The Zombie Virus: A Virtual Byte Too Far

A Mathematical Modelling of Movie & Gaming Zombies
By Daniel Wells – Supervised by Dr. Hadi Susanto

Abstract

The Oxford Dictionary defines a zombie as “A corpse said to be revived by witch” and that in popular fiction; “A person or reanimated corpse that has been turned into a creature capable of movement but not rational thought, which feeds on human flesh”. An apocalypse is defined as “An event involving destruction or damage on a catastrophic scale”. The use of zombies in media has risen over the years, to the point where we have numerous TV shows, movies and games being released every year. Recent examples include: The Walking Dead, World War Z and The Last of Us.

This report will look over other zombie model papers and try to replicate the results. Followed by expansion and adapting to different movies and games. It will conclude with the chance of survival if a zombie apocalypse ever happened.

The report will also show that the addition of a permanently dead group is more realistic then the removed group that can resurrect dead zombies, as well as the effects a cured group that cannot be infected again has.

Introduction

The Idea of a Zombie or a reanimated corpse can be traced throughout time to as far back as Circa 2100BC where a poem in ‘Epic of Gilgamesh’, in which it describes the return of the dead to eat the living. More commonly zombies can be referenced in Haitian folklore in which voodoo magic is used to reanimate corpses to be enslaved under the control of the person who raised them, since they have no free will of their own.

According to Leads Zombie Film Festival, the first Zombie movie was 1932’s White Zombie. Based on the Haitian zombies with voodoo magic, a plantation owner raises zombies to work for him as slaves. It wasn’t until 1968 and George Romero’s Night of the Living Dead, that movies used the flesh-eating zombies instead of voodoo ones. He also introduced the idea of it being a pandemic with the zombies attacking not only a small closed area. While zombie games were popularised by Capcom in 1996 with Resident Evil, zombie games have been around as early as 1984 and the first zombie game is attributed to Zombie Zombie.

Over the past few years we have seen a rise in not only the amount of Films and Games being made with a Zombie theme, but also the great deal of high grossing zombie films and games, for example: World War Z, Zombieland, Dying Light, The Evil Within, 7 Days to Die, Last of Us, Walking Dead (Game), any Treyarch Call of Duty console game, Day Z and the TV series Walking Dead.

Comparing the original and modern zombies, shows there is a wide variety of differences, for example we notice that the older types of zombies tend to be slower and work as a pack, whilst modern zombies can have a multitude of strengths and intelligence and can work surprising well alone as well as in a pack. It’s not that surprising then, that over the past couple of years, zombies with different strengths, intelligences and zombification causations have been dubbed with different names. The Haiti zombies being dubbed Voodoo Zombies, other zombies that will be looking at are Classic Romero Zombies, Brain Eating Zombies, Walkers, Fast Zombies and Rage Zombies.
Classic Romero Zombies are the ones mainly used in the ‘When Zombies Attack! : Mathematical Modelling of an Outbreak of Zombie Infection’ Report. These are the slow moving, low intelligence and group huddling zombies, most notably used in the film; ‘Night of The Living Dead’. This report will be using these zombies as the basis for the other types of zombies. Walkers is the term used in the Walking Dead Series (Game & TV). They are slow moving, group walking zombies like Romero’s and are easily susceptible to being deceived if you can cover your living scent.

Brain Eating Zombies are the ones that move around asking for brains. They jump you before ripping your head open and eating your brains, they also can’t be killed by usual zombie killing methods (Removing the head or destroying the brain), The only way to kill these ones is with fire. These Zombies appear in movies such as ‘The Return of the Living Dead’.

Fast Zombies are zombies that are faster than the original type. They can chase can catch up to even the fastest of people. They are seen in the ‘Dawn of the Dead’ Remake in 2004. And Rage Zombies are famous for being the zombies in the movie ‘28 Days Later’, named after the Rage Virus, these ‘zombies’ are not of the dead variety like others, another example is the Last of Us ‘zombies’ which are from a fungal Infection.

Some assumptions to take into consideration throughout this report are: there is only one zombie to start with [unless otherwise stated], the alpha value is the rate at which a zombie is decapitated or suffers brain damage. The zombie apocalypse happens to a village of 500 and in a short time frame, so the birth rate can be taken as zero.

**Phase 1 – Repeating existing data and expanding.**

Munz et al’s paper on classic Romero Zombies has take some of these assumptions into consideration when modelling their zombies, but also some assumptions that do not make sense. The paper starts off with explaining why they are using Romero Zombies, and what data values to use in the following models. It then moves onto the ‘Basic Model’ design, this is shown in Figure 1.

![Figure 1 - The Basic Model by Munz et al](image)

The model shows three groups in bold squares, Susceptible [Humans who can be turned], Zombies and Removed. The arrows are used to show the direction of the flow [an event] of an entity as the move between groups. This model shows that Susceptible will eventually become part of the Zombie – Removed loop. The events taking place in this model are: human kills a zombie by removal of head or brain damage rate ($\alpha$), zombie bites a human rate ($\beta$), zombie resurrection rate ($\zeta$), death by natural causes rate ($\delta$). There is also a $\Pi$ Value, this is the birth rate, because of the assumption earlier, this value will be zero for the remainder of this paper.

The way an ‘event’ works in these models is by looking at who is participating in the event and then multiplying it by the Greek letter relating to it. For example, when looking at $\beta$ [zombie bites humans rate] it needs both the Susceptible and Zombie group since it is a data value in which affects both groups taking part [Since, if S or Z is zero, the total rate is 0], it is should be written as $Z\beta S$, since it is a slightly more realistic way of writing it, since its zombies biting humans [However with multiplication it doesn’t matter what order we multiply numbers and $\beta Z S$ is a little tidier to use in coding].
When a value is set to the Greek letter, the result is an ODE and when combined with the other groups, it becomes a system of ODE’s to be solved. The right hand side [RHS] of Figure 1 shows the system of ODE equations. Figure 2 shows the graph when the values \( \{\alpha = 0.005, \beta = 0.0095, \zeta = 0.0001, \delta = 0.0001\} \) are plugged into the ODE coding given at the end of their [and this] paper.

Figure 2 - The graph for the Basic Model

The next section is the infection model; this is an adaptation of the basic model and is shown in Figure 3. It adds a fourth group to the model, the Infected, it affects the model by delaying the rate a Susceptible becomes a Zombie. Adding the new group increases the total number of ODE’s to four and it also introduces two new data values, \( \delta_I \) [the natural death rate of infected humans] and \( \rho_I \) [the rate at which infected become full zombies].

Figure 3 - The Infection Model

The data values used on this model is the following, \( \{\alpha = 0.005, \beta = 0.0095, \zeta = 0.0001, \delta = 0.0001, \rho = 0.005\} \), however when you plug these values into the code, you get Figure 4a, this graph however is not the same one as displayed in Munz et al\(^{18}\) paper. This is where a paper by Cati et al\(^{22}\) comes in, this paper has already looked at Munz’\(^{18}\) and came to the same conclusion, something is wrong. Cati’s\(^{22}\) paper shows that values that should have been used are \( \{\alpha = 0.001, \beta = 0.0028, \zeta = 5, \delta = 0.0001, \rho = 5\} \). When these data values are used, we get Figure 4b, this graph is more like the one displayed in Munz’\(^{18}\) paper.

Figure 4 - The graphs for the Infection Model with different values
The next two sections of Munz et al.'s values not giving the same graphs as their paper shows. However Cati et al. has figured out the correct data values and once these are plugged in, the graph looks similar to the on found in the original paper. Figures 5 & 6, show both the quarantine and cure model respectfully. Figures 7 & 8 are the comparison between Munz et al.'s and Cati et al.'s data values.

The quarantine model adds the quarantine group, raising the total group number to five. This group also adds three new data values \( \sigma Z \) (Zombies Moved to Quarantine), \( \kappa I \) (Infected moved to Quarantine), \( \gamma Q \) (Quarantine Killed Rate, when zombies try to escape).

Figure 7a, uses values \( \alpha = 0.005, \beta = 0.0095, \zeta = 0.0001, \delta = 0.0001, \rho = 0.005, \kappa = 0.0045, \sigma = 0.0045, \gamma = 0.0045 \) and Figure 7b, uses \( \alpha = 0.001, \beta = 0.0028, \zeta = 5, \delta = 0.0001, \rho = 5, \kappa = 0.0045, \sigma = 0.0045, \gamma = 0.0045 \).

The quarantine model adds the quarantine group, raising the total group number to five. This group also adds three new data values \( \sigma Z \) (Zombies Moved to Quarantine), \( \kappa I \) (Infected moved to Quarantine), \( \gamma Q \) (Quarantine Killed Rate, when zombies try to escape).
The cured model, removes the quarantine group and its associated data values, but adds the data value $cZ$ (Cure Zombification Rate). It does bring up the question: Is the ability to cure zombies back to human reasonable, or is it more likely that the infected group would be curable instead? This will be looked at later in the paper. Also, is the idea that a cured infected or zombie can then be infected again plausible?

Figure 8a, uses $[\alpha = 0.005, \beta = 0.0095, \zeta = 0.0001, \delta = 0.0001, \rho = 0.005, c = 0.005]$ and finally Figure 8b uses $[\alpha = 0.001, \beta = 0.0028, \zeta = 5, \delta = 0.0001, \rho = 5, c = 0.1]$.

Munz et al.\textsuperscript{18} wrapped up their paper by talking about Impulsive Eradication, the idea of attacking zombies with increasing power. The issue with the models above is the use of a zombies – removed loop with zombies being killed and then [more or less] immediately resurrected again, this end up being an infinite loop [until the human population reaches zero] with not only the turned susceptible group but also background death rate feeding this loop, eventually the zombies win because of it.

Cati et al.\textsuperscript{22} brought up the same point in their paper, however they criticised that the idea of zombie resurrection and reuse was not in any film. This is disagreeable since both papers were using the assumption that $\alpha$ was the Zombie Destruction Rate by removing the head or destroying the brain\textsuperscript{18} [page 135 if you’re curious]. There exists a movie, The Return of the Living Dead\textsuperscript{19}, in which a zombie could only die by fire, therefore with the assumption in place, these zombies would be ‘removed’ for a little while before becoming reanimated again. Also some movie use the idea that a human has to die for a short time before becoming a zombie, in these cases, a data value for resurrection would be needed in order to move the dead bodies with the zombification virus [fungus, chemical or other] in them from the Removed group to the Zombie group.

The next four models are original Munz et al.\textsuperscript{18} models but with the addition of a permanently dead group added, this also changes where some data values move entities to and from. The values that will be used with these models are the ones given by Cati et al.\textsuperscript{22}.

The Basic Model now starts with four groups instead of three, Figure 9. There is also no more loops in the model allowing entities to move more freely around the model. The model does have a source (Susceptible) and sink (Dead), which raises a new problem, if time is allowed to continue, and there exists an infinite income for the Susceptible group, then eventually everyone will move into the dead group. However we have assumed no one is born in the short time period, also due to alpha being less then beta, we find that actually, the zombie group ends with more than the dead group, due to the zombies turning the humans before they can kill the zombies.
Figure 9 - The Basic Model with Dead group

The data values used for this model are \([\alpha = 0.001, \beta = 0.0028, \zeta = 5, \delta = 0.0001]\), this gives the graph shown in Figure 10. The removed group barely rises throughout the time period, which is what you would expect to see in zombie films, the person died and then becomes a zombie not to long after.

\[
\begin{align*}
S' &= \pi - \beta SZ - \delta S \\
Z' &= \beta SZ + \zeta R - \alpha SZ \\
R' &= \delta S - \zeta R \\
D' &= \alpha SZ
\end{align*}
\]

Figure 10 - The graph for the Basic Model with Dead group

Figure 11 shows the same Infection model as before but with the new dead group. Again, the flow has a distinct source and sink.

\[
\begin{align*}
S' &= \pi - \beta SZ - \delta S \\
I' &= \beta SZ - \rho I - \delta I \\
Z' &= \rho I + \zeta R - \alpha SZ \\
R' &= \delta S + \delta I - \zeta R \\
D' &= \alpha SZ
\end{align*}
\]

Figure 11 - The Infection Model with Dead group
Looking at Figure 12, there is a slight shift in how long it takes before Humanity is wiped out. This is due to the infected group; it delays the increase in the zombie group which, in turn, delays the $\beta SZ$ term. There is also a distinct curve in the infected line. This is actually realistic [given that zombies existed] since it shows that zombies would start of by biting a few humans that in turn become more zombies, causing more infected, causing more zombies and eventually in a closed system there would be no more humans to infect and hence the distinct curve in the infected line. The other four lines resemble the same depicted in the Basic Model graph, but with the offset due to the infected group.

Adding the dead group to the quarantine model changes it to become one of the more confusing models, as shown in Figure 13. The addition of the dead group causes both $\alpha SZ$ and $\gamma Q$ data values to change from heading to the Removed group and to the dead group.

Figure 14 shows that the addition of the quarantine group compared to the model above has little to no effect on the overall graph, with the exception of the new quarantine line [purple] which ends on a very low number of infected/zombies in this group.
The Cured Model with the dead group brings back the problem of a loop, although this time it is in favour of the humans. Figure 15 shows that there are three possible loop paths in this model. This model has removed the quarantine group and puts the total amount of groups to five.

The graph in Figure 16, is the first graph with a dead group to not have zombies become the dominate group once the coding had run its course. The graph also takes nearly ten times as long complete it. Since the model cures zombies, the graph shows how zombies do take over the humans before succumbing to both the curing and the attacks from humans. Hence the human race survives but at less than 10% of the original populations.
Phase 2 – Games and Movies: Take 1

Moving away from the models described in Munz et al, it’s time to look at different types of zombies from both movies and games. The following seven movies and four games will be used as a premise to design different zombie models based on the type of zombie from these movies/games. The game, The Last of Us was also chosen to be tested to see if the effect of a cure being found would change the dynamics of the model.

The following graphics show a comparison of the different zombies with respect to intelligence and speed. This will be used as the main way of determining the different values to use for the models. The first graphic is from Yahoo! Movies while the second one has been designed after researching the different games.

The following table is a compilation of the different zombie types with respect to different categories. The graphics from above have been turned into a numeric value from between -10 and 10. Strength is another value that will affect the values in the models. A zombie with an intelligence, speed and strength of zeros, is modelled after an average human. Data such as if the game or movie has a cure or quarantine has also been taken into consideration, however both of them do not turn up at all in any of the following models, with the exception of the Last of Us model that will have a cure. Turn Dead is a term used to describe if the dead become zombies or if the humans become zombies. The four that do turn dead [The Walking Dead, Dawn of the Dead (1978), Return of the Living Dead and Graveyard Zombies] all show that once humans are bitten by the βSZ event, will die and move to the Removed group before going to the Zombie groups. The Infectious column, is used to show how infectious a zombie is, this will give different penalties depending on what type of infectious spread it uses. Finally, ‘Kill, Turn or Both’ is used to show if the zombies would just turn humans by infecting them, just turn them or both, if the answer is both, then there is a note saying how many they would kill and turn for every 5 humans.
### Table 1 - Zombie Comparison Table

<table>
<thead>
<tr>
<th>Zombie</th>
<th>Cause</th>
<th>Speed</th>
<th>Intelligence</th>
<th>Strength</th>
<th>Infectiousness (1 - 3)</th>
<th>Turn Dead</th>
<th>Return Dead (Assume Brain Damage)</th>
<th>Cure</th>
<th>Quarantine</th>
<th>Both</th>
<th>Notes</th>
<th>Beta Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (Munz et al)¹⁸</td>
<td>Undead</td>
<td>-7</td>
<td>0</td>
<td>0</td>
<td>Bite (2)</td>
<td>Only</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Turn</td>
<td>0.0028</td>
</tr>
<tr>
<td>Walking Dead (game)¹⁴</td>
<td>Undead</td>
<td>-3</td>
<td>-8</td>
<td>4</td>
<td>Deep Bite (3)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Both</td>
<td>0.00364</td>
</tr>
<tr>
<td>Resident Evil²</td>
<td>Disease</td>
<td>-3</td>
<td>2</td>
<td>5</td>
<td>Deep Bite (3)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Both</td>
<td>0.00465</td>
</tr>
<tr>
<td>Last of Us²³</td>
<td>Disease</td>
<td>2</td>
<td>3</td>
<td>0, 2, 4, 6, 8</td>
<td>Contact (1)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Turn</td>
<td>DIES EVENTUALLY 0.0034 0.00408 0.00476 0.00544</td>
</tr>
<tr>
<td>Last of Us – Cure¹³</td>
<td>Disease</td>
<td>2</td>
<td>3</td>
<td>0, 2, 4, 6, 8</td>
<td>Contact (1)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Turn</td>
<td>DIES EVENTUALLY – CURES ONLY INFECTED 0.0034 0.00408 0.00476 0.00544</td>
</tr>
<tr>
<td>Dead Rising²⁴</td>
<td>Disease</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>Deep Bite (3)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Turn</td>
<td>0.00414</td>
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<tr>
<td>Dawn of the dead (1978)²⁶</td>
<td>Undead</td>
<td>-7</td>
<td>-7</td>
<td>-5</td>
<td>Bite, but must die first (2)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Kill</td>
<td>0.00245</td>
</tr>
<tr>
<td>Shaun of the Dead²⁵</td>
<td>Undead</td>
<td>-10</td>
<td>-10</td>
<td>-5</td>
<td>Bite (2)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Turn</td>
<td>0.001075</td>
</tr>
<tr>
<td>Zombieland³</td>
<td>Disease</td>
<td>9</td>
<td>-2</td>
<td>0</td>
<td>Bite (2)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Turn</td>
<td>0.0035</td>
</tr>
<tr>
<td>Dawn of the Dead (2004)²⁰</td>
<td>Disease</td>
<td>9</td>
<td>4</td>
<td>5</td>
<td>Bite (2)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Turn</td>
<td>0.0037</td>
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<tr>
<td>Quarantine²⁷</td>
<td>Disease</td>
<td>2</td>
<td>4</td>
<td>0</td>
<td>Bite (2)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Turn</td>
<td>0.00345</td>
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<tr>
<td>28 Days Later²¹</td>
<td>Disease</td>
<td>9</td>
<td>7</td>
<td>4</td>
<td>Body Fluid (2)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Both</td>
<td>Kill</td>
<td>0.00553</td>
</tr>
<tr>
<td>The return of the living dead¹⁹</td>
<td>Undead</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>Chemical (1)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Kill</td>
<td>0.006225</td>
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<tr>
<td>Grave Yard /Magic²⁰</td>
<td>Undead /Magic</td>
<td>-10</td>
<td>-10</td>
<td>0</td>
<td>Non Infectious (3)</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Kill</td>
<td>0.00215</td>
</tr>
</tbody>
</table>

The following table is created by taking the control zombies beta value [That is, Catî et al²² value] of 0.0028, and then increasing up and right by 0.00005 and by decreasing by the same amount going down and left [Table 2’s Speed/Intelligence cross values are multiplied by 100,000 for space]. The control zombie value is located at (0, -7). The strength value is used as a modifier to the speed/intelligence table. The strength modifier ranges between 0 and 2, with a strength of zero, resulting in a modifier of 1. Multiplying the tables’ value with the strength modifier gives the beta value for that model.
Daniel Wells

Table 2 - Speed, Intelligence & Strength Table

<table>
<thead>
<tr>
<th>Speed</th>
<th>0.00xxx</th>
<th>Intelligence (0.00xxx)</th>
<th>Strength v</th>
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<tbody>
<tr>
<td>10</td>
<td>315</td>
<td>0.2</td>
<td>3.0</td>
</tr>
<tr>
<td>9</td>
<td>310</td>
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<tr>
<td>8</td>
<td>305</td>
<td>0.2</td>
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</tr>
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<td>7</td>
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<td>4</td>
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<td>3.0</td>
</tr>
<tr>
<td>-10</td>
<td>215</td>
<td>0.2</td>
<td>3.0</td>
</tr>
</tbody>
</table>

The Walking Dead

The Walking Dead is a multi-end game set in a post-apocalyptic world, where the zombies have already taken over. Your character is an escaped convict who has to survive through countless ‘walker’ attacks as the game progresses.

The zombies from Walking Dead infect people with a deep bite. The deep bite [and any other type of death] then kills off the humans before they reanimate as a zombie. However, once they have been killed via decapitation or brain damage, they do not come back. In the game, there is no zombie quarantine or cure to help people. The zombies also turn and kill their targets, resulting in a 1:4 kill/turn ratio, giving a new data value, \( \mu \) [which is equal to \( \beta/4 \)]. Since it infects by deep bite, it has an infectious penalty (\( Rn \)) of 3, this means that its beta value will be multiplied by 1/3. This results in the following model and ODE’s in Figure 19.

\[
\begin{align*}
\delta S' &= \pi - \frac{\beta SZ}{\ln n} - \mu SZ - \delta S \\
I' &= \frac{\beta SZ}{\ln n} - \rho I - \delta I \\
Z' &= \rho I + \zeta R - \alpha SZ \\
R' &= \delta I + \delta S - \zeta R \\
D' &= \alpha SZ + \mu SZ
\end{align*}
\]

Figure 19 - The Walking Dead Model

These zombies are slow and clunky, they can easily be deceived if you can hide your scent, and this is why they have been given a speed of -3 and an intelligence of -8 but has an infectious penalty of 3. However, they are slightly stronger than normal, giving them a 4. The overall beta value is 0.00364 [Before infectious penalty]. The alpha value will remain as 0.001, Rho is 5, Mu is Beta multiplied by 1/4, Zeta is 5 and delta is 0.0001. This gives us the graph in Figure 20.
The graph shows that the humans will eventually be wiped out and zombies will rise, however there will only be a short amount of zombies compared to the total number of entities in the system, since most will end up dead.

**Resident Evil**

Resident Evil is a multi-ending game set before the discovery of zombies and directly after the events of Resident Evil Zero. You are one of two possible characters who is part of a two team task force. You are tasked with finding out what happened to Beta Team. After landing at the site of last contact, you find the helicopter and a severed hand. As the game progresses, you tackle puzzle, traps and zombies and eventually find out about the T-virus experiments causing the zombies.

The Zombies in this game are slightly slower than a human, but gain a little intelligence as well as strength. The T-virus is transmitted via a deep bite, the human then becomes infected before turning into a zombie. The human or infected can die of natural causes and become permanently dead, however once they become a zombie, the only way to kill them is by the usual brain damage or decapitation. These zombies do not re-rise after dying either and there is no cure or quarantine. They turn and kill to feed and again at a 1:4 kill/turn ratio. The model and ODE’s are found in Figure 21 below.

**Figure 21 - Resident Evil Model**

The values used on this model will be: \( \alpha = 0.001, \beta = 0.00465, \delta = 0.0001, \mu = 0.00465/4, \rho = 5, \ln = 3 \). These values give Figure 22. The graph shows that that again, humans will be wiped out, zombies will remain but only a fifth of the total population.
The Last of Us starts of 12 years before the main game; here you witness the uprising of the zombies, due to the Cordyceps fungus. After the events of that day, we awake in the present, where humans have been put into these heavily guarded ‘quarantine’ zones. You are tasked with transporting a young girl named Ellie out of the quarantine zone. She has been infected and (would normally been turned into a zombie after two days) is still human after three weeks. It is believed that she could be the key to a cure since she is both infected and immune.

The zombies are caused by the Cordyceps fungus, a fungus that normally is seen in some ant species. They [fungus] take over the brain and cause the ants to go insane, spreading more air borne spores to infect more ants. Eventually they die and a fungal spore grows out of their head. This is similar to what happens in The Last of Us, the fungus takes over once infected and takes them through different types/stages of zombification. The different zombies [in order] are Runner, Stalker, Clicker and Bloater.

Runners are the first stage of zombie after infection; the fungus causes the zombies to become slightly insane, making them run after any humans that it sees, trying to spread the fungus as much as possible.

Any time between a week and a year, Runners turn into Stalkers, they become more insane, vision is slightly decreased by being blinded in one eye, causing them to walk a little slower than an average human but they have a slightly high intelligence due to the fungus. They still however have the same strength as a human. They, as their name states, stalk humans by hiding before ambushing and biting.

After around eight years as a stalker, the fungus has removed all vision from the host. The fungus is smart enough, however, to make the host use echolocation by ‘clicking’. With the addition of echolocation, the Clickers can now move slightly faster again. The fungus causes a plating to form around their head making them slightly harder to kill. They are also highly intelligent and stronger than most humans. These are the worst zombies to come across. These tend to kill more than infect.

The Bloater zombie stage comes after another seven years; the fungus is all over the body of the host, causing it to have heavy armour and resistant to most low calibre bullets. They are highly aggressive and due to the fungus bloating them, they are once again, slow moving. The echolocation is worse than the clickers. These kill and do not infect [However, this will only be looked at later].
After fifteen years as a Bloater, the fungus has used most of the resources and kills the host. The dead body, however, is still super infective, a giant spore grows from the body sending the fungus into the air. This also happens to all zombies that die due to head injuries since the fungus is still alive.

Figure 23 shows the basic model for all the ‘living’ [all except dead group] zombies in The Last of Us. This model will focus on one zombie each time, therefore if a zombie converts, it will be removed from this system.

\[
S' = \pi - \beta SZ - \delta S \\
I' = \beta SZ - \rho I - \delta I \\
Z' = \rho I - \alpha SZ - \varepsilon Z \\
D' = \alpha SZ + \varepsilon Z + \delta I + \delta S
\]

Figure 23 - The Last of Us Model (No In Term)

The values that will be used in these \( \alpha = 0.001, \delta = 0.0001, \rho = 5, \varepsilon \) [The chance of a zombie converting] = 0.0001[Runner], 0.0002 [Stalker], 0.0003 [Clicker], 0.0004 [Bloater], \( \beta = 0.0034 \) [Runner], 0.00408[Stalker], 0.00476[Clicker], 0.00612[Bloater].

The graphs shown in Figures, shows that once again, humans die out (and at an increasing rate depending the stage of the zombie), the zombies become the dominate group (higher than the dead group) and again, the higher stage zombies end up being more then the lower end ones.
The Last of Us – Cure

This version follows the same as above, except the cure has been found instead. The zombies stay exactly the same as above and the model stays close with the exception of a cured group. With the addition of this group, we add two new data values; \( \delta C \) and \( cl \). \( cl \) is the rate at which an infected human becomes cured before the zombification takes place and \( \delta C \) is the rate at which cured people die of natural causes. The cured group cannot however be infected again by zombies. The model and ODE’s are shown on Figure 25.

\[
S' = \pi - \beta SZ - \delta S \\
I' = \beta SZ - \rho I - \delta I - cl \\
Z' = \rho I - \alpha SZ - \varepsilon Z \\
D' = \alpha SZ + \varepsilon Z + \delta I + \delta S + \delta C \\
C' = cl - \delta C
\]

Figure 25 - The Last of Us Model with a Cure

The values used are the same as above, with the addition of the \( c \) term. \( c = 0.1 \). The graphs are displayed in Figure 26.

Figure 26 - The graphs for The Last of Us Model with a Cure, increasing zombie beta values

The graphs shown show that no matter what zombie you are up against, humanity will survive but at around 1/50 of the population. The zombies and dead groups are the only ones that seem affected by the change in beta and epsilon values. As both increase, the amount of zombies at the end increases and the total amount of dead decreases.
Dead Rising

You play as a photojournalist, Frank West, and start off with you in a helicopter flying into Willamette, Colorado. You have been tasked with finding out why it has been sealed off by the National Guard. After landing on shopping centre, after telling your pilot to come back in 72 hours, you discover a group of survivors of a localised zombie outbreak. The game has multiple ending depending on what you do during the ‘72 hours’ inside the centre.

The zombies in Dead Rising are from an unknown disease. They are slightly stronger and more intelligent than an average human; they have the speed of an athlete running. They infect via a deep bite to turn humans, they don’t kill the target to eat them. These zombies don’t turn the dead or re-rise the dead either. Finally there is no cure or quarantine [other than the quarantine around the city]. Figure 27 shows the model and the ODE’s.

\[ S' = \pi - \frac{\beta SZ}{In} - \delta S \]
\[ I' = \frac{\beta SZ}{In} - \rho I - \delta I \]
\[ Z' = \rho I - \alpha SZ - \epsilon Z \]
\[ D' = \alpha SZ + \epsilon Z + \delta I + \delta S \]

Figure 27 - Dead Rising Model

The values used for this model are: \( \alpha = 0.001, \beta = 0.00414, \delta = 0.0001, \epsilon = 0.0001, \rho = 5, \ln = 3. \)

Figure 28 - The graph for the Dead Rising Model

The results are not good for the humans. Out of the 500 humans and 1 zombie, we end with no humans and around 150 zombies.

Dawn of the Dead (1978)

In the Movie, the USA is starting to become overrun by zombies. A group of four escapes in a news-station helicopter, they eventually [after several encounters with zombies] find a shopping centre, here they land on the roof and find a way into an upper office room. After a while, they make the shopping centre safe by killing all the zombies inside and blocking up the entrances.
The zombies in this film are slow, unintelligent and weak. Most scenes show the humans just pushing or running past the zombies. The zombies work better in groups or by surprising the humans. In this version of Dawn of the Dead any and all they have died of a non head related injury will become a zombie. However once dead from a decapitation or brain damage, will not re-rise. There is no cure or quarantine in this world. The zombies will actually try and kill you to turn you but even a small bite is affective enough to eventually kill you before you come back as a zombie. This is why we get the following model and ODE in figure 29.

\[ S' = -\delta S - (\beta / \ln S)SZ \]
\[ R' = (\beta / \ln S)SZ + \delta S - \zeta R \]
\[ Z' = \zeta R - \alpha S \]
\[ D' = \alpha S \]

Figure 29 - Dawn of the Dead (1978) Model

The values for this model are: \( \alpha = 0.001, \beta = 0.00245, \delta = 0.0001, \zeta = 5, \ln = 2 \).

Figure 30 - The graph for the Dawn of the Dead (1978) Model

The graph [shown in Figure 30] is different to most of the other ones. It shows that, while zombies survive, they do not actually take over and become a massively dominating ‘race’, unlike other models. This one shows that with lots of time, the human population actually wipes out with a few zombies serving but the majority of zombies and humans will end up in the dead pile. This model isn’t realistic either since with such a great time needed; more babies would be born, changing the dynamics of the model.

Shaun of the Dead

This film is the black sheep of the list, while not the only comedy styled movie to have been looked at; it is the only one that uses zombie stereotypes. The movie starts just as the zombie apocalypse is beginning, it follows two best friends as they try to survive in a pub as zombies try to gain entry.

The zombies in this film are stereotypical super slow and unintelligent and super weak ones. They can easily be deceived as at one point the group bypasses them to get into the pub. They can however turn a human with the tiniest bite, they don’t turn dead or re-rise meaning that if a human dies, it is permanently dead with the same applying to a zombie that dies from brain damage. The infected don’t
last long so natural death at this stage can be ignored. The figure below shows the model and the set of ODE’s.

\[
S' = -\delta S - (\beta/\ln)SZ \\
I' = (\beta/\ln)SZ - \rho I \\
Z' = \rho I - \alpha SZ \\
D' = \alpha SZ + \delta S
\]

The values used are: \(\alpha = 0.001, \beta = 0.001075, \delta = 0.0001, \rho = 7, \ln = 2\).

Figure 31 - The Shaun of the Dead Model

Figure 32 - The graph for the Shaun of the Dead Model

Figure 32 shows that due to the values for alpha and beta being so close [0.000075 in difference], it causes similar curves as the one in the previous model [Figure 30], however with the time frame extended by six times. It shows that once again, humans die, one or two zombies survive and everyone else becomes dead. This model is again unrealistic since in the time frame, births would of happened, changing the model dynamics.

Zombieland\(^9\)

The other comedy, this one acts like a regular zombie film but with comedic twists to make it more enjoyable. The movie starts two months after a mutant strain of mad cow disease mutates into mad human disease. A college student that goes by “Columbus” is trying to make his way from his college in Austin, Texas to his parents’ home in Columbus, Ohio to see if they are alive. Throughout the movie, “Columbus” mentions a list of rules which grow as the movie progresses, a total of thirty three rules are made by the end of the movie.

While being a comedy, the zombies have a heightened speed with “Columbus” stating “Rule number 1: Cardio”\(^9\); people with poor cardio were the first to go. They do however have average strength and are slightly less intelligent with the group at one point ringing a bell and killing the zombie as it runs past them. The zombification is caused by a virus and even a small bite is enough to infect someone and since it is a virus, the zombies only turn humans and never actually die (unless from natural causes [Humans] and brain damage [zombies]) and once either a human or zombie is killed it is permanently dead. The model and ODE’s is shown in Figure 33.
The values used in this model are: \( \alpha = 0.001, \beta = 0.0035, \delta = 0.0001, \rho = 5, \ln = 2 \).

The graph shown above in Figure 34 shows a little infected curve along with the usual humans being wiped out and the zombies taking over.

**Dawn of the Dead (2004)**

This Dawn of the Dead\(^{20}\) is a remake of the 1978\(^{26}\) with the same name. This movie has the same premise as the original, a couple of people find a safe haven in a shopping centre before having to evacuate later on. The zombies however are completely different to the original movie.

The zombies in this remake are faster, they chase down humans at speed, and they cannot be brushed past like the original. They have a heightened intelligence as one is seen following a dog [which they have no use for] go down a hatch and just before it closes it opens it up allowing multiple zombies to reach a human [which they feed on] hiding behind it. They turn humans by the zombie drawing blood from the human. For example a woman gets infected by a little scratch but someone is not infected by a cut from a piece of metal and then being in the same water as a zombie.
Figure 35 above, shows the model and ODE’s. The values used in this one are similar to the Zombieland\textsuperscript{9} values, except for $\beta$ being increased by 0.0002. Overall the values are: $\alpha = 0.001$, $\beta = 0.0037$, $\delta = 0.0001$, $\rho = 5$, $I_n = 2$.

![Graph of the Dawn of the Dead (2004) Model](image)

The graph, when compared to the Zombieland\textsuperscript{9} one, has very little in difference. They both use the same model and almost the same values; this graph however shows that the number of zombies and the number of dead people are a lot closer.

**Quarantine\textsuperscript{27}**

This movie is one of a few that shows you or explains to you the origin of the zombie virus. In this movie, it is a mutated rabid virus that had been stolen by a doomsday cult from a chemical weapons facility. This movie also has the additional feature that the zombies target any species, even dogs. It follows a news team following two fire-fighters on their shift. They get called to an apartment building and everything goes downhill from there.

The zombies, while vicious and bloodthirsty, increasing their speed and intelligence, still have human strength. They infect people by biting [like most zombies]. The figure below shows the model and ODE’s.

![Diagram of the Quarantine (Movie) Model](image)

The values are again similar to the previous two [Dawn of the Dead\textsuperscript{20} and Zombieland\textsuperscript{9}] but with beta being slightly less the both of the others. The values used are: $\alpha = 0.001$, $\beta = 0.00345$, $\delta = 0.0001$, $\rho = 5$, $I_n = 2$. 
Figure 38 - The graph for the Quarantine [Movie] Model

The graph follows a similar trend to the ones above, but with the distance between zombies and dead being greater. The total amount of zombies is the lowest of the three.

28 Days Later

28 Days Later is a zombie film and not a zombie film at the same time, it follows a man named Jim who wakes up from a coma, 28 days after three activists released the ‘Rage’ virus from a testing facility. The virus is spread through body fluids such as blood or saliva. The infected become mindless with extreme hostility and violence; they however do not resort to cannibalism unlike other zombies, this may be due to the infection taking less than 20 seconds to take effect. This is why the model has no ‘infected’ group. Also these zombies can die from starvation like humans but this would only come into affect once all humans had been killed, therefore there would be a downward red [zombie graph line] curve and an increasing black curve [dead graph line] after the code has finished running.

The ‘zombies’ in this film, are very fast and intelligent and also physically strong all due to the virus. Since the ‘zombies’ can accidently kill a human before they turn, the addition of the $\mu$ variable has returned. The ODE’s and model are displayed on Figure 39.

![Figure 39 - The 28 Days Later Model](image)

The values used in this model are: $\alpha = 0.001$, $\beta = 0.0053$, $\delta = 0.0001$, $\mu = 0.00553/4$, $\ln = 2$

The graph in Figure 40 shows that once again, the zombies will win with just under half the population becoming a zombie.
Figure 40 - The graph for the 28 Days Later Model

The Return of the Living Dead

The movie follows a group of people as a chemical gas is released causing the dead and people with long exposure to it, to become zombies. The zombies are also unfazed by decapitation or brain damage, being that they will reanimate again if this is used to ‘kill’ them. The only way to kill them is by burning the bodies. They also have super speed and intelligence with instances of zombies using a chain and winch to try and remove a door because a human is behind it, and at one point a zombie using a police radio to send backup. These zombies also kill the human before the gas causes them to reanimate. The model will assume that the gas is covering all 500 humans but they haven’t had long enough exposure to cause zombification from the gas alone.

Figure 41 - The Return of the Living Dead Model

The values that will be used in the model and ODE’S shown above in Figure 41 are: $\alpha = 0.001$, $\beta = 0.006225$, $\delta = 0.0001$, $\zeta = 5$, $In = 1$. 

\[ S' = -\delta S - (\beta/In)SZ \]
\[ R' = (\beta/In)SZ + \delta S + \alpha SZ - \zeta R \]
\[ Z' = \zeta R - \alpha SZ \]
The graph shows that again, humans will become extinct and zombies will all rise under this gas. A small amount of dead bodies will form before rising as well.

Grave-Yard Zombies

Graveyard zombies are the most basic and most known [before TV shows, Games and Movies changed the way we look at them], they are the once dead and they rise from their graves at midnight. These zombies are the similar to the ones you would find in the game Minecraft. They roam around until sunrise at which time they either go back to their graves or hide from the sun [Since it burns them]. Burning in the sun or brain damage will permanently kill these zombies. This model is a time dependant one, meaning the ODE’S used depend on the time. The model is spilt into five different times; 00:00 – 00:59, 01:00 – 05:59, 06:00 – 06:59, 07:00 – 18:59, 19:00 – 23:59. Figure 43 shows the model and ODE’s used.

The zombies once raised, kill the humans which then rise at midnight. The graveyard in this village [with population 500] has 100 graveyards which the bodies didn’t die of a brain trauma. These zombies though are the slow limp walking zombies that are un-intelligent but have the same strength as a human. At 06:00 in the morning, 60% of the zombies return their graves.

The values in this model are: $\alpha = 0.001$, $\beta = 0.00215$, $\delta = 0.0001$, $\zeta = 5$, $x = 0.02$, $y = 0.6$, $\ln = 3$.

Figure 44, shows three different graphs; the top left graph displays all the lines showing that humanity will survive with about 4/5th the original population. The 100 zombies will eventually be killed and all other deaths will be easily taken care of as they happen. The top right graph shows just the zombie population, and shows it gradually decreasing over the course of 800 hours [This is the only model to have a proper time frame for the y-axis]. The bottom left graph shows the removed group, it shows the affect the rising at midnight has on the model. Overall this model shows that these zombies would be the easiest to counter.
Figure 43 - The Graveyard Zombie Model

Figure 44 - The graphs for the Graveyard Zombie Model
Phase 3 – Games and Movies: Take 2

Phase two is about improving on the results gained in phase one. Instead of making the table of beta values from arbitrarily increasing or decreasing by a set value, it will be designed around the regression values of two movies. Also the strength line is not a modifier any more it now gives the values for alpha, the reasoning for this is because a weaker zombie should be easier to kill then a stronger one. From here, once the values are placed, intermediate values will be placed and from there, the table will be constructed. The two movies in question are both Dawn of the Dead (1978)\textsuperscript{26} and its remake in 2004\textsuperscript{20}. The models shall be the same as above, unless otherwise stated, so they will not be displayed below.

![Figure 45](image)

Figure 45 - A plot between time (Minutes) & Ln(Total Deaths) for the 1978 Dawn of the Dead

Figure 45 shows the natural log of the total deaths [human or zombie] against time in minutes for Dawn of the Dead (1978)\textsuperscript{26}, the blue line showing zombies and red line showing humans. When you plug the correct values into the regression coefficient equation;

\[
r = \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2}
\]

The value for r ends up being 0.0229 for the zombie deaths and 0.011 for human deaths. This sets the value in the beta table to be 0.011, and the alpha line being 0.0229.

The graph shown in Figure 46 shows the natural log of the total deaths [human or zombie] against time in minutes for Dawn of the Dead (2004)\textsuperscript{20}. The regression values end up being 0.044 and 0.022 for zombies and humans respectably. A full table with values showing the regression can be found at the back of this report.

![Figure 46](image)

Figure 46 - A plot between time (Minutes) & Ln(Total Deaths) for the 2004 Dawn of the Dead
Daniel Wells

The new values for beta are created by increasing the value by 0.0004 up and right and decreasing by the same amount going left or down and similarly for alpha by increasing and decreasing by 0.002.

Table 3 shows the beta and alpha values in same style as Table 2, with values being multiplied by 10,000 [for easier display]. Table 4 shows the values that will be used in the models below.

### Table 3 - New Alpha & Beta values

<table>
<thead>
<tr>
<th>Speed - y</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
<th>90</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
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<td>0.00003</td>
<td>0.00005</td>
<td>0.00007</td>
<td>0.00009</td>
<td>0.00011</td>
<td>0.00013</td>
<td>0.00015</td>
<td>0.00017</td>
<td>0.00019</td>
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<td>2</td>
<td>0.00002</td>
<td>0.00004</td>
<td>0.00006</td>
<td>0.00008</td>
<td>0.00010</td>
<td>0.00012</td>
<td>0.00014</td>
<td>0.00016</td>
<td>0.00018</td>
<td>0.00020</td>
<td>0.00022</td>
</tr>
<tr>
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<td>0.00009</td>
<td>0.00012</td>
<td>0.00015</td>
<td>0.00018</td>
<td>0.00021</td>
<td>0.00024</td>
<td>0.00027</td>
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</tr>
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<td>0.00012</td>
<td>0.00016</td>
<td>0.00020</td>
<td>0.00024</td>
<td>0.00028</td>
<td>0.00032</td>
<td>0.00036</td>
<td>0.00040</td>
<td>0.00044</td>
</tr>
</tbody>
</table>

### Table 4 - All the values to be used in models below

<table>
<thead>
<tr>
<th>Zombie</th>
<th>Alpha</th>
<th>Beta</th>
<th>Delta</th>
<th>In</th>
<th>Rho</th>
<th>Epsilon</th>
<th>c</th>
<th>mu</th>
<th>x</th>
<th>z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking Dead (game)³⁵</td>
<td>0.026</td>
<td>0.0124</td>
<td>5</td>
<td>0.0001</td>
<td>3</td>
<td>5</td>
<td>n/a</td>
<td>n/a</td>
<td>0.0031</td>
<td>n/a</td>
</tr>
<tr>
<td>Resident Evil³</td>
<td>0.024</td>
<td>0.0164</td>
<td>n/a</td>
<td>0.0001</td>
<td>3</td>
<td>5</td>
<td>n/a</td>
<td>n/a</td>
<td>0.0041</td>
<td>n/a</td>
</tr>
<tr>
<td>Dead Rising³³</td>
<td>0.030</td>
<td>0.0192</td>
<td>n/a</td>
<td>0.0001</td>
<td>3</td>
<td>5</td>
<td>0.0001</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Dawn of the dead (1978)²⁶</td>
<td>0.044</td>
<td>0.0112</td>
<td>5</td>
<td>0.0001</td>
<td>2</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Shaun of the Dead²⁵</td>
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<td>0.0088</td>
<td>n/a</td>
<td>0.0001</td>
<td>2</td>
<td>5</td>
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<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<tr>
<td>Zombieland³</td>
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<td>0.0196</td>
<td>n/a</td>
<td>0.0001</td>
<td>2</td>
<td>5</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Dawn of the Dead (2004)³⁰</td>
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<td>0.0220</td>
<td>n/a</td>
<td>0.0001</td>
<td>2</td>
<td>5</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Quarantine²²</td>
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<td>0.0192</td>
<td>n/a</td>
<td>0.0001</td>
<td>2</td>
<td>5</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>28 Days Later³³</td>
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<td>n/a</td>
<td>0.0001</td>
<td>2</td>
<td>n/a</td>
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Walking Dead\textsuperscript{14}

The walking dead graph changes a lot when compared to original, so much so, that the amount of zombies is increased to 500 because even at 100 zombies, the graph didn’t last long and with 500 zombies we still win before 1 ‘time’ has past, this is due to the Removed group becoming less than zero, causing the code to stop. Figure 47 shows that still zombies will lose, a much need change from previous models. Humans will survive around 4/5\textsuperscript{th} the original population.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{walking_dead_graph.png}
\caption{The graph for The Walking Dead Model with new values used}
\end{figure}

Resident Evil\textsuperscript{5}

Once again, the amount of zombies is increased from 1 to 100. Even with this increase, humans win and zombies lose.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{resident_evil_graph.png}
\caption{The graph for the Resident Evil Model with new values used}
\end{figure}

This is very much anti what is thought of by a zombie apocalypse. However when you look at movies and games, there is only a select few where the zombies actually win by wiping out the human race. Most end with the human race on low numbers but surviving in camps.

Even with the next few graphs, all come to the same conclusion, with the values based of movies, humans win.
Daniel Wells

Dead Rising

Figure 49 - The graph for the Dead Rising Model with new values used

Dawn of the Dead (1978)

Figure 50 - The graph for the Shaun of the Dead (1978) Model with new values used
Shaun of the Dead

Figure 51 - The graph for the Shaun of the Dead Model with new values used

Zombieland

Figure 52 - The graph for the Zombieland Model with new values used


Figure 53 - The graph for the Dawn of the Dead (2004) Model with new values used
The Return of the Living Dead

Once again, the movie with the zombie that only die by fire, has shown that zombie do in fact win if this was the case. Even with the alpha and beta values being 0.0008 greater in the beta value, zombies win. The graph shown in Figure 56, gives a nice green ‘removed’ curve, showing how the humans would die before the gas resurrected them as zombies.

Grave-Yard Zombies

The coding used for this model, makes the graph [Figure 57] not that pleasing to the eye. It does, however, show that even if 500 zombies rose at midnight in a village of 500, they would all be dead by 4 am in the morning.
This model has been revamped compared to the original one. This model includes all the different types of zombies at once, it has a progressive rho value showing that it takes longer for the zombies to move to the next stage. The zombies also have different beta and beta* values, this is due to that fact, the different types of zombies, not only have different speeds and intelligence and strengths but also kill or infect at different ratios. Table 5 shows that values that will be used in the following two models.

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Figure 58 - The Last of Us Model redesigned

Figure 58 shows the model and ODE’s used for all the different types of zombies. Since this model is based on the fungus just appearing, in this small village, S will start at 500, Z1 start at 1 while the others start at 0. They give the following graphs shown in Figure 59 (Zoomed in) and Figure 60.
Even with the alpha value being higher than beta, humanity will still be wiped out from a single zombie. This is due to the way the model is set up. As time progresses, not only is there more zombies, but they are of different strengths and even more so, that once a zombie dies, the fungus can still infect people. Eventually all the zombies will ‘die’ and become giant spore in the ground.

**Last of Us Cure**

Like the model above, it will use the same starting values with the addition of the c term, c being 0.1.

The following model and ODE’s are shown on Figure 61 and graphs are shown on Figures 62 & 63.

\[
S' = -(\beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_5 R + c + \delta) S
\]

\[
I' = (\beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 R) S - (\alpha_1 + c) I
\]

\[
Z_1' = \rho_1 I - \alpha_2 Z_1 S - \rho_1 Z_1
\]

\[
Z_2' = \rho_2 I - \alpha_3 Z_2 S - \rho_2 Z_2
\]

\[
Z_3' = \rho_3 I - \alpha_4 Z_3 S - \rho_3 Z_3
\]

\[
R' = \rho_4 I + (\alpha_5 I + \alpha_1 Z_1 + \alpha_2 Z_2 + \alpha_3 Z_3 + \alpha_4 Z_4) S
\]

\[
C' = c(I + S) - \delta C
\]

\[
D' = (\beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \delta) S + \delta C
\]
The graph shows that having a cure will keep humanity alive but at around 1/10\textsuperscript{10} of the original population. The model also does not take into consideration the fact that a zombie could still kill a cured person. This could be explained by them staying inside the heavily quarantined zones as seen in The Last of Us\textsuperscript{13}.

**Phase 4 – Combining the data**

One thing that seems to be recurring in games and movies is that the zombie apocalypse seems to take everyone by surprise and the next you know, there are millions of zombies. The original set of data values shows this all too well, with most showing that humanity will be wiped out sooner or later and the reign of zombie beginning. This theory however is only shown in a few movies, and even then, the future is uncertain (that is, no one knows who won). The second set of values that is derived from both the Dawn of the Dead movies\textsuperscript{20, 26}, shows a completely different story. These graphs mostly show that zombies are not a problem even with 100 or 500 to begin with. There are some exceptions such as The Return of the Living Dead\textsuperscript{19}.

Humanity seems to kick in its survival instincts when doomed with the prospect of the human population dropping below the zombies\textsuperscript{1}. It would seem that a model which uses the original values, until the number of humans drops below the number of zombies and then uses the derived values after. Since the models for Zombieland, Dawn of the Dead 2004\textsuperscript{20} and Quarantine are all the same and with value being very close, they can be used for this as a comparison.

As time goes on, the human population drops from the threat of originally one zombie, however once the human instinct takes over, it shows how humans can attack back and survive, again on little numbers. Even with the values used all varying by very little. The amount in the Susceptible group in the end varies a lot. Figure 64 shows the graph for Dawn of the Dead\textsuperscript{20}, Figure 65 shows Quarantine and Figure 66 shows Zombieland.
Figure 64 – Dawn of the Dead (2004) Model with both values

Figure 65 – Quarantine [Movie] Model with both values

Figure 66 – Zombieland Model with both values
Results

Step one of this report was about looking at other zombie models that have already been published, and showing their results. It showed that while the coding worked and was subsequently used in this report throughout, the values given in Munz et al\textsuperscript{18} were incorrect, this was quickly corrected by the paper by Cati et al\textsuperscript{22}. Now with the correct coding and values, the graphs show us exactly what is shown in the original Munz et al\textsuperscript{18} paper. This gave the perfect basis to expand into different types of zombies in films and games.

Using data already gathered from Cati et al\textsuperscript{22}, a table of values was designed to give us different beta values for the different zombies, due to some zombies being stronger than others. With the different models designed and values in place, the graphs showed that humanity didn’t really stand a chance. However, the values used felt like it was cheating the system, the alpha value stayed the same while beta got increasing higher. Also in games, if you die, you respawn until you complete the plot line, most of the time leaving on a cliff hanger, but with humanity not being wiped out completely. The same was seen in movies, not everyone died, but it was left on a cliff hanger. The addition of a cure also shows that humanity will remain but at low levels, this seems the most realistic so far.

After using the regression method on two movies to find the coefficient that represents alpha and beta better, a new table was designed and these new alpha and beta values were used instead. This time, the opposite was true; humanity would win most of the time with zombies being killed almost instantly, even with a zombie to human ratio of 1:5 or even 1:1. There was only four models that didn’t show humans winning; Dawn of the Dead 1978\textsuperscript{26}, Shaun of the Dead\textsuperscript{25}, The Return of the Living Dead\textsuperscript{19}, and The Last of Us\textsuperscript{13} (Redesigned model). Both the Dawn of the Dead\textsuperscript{26} and Shaun of the Dead\textsuperscript{25} show that humanity will die out, but only over a long period of time. The Return of the Living Dead\textsuperscript{19} once again shows nice curves and even with beta and alpha being marginally different, humans lose to the zombies because of the need for fire to kill them. Finally, The Last of Us\textsuperscript{13} shows that even with one stage 1 zombie, humanity will become extinct; this is because even when a stage 1 zombie dies, it becomes a fungus spore on the ground which can still infect a susceptible. Eventually all the infected will go through the cycle and earth will become a planet full of animals, plants, giant spores and dead bodies. Unless, a cure is found, the Last of Us\textsuperscript{13} model with a cure shows that humanity will survive but in low numbers.

Phase 4, looked at the fact most humans seem to be oblivious to the zombie infection until they have killed or turned most of the population. This phase, looks at the survival rate given half of the population has turned into zombies by the values given in phases 1 & 2. After the human population reaches the zombie population, survival instincts kick in and change to the values given in phase 3. These models show that humans can bounce back from this pandemic. However, it seems that values (even when changing by very little) in the second half, have massive impacts on the number of survivors in the end.

Improvements to these models could come in the form of a movement constant, having the zombies move and spread out, would of made these models more realistic, you never see a zombie apocalypse happen to just a village of 500. With this also comes the idea that in movies and games, a lone zombie can easily be killed, no matter its speed, strength or intelligence, however when faced against a pack (? Group? Murder? Horde? [More collective noun suggestions can be found at this website\textsuperscript{32}]) of zombies, you find that the difficulty exponentially grows. Two zombies are more difficult than one, but ten zombies and you’re dead (most of the time). Adding movement and group effects to the models would definitely make them more applicable to games, films and possibly real life. Looking at other types of zombies as well to get a broader range would help. There exist other zombies that don’t follow similarly to above such as vampire zombies such as the ones in I Am Legend\textsuperscript{33} and zombie aliens\textsuperscript{34}.

In conclusion the zombie apocalypse would bring devastation to the human race, many other models show this; however there is hope, as long as there exists a cure or that the zombie humans come up
against are weak singular zombies, we can survive. Let’s just hope zombies remain a thing of fiction and if anything did happen, you have watched and played enough in the zombie genre to know what to do when they rise.

Coding & Regression data

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The sums are the values given under the bold black line. N = 29, meaning for the zombie, the top left of the regression coefficient is 225880.341, top right = 192174.14, bottom left = 5592650 and bottom right = 4120900, this give a total top of 33706.2017 and total bottom of 1471750, giving a coefficient of 0.02290212 ≈ 0.0229.

N = 29, meaning for the humans, the top left of the regression coefficient is 225880.341, top right = 192174.14, bottom left = 5592650 and bottom right = 4120900, this give a total top of 33706.2017 and total bottom of 1471750, giving a coefficient of 0.02290212 ≈ 0.0229.
### Regression for the Dawn of the Dead 2004

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The sums are the values given under the bold black line. N = 22, meaning for the zombie, the top left of the regression coefficient is 70500.19206, top right = 49216.28808, bottom left = 1821050 and bottom right = 1334025, this give a total top of 21283.90398 and total bottom of 1334025, giving a coefficient of 0.043701872 ≈ 0.044.

N = 22, meaning for the humans, the top left of the regression coefficient is 43253.17606, top right = 32380.79125, bottom left = 1821050 and bottom right = 1334025, this give a total top of 10872.38481 and total bottom of 1334025, giving a coefficient of 0.022324079 ≈ 0.022.
function [] = ZombieModel(a,b,r,d,T,dt)

% Function Inputs:
% a - Alpha value in model : "zombie destruction" rate
% b - Beta value in model : "new zombie" rate
% r - Zeta value in model : "zombie resurrection" rate
% d - Delta value in model : background death rate
% T - Stopping time
% dt - time step for numerical solutions
% Originally created by Phillip Huma, November 12 2009
% Original input values changed under suggestion of Refay 2019, Casi Halkowski, Brian Blake
% Changes to ODE coding (other than Zombie, Infected, Dead & Cure.m (Huma et al, 2008)) by Daniel Wells, 2014 - 2015.
% Thanks to my supervisor Dr Neal Basse for help throughout the project.

% Initial set up of solution vectors and initial condition
N = 1000; % N is the population
n = 1/50; % t = n*1;
s = zeros(1,n*1);
r = zeros(1,n*1);
r = zeros(1,n*1);
D = zeros(1,n*1);
s(1) = N;
z(1) = 1; % 0 zombies = unstable equilibrium
x(1) = 0;
D(1) = 0;
t = 0:dt:T;

% Define the ODE's of the model and solve numerically by Euler's method:
for t = 1:n*1
    z(1) = z(1) + dt*(b*s(1)*r(1) - d*z(1));
    n(1) = n(1) + dt*(a*n(1) - b*s(1)*r(1) + z(1)*r(1));
    D(1) = D(1) + dt*(a*n(1) - z(1)*r(1));
    if z(1) < 0 || z(1) > N
        break
    end
    if n(1) > N || n(1) < 0
        break
    end
    if D(1) < 0 || D(1) > N
        break
    end
end

hold on
plot(t,n,'b');
plot(t,s,'g');
plot(t,r,'m');
plot(t,D,'k');
legend('Susceptible','Zombie','Infected','Dead')
function $f[] = Xycp(s, i, z, b, t)$
%initial values must be divided by 24 due to the way the code is set out.

$s = s/24$;
b = i/24;
$ze = g/24$;
d = b/24;
x = 0.02;
y = 0.6;

$N = 500$;
d$t = 1$;
s = zeros(1, n+1);
z = zeros(1, n+1);
r = zeros(1, n+1);
D = zeros(1, n+1);

$s(1) = N$;
r(1) = 0;
x(1) = 500;
D(1) = 0;
v(t) = 0;
In = 3;
c = 0:d$t$:T;

for $i = 1:In$
    if $i == 1 + (24 * v(1))$
        $s(i) = s(i) + dt*(- (b/N)*s(i)*z(i) - d*s(i))$;
        $z(i) = z(i) + dt*(- (b/N)*s(i)*z(i) + d*s(i) + r(i) - a*z(i)*s(i))$;
        $r(i) = r(i) + dt*(- x(r(i))$;
        d$i(i) = D(i) + dt*(e*{(i)*s(i)});$
    elseif $i == 1 + (24 * v(1))$ 66 (1 <= 66 (24 * v(1))
        $s(i) = s(i) + dt*(- (b/N)*s(i)*z(i) - d*s(i))$;
        $z(i) = z(i) + dt*(- (b/N)*s(i)*z(i) - a*z(i)*s(i))$;
        $r(i) = r(i) + dt*(- x(r(i))$;
        $D(i) = D(i) + dt*(e*{(i)*s(i)});$
    elseif $i == 7 + (24 * v(1))$
        $s(i) = s(i) + dt*(- (b/N)*s(i)*z(i) - d*s(i))$;
        $z(i) = z(i) + dt*(- (b/N)*s(i)*z(i) - a*z(i)*s(i))$;
        $r(i) = r(i) + dt*(- x(r(i))$;
        $D(i) = D(i) + dt*(e*{(i)*s(i)});$
    elseif $i == 8 + (24 * v(1))$ 66 (1 <= 19 + (24 * v(1))
        $s(i) = s(i) + dt*(- (b/N)*s(i)*z(i) - d*s(i))$;
        $z(i) = z(i) + dt*(- (b/N)*s(i)*z(i) - a*z(i)*s(i))$;
        $r(i) = r(i) + dt*(- x(r(i))$;
        $D(i) = D(i) + dt*(e*{(i)*s(i)});$
    elseif $i == (24 * v(1)) + 1$
        $s(i) = s(i) + dt*(- (b/N)*s(i)*z(i) - d*s(i))$;
        $z(i) = z(i) + dt*(- (b/N)*s(i)*z(i) - a*z(i)*s(i))$;
        $r(i) = r(i) + dt*(- x(r(i))$;
        $D(i) = D(i) + dt*(e*{(i)*s(i)});$
    end
    if 0 == rem(1,24)
        $v(i+) = v(i) + 1$;
    else
        $v(i+) = v(i)$;
    end
end
if $s(t) < 0 || z(t) > N$
    break
end
if $r(t) < 0 || z(t) > N$
    break
end
if $z(t) > N || z(t) < 0$
    break
end
if $D(t) < 0 || D(t) > N$
    break
end
hold on
plot(t,s,'b');
plot(t,z,'r');
plot(t,r,'m');
plot(t,D,'k');
legend('Susceptible', 'Zombie', 'Removed', 'Dead')

40
function [] = SIRV2(a0,a1,a2,a3,a4,b1,b2,b3,b4,b12,b13,b14,p0,p1,p2,p3,p4,d,T,dc)

N = 500;
n = T/dc;
t = zeros(1,n+1);
s = zeros(1,n+1);
I = zeros(1,n+1);
z1 = zeros(1,n+1);
z2 = zeros(1,n+1);
z3 = zeros(1,n+1);
z4 = zeros(1,n+1);
r = zeros(1,n+1);
D = zeros(1,n+1);
S(1) = N;
I(1) = 0;
z1(1) = 100;
z2(1) = 0;
z3(1) = 0;
z4(1) = 1;
r(1) = 0;
D(1) = 0;
t = 0:
for i = 1:n
    S(i+1) = S(i) + dc*(a0*xi(i) + (b12+b13)*z2(i) + (b13+b3)*z3(i) + b14*z4(i) + b3*r(i) + d)*s(i));
    I(i+1) = I(i) + dc*(a1*zi(i) + b2*z2(i) + b3*z3(i) + b4*r(i) - a0*I(i) + d)*s(i));
    z1(i+1) = z1(i) + dc*(a0*I(i) - a1*zi(i) - b1*z1(i));
    z2(i+1) = z2(i) + dc*(a1*I(i) + b2*zi(i) - a2*z2(i)) - p2*z2(i));
    z3(i+1) = z3(i) + dc*(b2*zi(i) - a3*z3(i) - p3*z3(i));
    z4(i+1) = z4(i) + dc*(p3*z3(i) - a4*z4(i) - p4*z4(i));
    r(i+1) = r(i) + dc*(p4*z4(i) + (a0*I(i) + a1*zi(i) + a2*zi(i) + a3*z3(i) + a4*z4(i))*s(i));
    D(i+1) = D(i) + dc*(b12*zi(i) + b13*z2(i) + b14*z4(i) + b3*r(i) + d)*s(i));
    if s(i) < 0 || s(i) > N
        break
    end
    if I(i) < 0 || I(i) > N
        break
    end
    if D(i) < 0 || D(i) > N
        break
    end
end
plot(t,S,'-b');
plot(t,I,'-r');
plot(t,z1,'-c');
plot(t,z2,'-g');
plot(t,z3,'-k');
plot(t,z4,'-y');
plot(t,r,'-');
plot(t,D,'--');
legend('Susceptible','Infected','Runner','Stalkers','Clickers','Blosters','Removed Fungi','Dead');
function [] = L0Wv2C(s0,a1,a2,a3,a4,b1,b2,b3,b5,b11,b12,b13,b14,p0,p1,p2,p3,p4,c,d,T,dc)

M = 500;
N = T/dT;
t = zeros(1,N+1);
s = zeros(1,N+1);
I = zeros(1,N+1);
z1 = zeros(1,N+1);
z2 = zeros(1,N+1);
z3 = zeros(1,N+1);
z4 = zeros(1,N+1);
r = zeros(1,N+1);
C = zeros(1,N+1);
D = zeros(1,N+1);
s(1) = N;
I(1) = 0;
C(1) = 1;
z1(1) = 1;
z2(1) = 1;
z3(1) = 1;
z4(1) = 1;
r(1) = 0;
D(1) = 0;
t = 0:
dt:

for i = 1:N
    s(i+1) = s(i) + dt*(c((b1+b1)*s1(i) + (b12+b2)*s2(i) + (b13+b3)*s3(i) + b5*s5(i) + c + d5*s5(i)));
    I(i+1) = I(i) + dt*(b1*s1(i) + b2*s2(i) + b3*s3(i) + b5*s5(i) + c + d5*s5(i));
    C(i+1) = C(i) + dt*(c(i) + c(i));
    z1(i+1) = z1(i) + dt*(p0*z1(i) - a1*z1(i) - p1*z1(i));
    z2(i+1) = z2(i) + dt*(p1*z2(i) - a2*z2(i) - p2*z2(i));
    z3(i+1) = z3(i) + dt*(p2*z3(i) - a3*z3(i) - p3*z3(i));
    z4(i+1) = z4(i) + dt*(p3*z4(i) - a4*z4(i) - p4*z4(i));
    r(i+1) = r(i) + dt*(p4*r4(i) + d0*I(i) + a1*z1(i) + a2*z2(i) + a3*z3(i) + a4*z4(i));
    D(i+1) = D(i) + dt*(b11*s1(i) + b12*s2(i) + b13*s3(i) + b14*s4(i) + c*(i) + d5*C(i));
end

if s(1) < 0 || s(1) > N
    break
end

if I(1) < 0 || I(1) > N
    break
end

if C(1) < 0 || C(1) > N
    break
end

if D(1) < 0 || D(1) > N
    break
end

hold on
plot(t,s,'-b');
plot(t,I,'-r');
plot(t,C,'-o');
plot(t,z1,'-z');
plot(t,z2,'-一句');
plot(t,z3,'-一句');
plot(t,z4,'-一句');
plot(t,r,'-一句');
plot(t,D,'-一句');
legend('Susceptible','Infected','Cured','Runner','Stalkers','Clickers','Blosters','Removed Fungus','Dead')
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