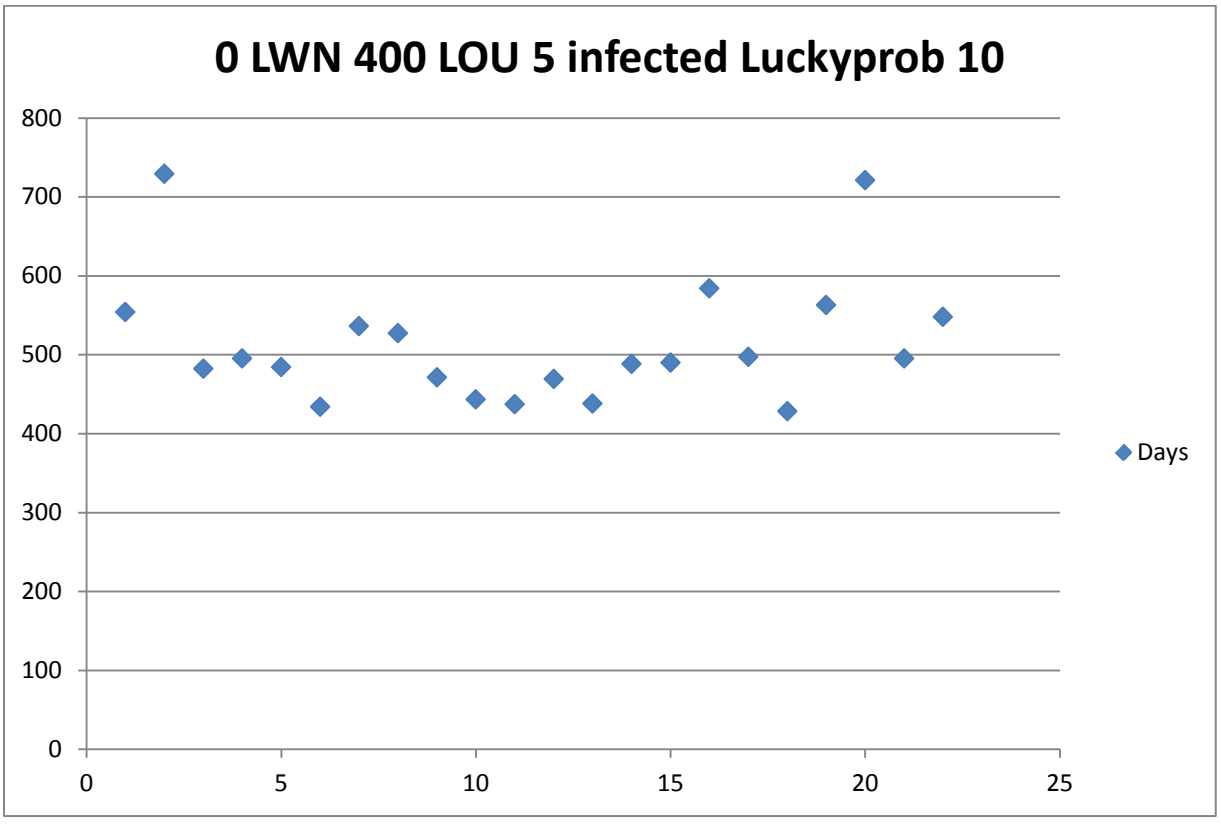

200 LWN 200 LOU 5 infected Luckyprob 10
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20
Days

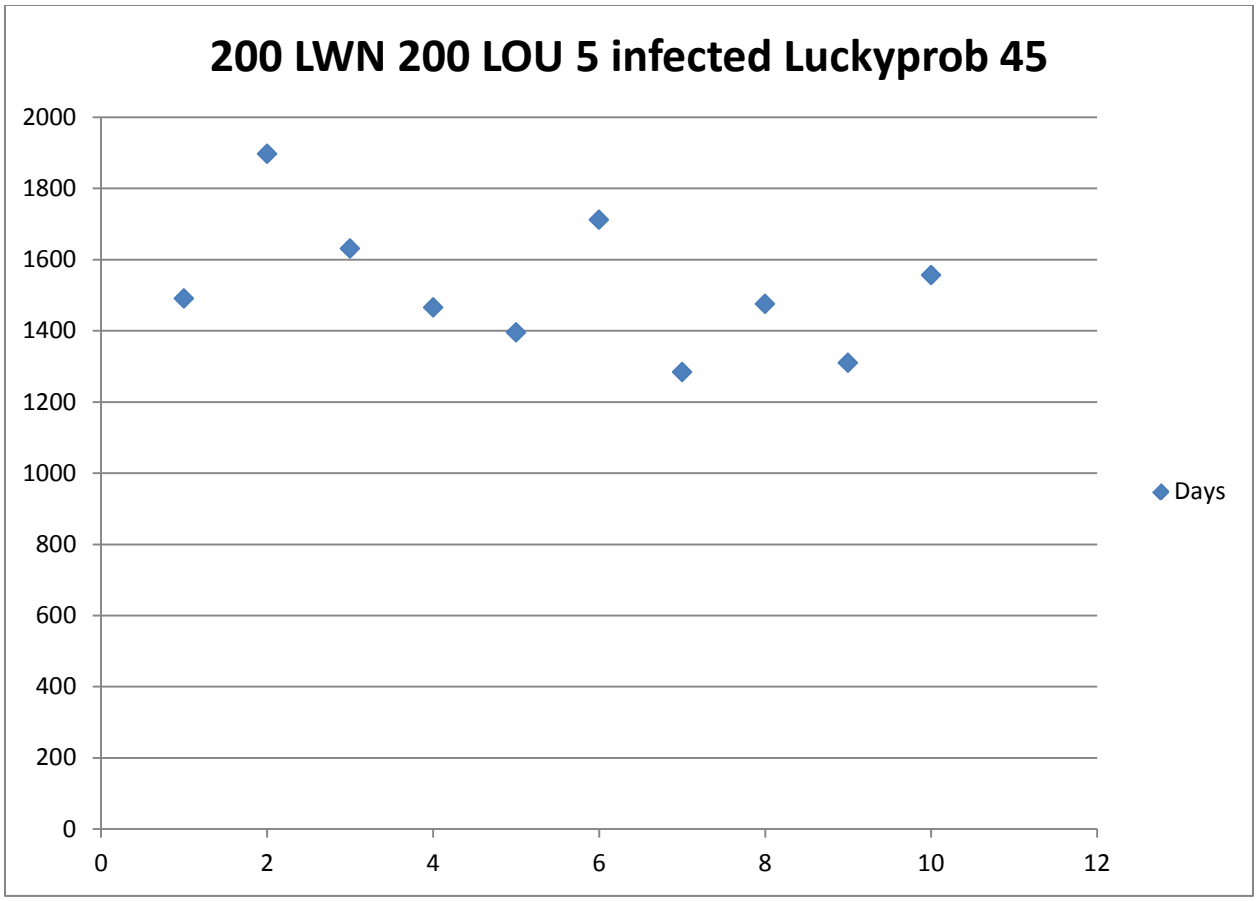

200 LWN 200LOU 5 infected Luckyprob 10
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
Days


100 LWN 300 LOU 1 infected Luckyprob 10
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
20
Days


100 LWN 300 LOU 5 infected Luckyprob 10
500
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
Days


0 LWN 400 LOU 1 infected Luckyprob 10
900
800
700
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
Days


0 LWN 400 LOU 5 infected Luckyprob 10
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
Days


200 LWN 200 LOU 5 infected Luckyprob 45
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12
Days