What Effect did the Government Precautionary Measures have on the Spread of COVID-19

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Abstract

SARS-CoV-2 is simulated in a UK pub environment using a random walk model and simulation. Using this model, we could determine how infectious coronavirus is and then learn how effective each of the sets of precautionary measures introduced by the UK government was at reducing the transmission. Our model predicted that the first set of precautionary measures would reduce transmission by half. Then we tested how adding mandatory face masks would affect our model. Face masks appeared to reduce infection by a further 66%. The final set of precautions includes opening windows, keeping rooms ventilated, and reducing time spent around people. The addition of these to our model would reduce the transmission rate of COVID-19 to $5.51\% \pm 0.28\%$. From our model, we could then determine that the combination of all precautionary measures would mean that coronavirus could not continue spreading as it had a basic reproductive number of < 1. Our model showed that all the government's precautionary measures were effective at reducing the spread of coronavirus and were required to stop the pandemic.

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1 Introduction

COVID-19 originated in Wuhan, China, in December 2019. Coronavirus disease is an infectious disease that is caused by the SARS-CoV-2 virus. Most people who contract coronavirus will experience a mild to moderate respiratory illness but can recover on their own with no special treatment required. People with underlying medical conditions, as well as old people, are much more vulnerable to COVID-19 and more likely to develop a more severe illness [1]. The virus is spread through tiny liquid particles from an infected person's nose or mouth whenever they sneeze, cough, or speak. These particles can range from large droplets to tiny aerosols. One study looked at how long SARS-CoV-2 could last in five different environments, including aerosols, plastics, stainless steel, copper, and cardboard [2]. It concluded that the disease was more stable on stainless steel and plastic rather than copper and cardboard, where the virus was detected up to 72 hours after application; however, the concentration of the virus had reduced significantly. The same study found that COVID-19 had a half-life of 1.2 hours in aerosols, agreeing with [1], which had an estimation of the virus lasting up to 3 hours when suspended in the air on respiratory particles.

Because COVID-19 was an airborne disease and could last in environments for long periods of time, it meant that the virus was highly contagious and fast-spreading. Its still debated how well surveillance checks at key travel points were made and disputed what the initial epidemic growth of the disease was. Rapidly, the epidemic had become a pandemic and By March 2020, a mere 3 months after the initial contamination of the virus, the pandemic was responsible for more than 800,000 confirmed cases and 40,000 deaths [3]. Once the virus had reached a nation, it could spread rapidly through the population. Our report will investigate the spread of COVID-19 in the UK, where the government website [4] recorded the first case of COVID-19 in the UK on January 31^{st} 2020. The first nationwide lockdown was introduced shortly after, on March 23^{rd} 2020. This would be the first of several precautionary measures introduced by the UK government over the preceding years.

Our study is to look at the spread of coronavirus in a typical environment for gatherings and then to simulate different precautionary measures implemented by the UK government and how they affect that spread. The lockdown and social distancing were the first precautions taken and would last for several weeks. After the first lockdown had ended, a social distancing rule of 2m was enforced throughout the UK. Included in this was that all venues would reduce the number of people they let in, meaning pubs, restaurants, and other gathering places would have a reduced capacity. These were enforced so people would keep a relative distance between them to reduce the chance of spreading the virus. Then, after an increase in coronavirus cases, on July 24^{th} 2020, face masks were made compulsory. This meant that in all indoor spaces, you would be required to wear a face covering of some description, with disposable surgical masks becoming the most popular. The timeline continues with a second national lockdown starting on November 5^{th} 2021. Also in November, a mandatory vaccination for health-care workers was implemented, which would encourage most of the population to get the COVID-19 vaccine. As of August 2022, the government website recognises that 93.6% of the UK population has had at least one COVID-19 vaccination. The 6^{th} of January 2021 would see the third and final lockdown [5]. In the same month, the NHS officially listed opening windows and ventilating enclosed spaces under COVID advice. All of these precautionary measures were taken to reduce the spread of coronavirus and help protect vulnerable people in the UK.

2 Method

Our simulation will be designed around an average UK pub, as this is a classic environment for social gatherings in British culture. Finding statistics on the size of the average UK pub and how many tables are often in average-sized pubs is very difficult and not particularly recorded. Therefore, for our simulation, we took five pubs from our local area and designed our simulated pub around the average size of these chosen pubs. We feel they are comparable to most UK pubs and therefore justifiable to use in this report. The average dimensions of the selected pubs were taken from Google Maps, and it was concluded that our simulation would have dimensions of $20m$ x $20m$ and would include 8 tables, all of which can hold between $1-6$ people.Although the simulation will not tackle the lockdowns, it is important to know that they had an important effect on the spread of the coronavirus and were key implementations in reducing the pandemic. It is, however, in our interest to study the other precautionary measures, including social distancing, the impact of wearing face coverings, and how opening windows and ventilating enclosed spaces influence the transmission of COVID-19.

2.1 Simulating the Spread of COVID-19 in a UK Pub Using Random Walks

As mentioned, we will be simulating coronavirus in a pub environment to see how it spreads and what can slow, limit and prevent the transmission of coronavirus. This will be achieved by utilising random numbers and using random walks to simulate the diffusion of coronavirus in an enclosed environment.

Because each pub has a different layout and the design of pubs changes through time, the decision was made that each simulation would randomly generate the positions of the tables inside the pub to help neglect any bias in our starting conditions. Once our environment has been established, the number of people per table is also randomised from $1-6$ and the number of initially infected people in the pub can be selected at the start. For much of this investigation, however, we will start with only a single randomly chosen infected person. The core idea of our simulation comes from the random motion and movement that infected aerosols can take when diffusing through an environment, which we modelled with a numerical random walk. If our coronavirus comes into contact with anyone, then they will become infected but cannot transmit the virus. Coronavirus has an incubation period of 5.6 days on average [6], and it can be transmissible as little as 3 days after catching it. Given our simulation is over the course of several hours, newly infected people will not be able to spread the virus further.

The simulation is run 100 times, and the number of infected people at the end of each simulation is recorded. An average is created for the current conditions set for the simulation. It is very important, when using simulations designed around random number generation, to repeat the simulation and record averages, as it lessens the effect of extreme cases. Once a base simulation of the transmission of COVID-19 was made, we could then implement precautionary measures that would affect the percentage of people infected. The amount at which the infection rate changes for the precautionary measures is what we care about in this report.

2.2 Justification to parameters and estimates

This section will justify why the precautionary measures were modelled the way they were and how we can estimate the effect that they will have on the spread of COVID-19.

Because the random walk in our simulation is the path the virus takes from the infected person around the bar, we can implement coughing and sneezing into our infected person, where they would release more infected aerosols, which would take their own path. A study shows that people cough and sneeze 4.6 times per day [7]. Assuming people with COVID-19 cough more frequently, we can add that every hour the person coughs again to release a new infected aerosol.

Large droplets from sneezes and coughs can travel as far as 2m, with small aerosols travelling further [8]; therefore, if tables are made sure to be separated by a minimum of 2 m, then people will have a reduced chance of catching the virus by large droplets. 'Social distancing' will force the tables in our model to be separated by at least 2m.

An important rule enforced by the government was compulsory mask wearing. How well masks prevent the transmission of coronavirus is not fully understood, but research into how well masks block aerosols from being breathed in has been done. One study found that surgical masks could prevent 90% of aerosols [9]. Masks work by preventing large droplets from being breathed in. Therefore, our 'masks' will require the virus to pass over a person 10x the amount compared to if they had no mask. This should reflect the fact that they reportedly block 90% of particles, and therefore, 9/10 times that the virus crosses the person, the mask would block it. Additionally, our 'masks' will also reduce the virus's interaction area, meaning the virus must be closer to the person for them to breathe it in and get infected.

Opening windows has been known to increase airflow in an enclosed space. Increased airflow will mean that the virus can be taken outside and dispersed by the wind, as well as bringing fresh, clean air inside. Our model reflects this by allowing the virus to travel through windows and disperse outside. Once outside, there is an increased chance the random walk will end; this is to replicate the wind taking it away.

Similarly, if an area is well ventilated, airflow can increase by 2.6-3.1x that of an unventilated room [10]. This increase in air flow means that infectious aerosols can be taken away before they land on surfaces, which should reduce spread. Our 'ventilation' will increase the chance of the random walk of a virus ending by 3x to align with the study.

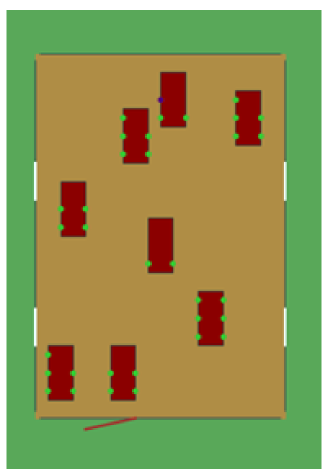

Figure 1: Random 20m x 20m pub with 3m garden, indigo person is infected with SARS-CoV-2, green people are healthy, white dashes marks the windows. No random walk applied yet.

3 Results and Discussion

To begin, we run our simulation with no precautions applied. This will create a baseline for how COVID-19 would spread in a pub if we did not take measures to protect ourselves. A 4-hour time period was chosen for the simulation as it is not an unexpected amount of time for people to socialise for and gives us a good idea of how infectious aerosols can diffuse through an area. Initial simulations show us that with no precautionary measures taken, the virus can reach all through the pub.

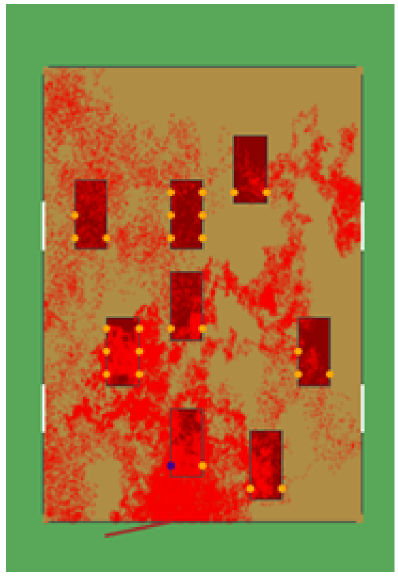

Figure 2: This figure shows how the virus modelled as a random walk can reach every person in the pub. There is a higher concentration closer to the infected person.

After running for 100 repetitions, the simulation shows that with no precautionary measures and only a single infected person to begin with, an average of 84.2% $\pm$ 1.1% of people will leave the pub having contracted COVID-19.

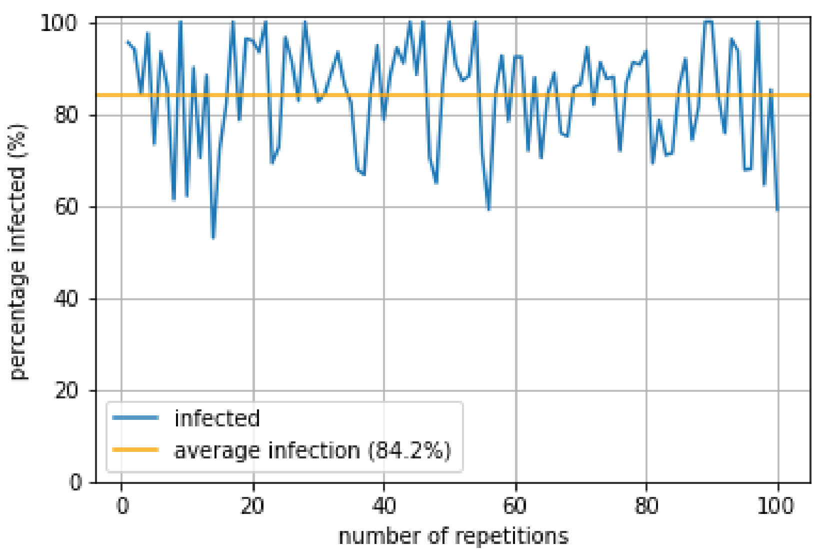

Figure 3: When no precautions are applied to our model, 84.2% of people contract COVID-19

Obviously, with over 4/5 people getting infected with coronavirus after being in a pub for 4 hours, measures should be taken to reduce this. Even if everyone you went with did not have COVID-19, our model predicts that there is a high chance you could still get it. Clearly, this is a problem for us, and hence, the government introduced precautions to help reduce the transmission.

Our model's high infection rate is supported by research from 2021, which shows that coronavirus had 100% susceptibility for different age ranges from 0 to 59 years. whilst people aged 60+ had a 60% susceptibility [11]. Researchers concluded that this was because elderly people wouldn't have as much contact with other people as their younger counterparts. We can assume mainly people under 60 years old will go to pubs, so susceptibility would be towards the higher outcome. However, we can also assume that people will be more cautious, similar to elderly people, about coronavirus reducing susceptibility to a smaller value. Our model falls directly between these two values and therefore agrees with our assumptions. Furthermore, a separate study that looked at a similar set-up to ours, with a bar of dimensions 20mx20mx3m, investigated the critical exposure rate of coronavirus for a 32 and 48 seat bar. The study found that the 32 and 48 seat bars had critical exposure rates of 0.74 and 1.17, respectively [12]. Given that our simulation has 8 tables with a maximum of 48 people, we should expect a critical exposure rate ≤ 1.17. High critical exposure rates such as this would reflect upwards of 80% of people getting infected, supporting our models prediction.

Given the randomness of our simulation, we can find the spread of our results and an error in them.

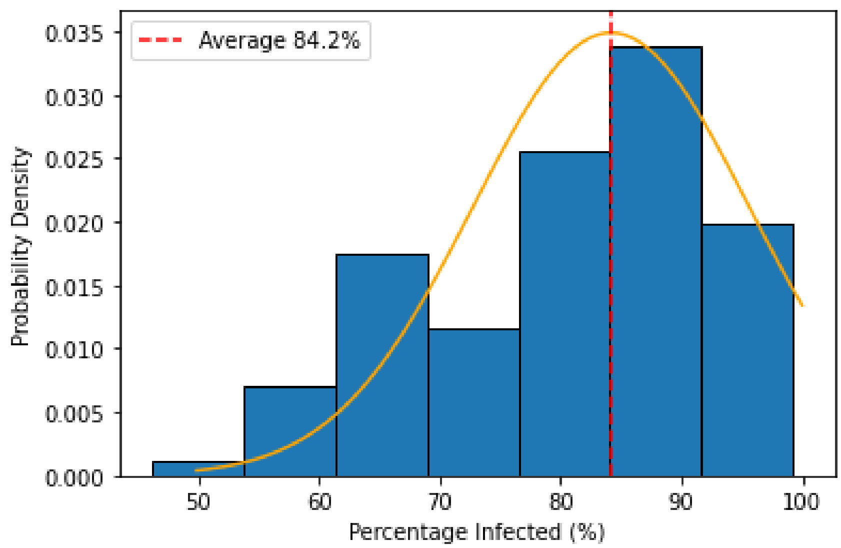

Figure 4: a Gaussian plot using our models average and standard deviation

Fig. 4 shows the spread of our simulated values around the average.From the randomly created virus walk, we can calculate that our infection rate had a standard deviation of 11.4. This is a large deviation from our mean value and could be due to different table layouts as well as different starting locations for the infected person. Although we have a large deviation, given the vast number of repetitions, we can keep a small error of $\pm 1.1\%$. Plotting this reveals a Gaussian distribution for our values, as seen in Fig. 4. Under the curve, bins filled with the individual infection rates of each simulation are plotted, allowing us to compare the curve to our produced data, and we can see that our data fits the curve with a skew towards the larger values. Because you cannot infect more than 100% of the population, we have a cutoff at that value.

The aim of the report is to study the precautionary measures made by the UK government; therefore, we have implemented these into our code and allowed them to be turned on or off. Here, we have run each precaution on its own to see its individual effect on the transmission of coronavirus.

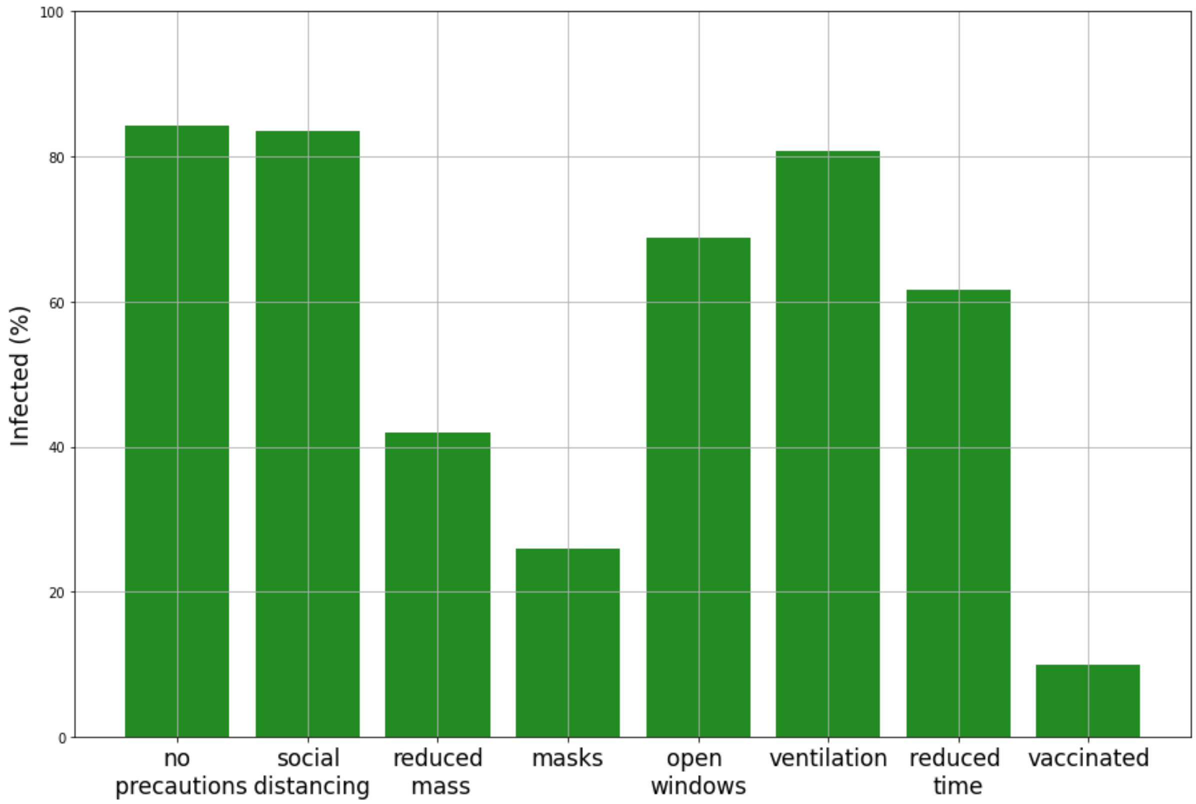

Figure 5: Shows how the average number of people infected in a pub environment varies with individual precautionary measures applied to the model.

Fig. 5 shows the average transmission rate of COVID-19 over 100 repetitions of each precaution. Excluding vaccinations, which we will discuss in our extended section. It is clear that face masks (25.9%) are the best individual precaution for reducing the spread of coronavirus. They decreased the spread to 1/3 of that with no precautions taken. Reduced mass (41.9%), opening windows (68.8%) and reduced time (61.6%) also had considerable effects on reducing the transmission of coronavirus. These reduced infection rates to 50.4%, 18.4%, and 26.9%, respectively. One reason why reduced mass has such a huge impact is because our model assumes that if people aren't allowed into the pub, they would stay at home, where they would remain healthy. This is a large assumption that should be taken into consideration. On the other hand, social distancing (83.5%) and ventilation (80.7%) seem to have a lack of effect on the spread alone. Notice that our coronavirus simulation, with no precautions, was able to reach the entire room, meaning that socially distancing alone would have little effect as the virus can still reach everyone. Combining this with other precautions, however, would have an increased result.

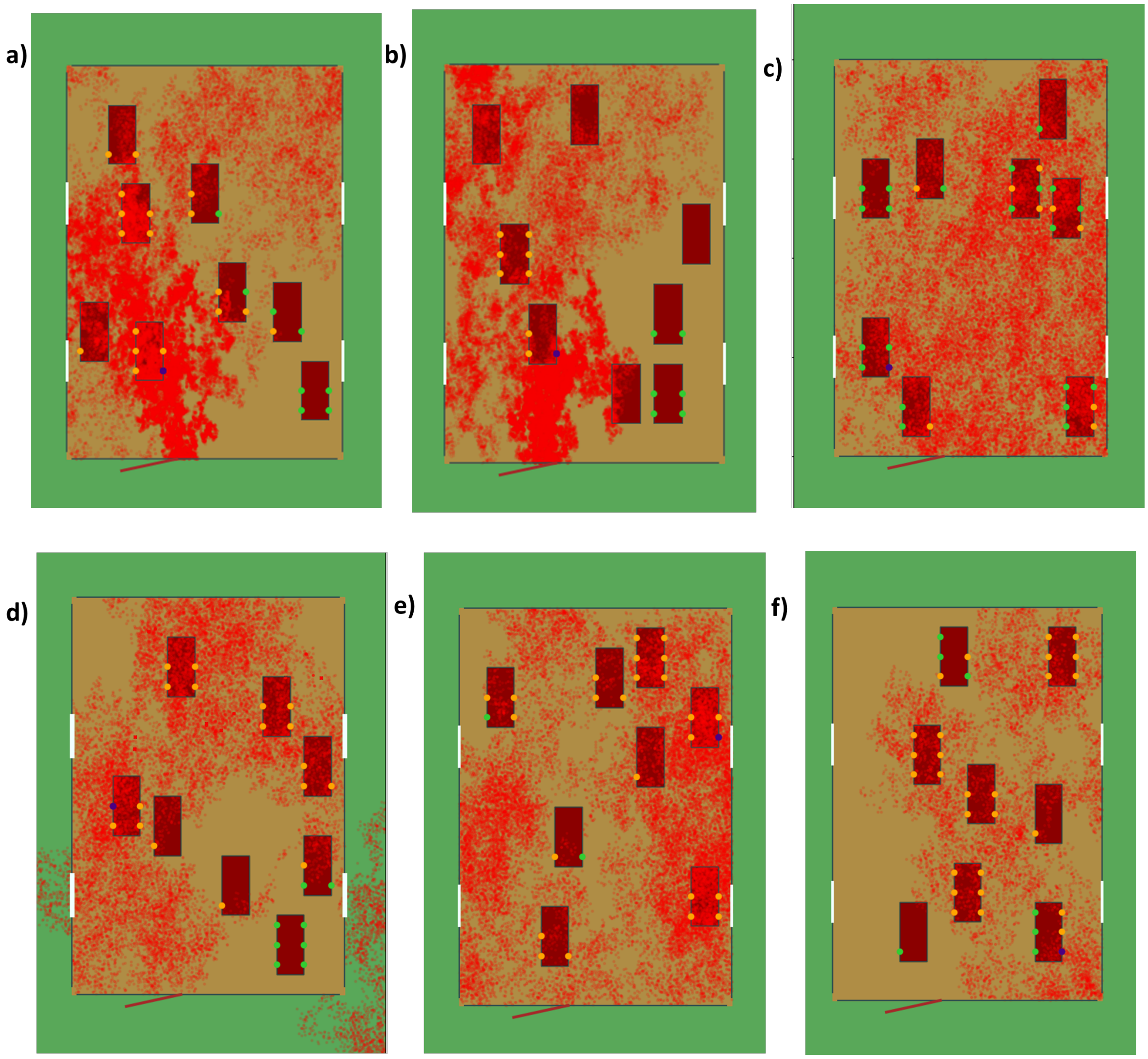

Figure 6: shows one example of each simulation with a single precaution active: a) social distancing, b) reduced mass, c) face masks, d) open windows, e) ventilation, f) reduced time

Above, we can see how every simulation of each individual precaution looks under our model. It is important to remember that these still shots are just one example of each simulation. Every time the simulation is run, we model a different environment with a unique layout and a random number of people. These simulation frames are here to allow us to visually understand how each precaution can help reduce the spread of coronavirus. Some of the simulations are obvious, such as a) where half the tables are empty so that there is a reduced number of people in the enclosed area; or d) where the infectious aerosols can leave the room, clearly reducing spread to other people. While others, such as e) where the room is well ventilated, it is much harder to see through visual diagrams how this has reduced spread.

It is helpful to know which precautionary measure had the biggest impact individually, as this can imply which is most important. However, the UK government implemented multiple precautionary measures in several sets because, although some precautions are not very helpful on their own, they can be useful when implemented with others. After the first nationwide lockdown, the government introduced the first set of precautions, where everyone had to remain socially distant and locations had to reduce the number of people going to the venues. We can then reflect this set of measures into our simulation and see how this affects the spread of COVID-19.

Figure 7 shows This set of precautions, where just social distancing and reduced mass are applied to our model. Our model shows the number of infected people dropping from 84.2% down to $44.5\% \pm 0.64\%$. This means that nearly half the number of people will contract COVID-19 when this first set of precautions is applied, compared to if there are no precautions.

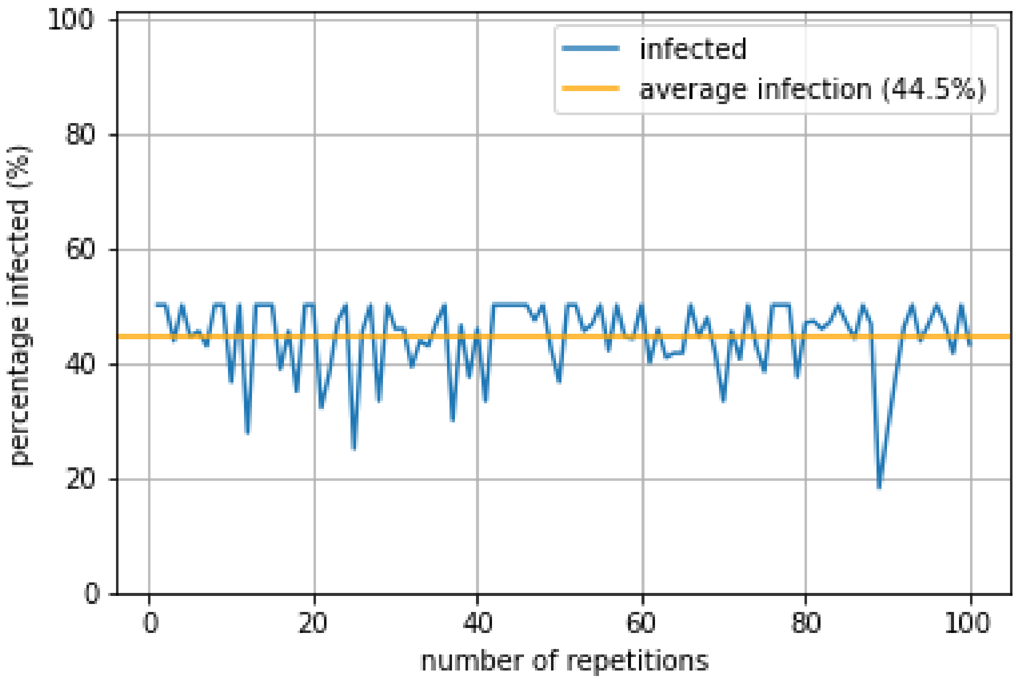

Figure 7: The average percentage of people who leave the pub with coronavirus after 4 hours but with a reduced number of people in the pub and social distancing enforced. The average population infected in this case is 44.5%

The huge reduction in COVID-19 transmission is very important. It means that half the people can return home healthy. And if we compare our model to actual data from 10 countries that did different degrees of social distancing, we can find that the UK had a decline rate of 25.9%, the second lowest in the list. whilst the average decline rate of all 10 countries was $\sim 39\%$ [13]. This much more closely represents our model and disagrees by only 5.5%, which for our model is < 3 people. Therefore, we can confirm that our model has adequate accuracy under the assumptions of this restriction. The UK government would go on to introduce more measures as they determined this reduction was not good enough. We can confidently agree that the government made the correct decision because the infection rate is still too high. This led to the introduction of the face mask, which made it mandatory to have some type of face covering when inside public spaces, restaurants, shops, and pubs.

If we refer back to 5, we can see, excluding vaccines, that face masks have the largest impact on reducing transmission on their own. Additionally, by including them in our current model, we can see what impact they will have.

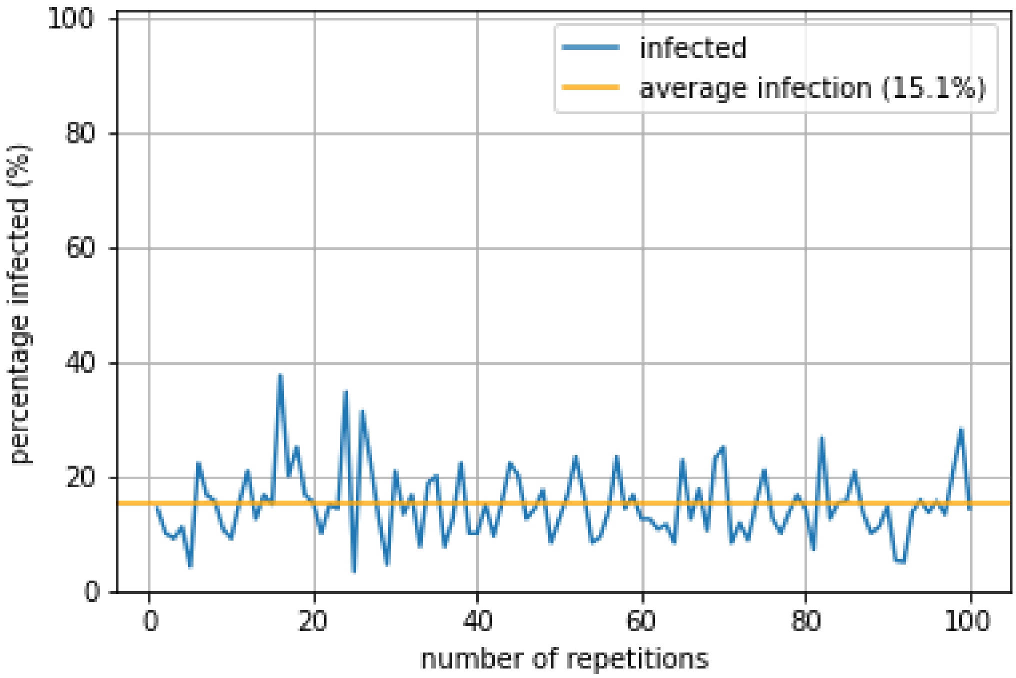

Figure 8: pub modelled using set 1 precautions as well as face masks being mandatory. The average population leaving the pub with COVID-19 is predicted to be 15.1%

We can argue that making face masks mandatory was a good decision by the UK government, as it significantly reduces the spread of coronavirus beyond the initial set of precautions alone. In fact, our model showed that face masks alone seemed to reduce the number of infected to a third of that without precautions. Similarly, the face masks appear to reduce the number of infected to a third of that of when only social distancing and reduced people were applied. Going from 44.5% down to 15.1% $\pm$ 0.62%. From this, we can infer that wearing masks appears to reduce the chance of catching COVID-19 by an almost flat 66%. Our model appears to agree with external research, which concluded that a range of different face masks could reduce pseudo-virus concentrations by 80%-98% [14].

Separate studies reinforce our model and the prior research concluding that face masks were associated with an average drop of 7% growth rate, which they calculated would result in an 88.5% reduction in coronavirus over 30 days [15]. Combining the two studies, we can confidently say that the additional implementation of face masks would reduce the transmission of COVID-19 by 80%-88.5%. Our model predicts that with all of the current precautionary measures applied, we get an 82% reduction in COVID-19. This is within the range of the study, but towards the lower end. One reason for this could be that our model does not consider how face masks would affect the contagious person and that face masks would also reduce the number of aerosols being released into the environment. In fact, the model makes no assumptions about how it infects the 'spreader' which is a limitation to our predictions.

Finally, the NHS would recommend opening windows, keeping venues well ventilated, and reducing the time you spend at gatherings. So set 3 of precautionary measures included all previous measures as well as the three new ones, which involve all of our model's measures.

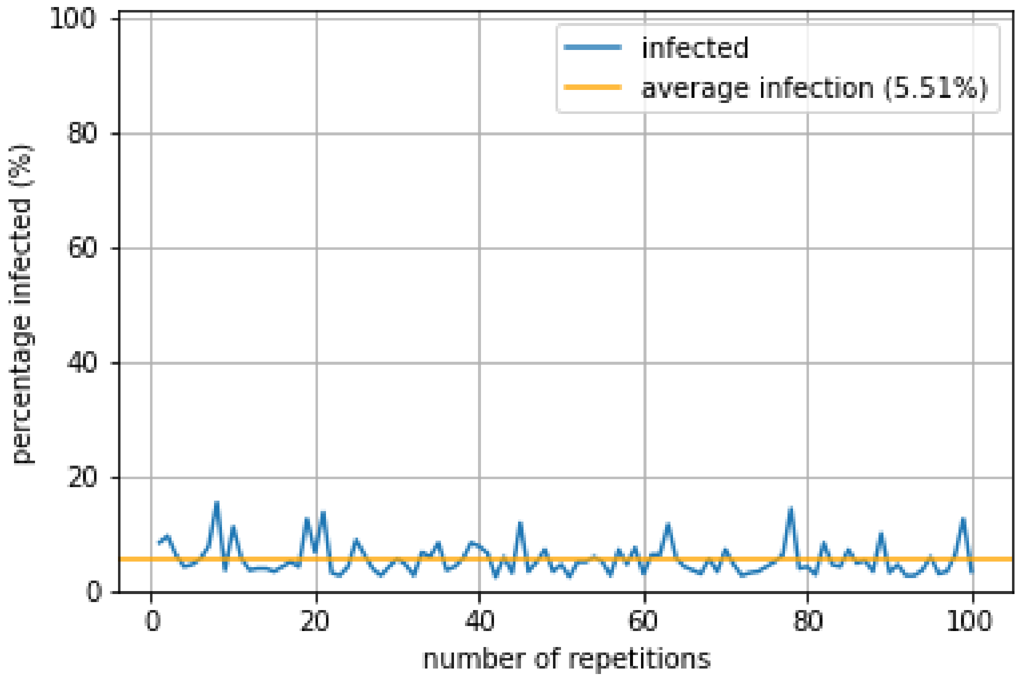

Figure 9: An average percentage infected of 5.5% is recorded when all precautionary measure are applied.

With all the precautions applied to our model, we can see that the average percentage of people infected when they leave the pub is reduced to $5.51\% \pm 0.28\%$. For our 8 tables on a reduced person calibration means about < 1.3 people will leave with the coronavirus. Considering 1 person began with the infection, this means there is a basic reproductive number of 0.3, which means if these precautionary measures are sustained, then COVID-19 would eventually stop. To exaggerate how important this is, coronavirus has a basic reproductive number in the range of 1.4-3.9 [16] when no precautions are taken. This is a very important prediction from our model and would completely back the UK government's decision to enforce all of these precautions, as our model suggests it is a successful approach. This further reduction in transmission is justifiable, as enhanced ventilation has been shown to decrease the number of inhaled doses from 140 particles/hr to only 40 particles/hr [17]. That is a 71% reduction of the initial inhaled dose rate. If you were to directly compare that to our model, then we would expect a final value of $\sim 4.3\%$; however, their study was on a small room of 4x4x3 m, whereas our pub has dimensions much larger than that of the study. It is important to consider room sizes when discussing the effect of ventilation on dispersing aerosols. This report on the critical exposure time based on 70 COVID-19 cases [18] was carried out and found that the larger the room, the less efficient ventilation is at reducing the critical exposure time. This may explain why, when we tested the effect of ventilation alone, it had a small impact on the total number of people infected. As well as explaining why our third set of precautionary measures was not as low as the previous study [17] would predict.

It is important to compare our model's results with those of other models and data when completing a scientific study. A similar simulation on the transmission of the SARS-CoV-2 virus in different environments [19] concluded that in a pub of 18 people, if no precautions are taken, 15 will leave with coronavirus after 4 hours, which would be an 83.3% infection rate. Remember that our initial infection rate with no precautions from Fig.3 was $84.2\% \pm 1.1\%$ which with our error would agree with the paper. Additionally, when the study introduced masks, they found that the infection rate would drop to $\sim 44\%$, which again falls within our model's error of $44.5\% \pm 0.64\%$. Finally, when all precautions were applied to their simulation, they found that only a single person was at risk of getting COVID-19, resulting in an infection rate of 5.5%. And for the third time, this directly agrees with our model's prediction of $5.5\% \pm 0.28\%$. Given that our model has been confirmed by a separate study, we can confidently state that our predictions are accurate for our pub environment.

Now that we have investigated all of the precautionary measures individually as well as in the sets that the government introduced, let us review and compare them. With every additional precaution introduced, the infection rate decreases to a minimum of 5.51%. However, it is also key to note that our standard error decreases as we introduce more precautions, but why?

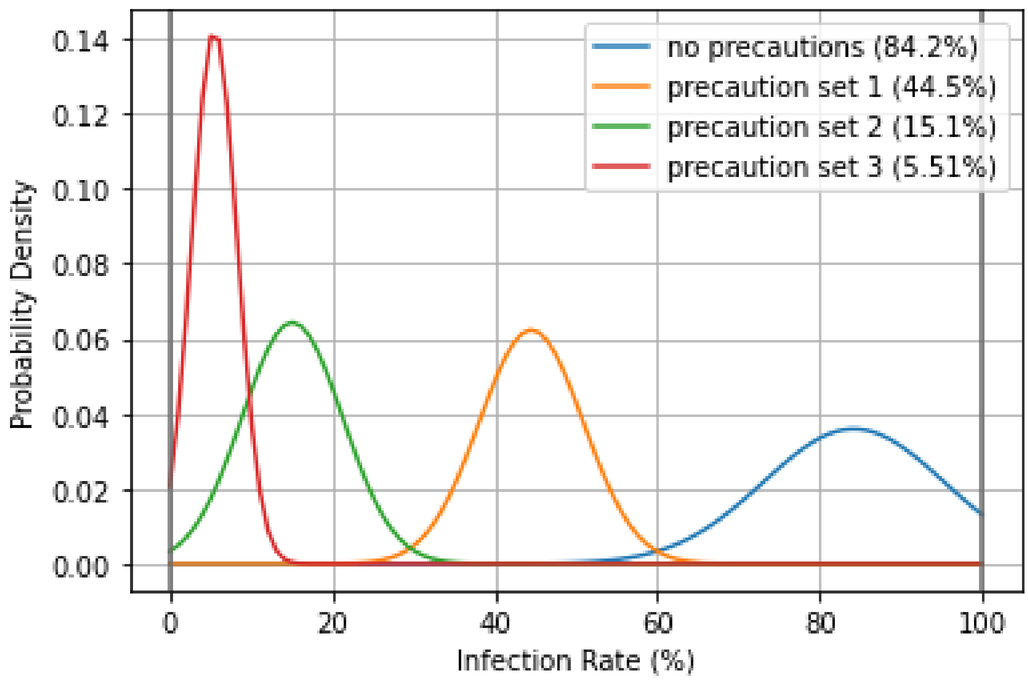

Figure 10: Shows the Gaussian distribution of the modelled precautionary sets. The x axis is limited between 0 and 100 because its a percentage. Each curve is centred on the mean value for that data which is found in the legend.

The figure above shows the distribution of the four key sets of precautions. From Fig. 10, we can infer that the spread of results decreases with more precautions included; a smaller spread will give a smaller error. This can be explained by the fact that the more precautionary measures implemented, the more limitations there are on the SARS-CoV-2 virus simulation, and hence the fewer possible actions to take. With fewer potential outcomes, the remaining ones must have an increased probability. Reading the plot, we find that 'no precautions', 'set 1', 'set 2', and 'set 3' have maximum probabilities densities of 0.033, 0.062, 0.064, and 0.141, respectively.Notice that set 1 and set 2 have very similar distributions. We can explain this because set 2 is when face masks were introduced, and as mentioned when we discussed the respective plot, our 'face masks' have no effect on the spreader or the virus' movement. In fact, the limitation is just the people's likelihood of gaining the virus, and therefore only the mean value for infection rate decreases, spread, and error remain very similar.

3.1 Additional Research and Limitations

Arguably one of the most important steps made to stop COVID-19 and its variants was the vaccination. These were made mandatory for healthcare workers and encouraged for the public. In our main review, we haven't discussed vaccinations, as they were not a precaution of the same calibre as the others discussed, and hence this is a limitation of our model. Firstly, the vaccines were introduced towards the end of the precautions, so not including them makes no impact on the first or second set of precautions. Secondly, because the vaccines are so effective, they would have watered down the effects of our other precautions. Clinical trials found that 3 different COVID-19 vaccines were $> 90\%$ efficient: Pfizer-BioNTech ($\sim 95\%$), Moderna ($\sim 94\%$) and Sputnik V ($\sim 92\%$) [20]. Given their importance and impact, we have still implemented them, but under this additional section.

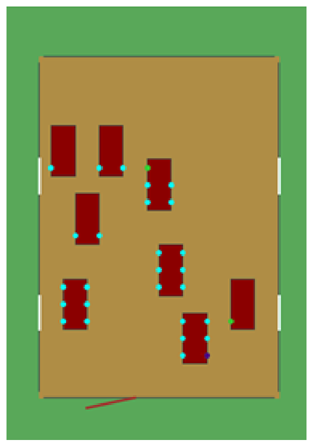

Figure 11: The same pub setting, now introduced vaccinations where 93.6% of people have had one. Cyan dots represent people who are vaccinated, green is healthy unvaccinated and indigo is the contagious person.

Our setup remains the same as before, but now we introduce vaccinated people. Let us see how vaccinations make a difference on their own, and then apply all our other precautions as if they were enrolled in Set 3.

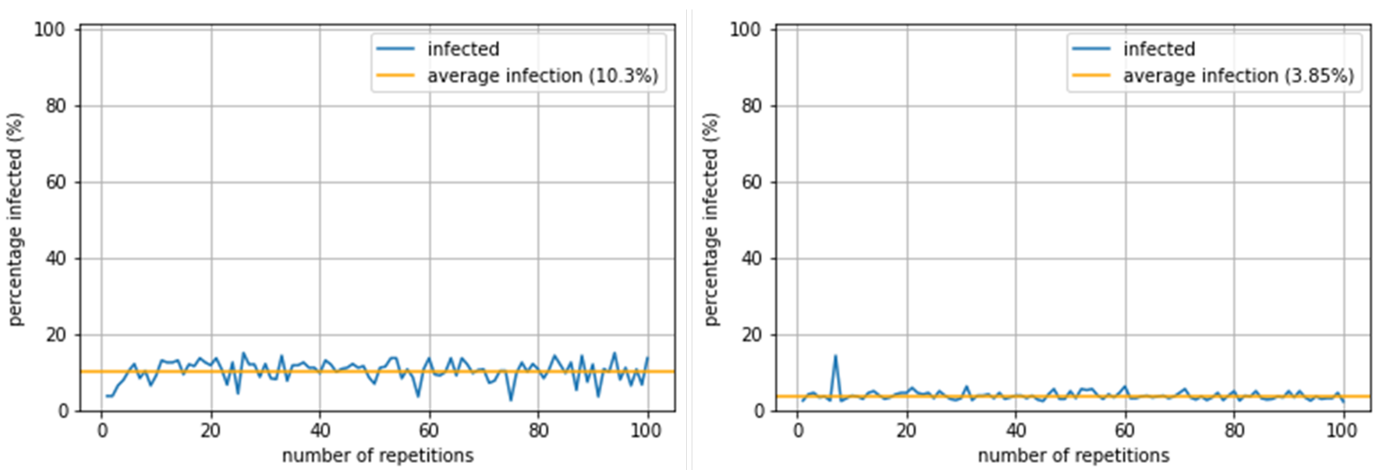

Figure 12: Left: the infection rate average with no other precaution, average of 10.3%. Right: the infection rate average with all precautions applied, average of 3.85%

From this data, we find that vaccines reduce COVID-19 spread to $10.3\% \pm 0.27\%$ on their own, and when combined with all other precautionary measures, the infection rate drops to $3.85\% \pm 0.14\%$. relating to a 95% reduction as expected. From this, we see that all the valuable data from this report about the effectiveness of the precautions is squeezed into a $\sim 7\%$ gap, losing the details of our report; hence, this was included under the limitations of our model as we did not include it.

Another limitation in our model is that during the timeline of COVID-19, there were several different variants with separate infection rates, vaccines, and death rates. Our model does not include any different variants. The key variants are Alpha, Delta, and Omicron. Alpha variant had mutations in the spike protein, which made it an estimated 30%-50% more contagious, and before Delta, it was responsible for 2/3 of all cases. Delta became prominent in late 2020, as it was recorded as being 80%-90% more transmissible than even the Alpha variant. The arrival of the Delta variant saw an increase in hospitalizations. Omicron would take the crown at the end of 2021. It is more transmissible than even the Delta variant. Research suggests this may be due to over 30 mutations on the spike protein, the sections that attach to human cells, and several other functions that increase the probability of infection [21]. Including different variants would most likely increase the value of the infection rates as they appeared more contagious. Although the difference between the setups could stay relative, this limitation may be small and affect the average infection values alone.

Finally, we mentioned in our method how our code had the implementation of increasing the initial number of contagious people. Because our report was to study the effects of the precautionary measures taken on the transmission of COVID-19, we believe varying the number of contagious people was unnecessary for demonstrating this. Therefore, this is a limitation to our report, and we will now briefly discuss the impact multiple spreaders have on the spread of COVID-19.

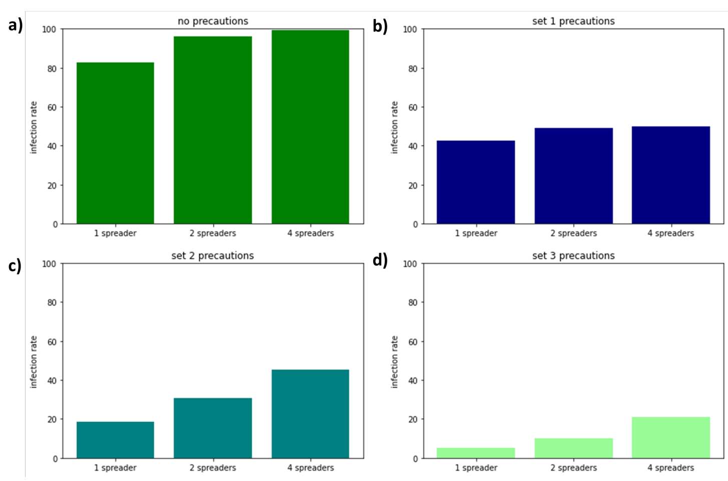

Figure 13: Compares how 1, 2 and 4 initial contagious people were change the infection rate in 4 set ups. a) no precautions, b) first precautionary set, c) second precautionary set, d) Third precautionary set

Introducing more initially infected people has the imagined effect of increasing the mean infection rate proportional to the number of spreaders. For example, in Fig.13, d) 1 spreader has an infection rate of $\sim 5\%$, while 2 spreaders have an infection rate of $\sim 10\%$, and 4 spreaders have an infection rate of $\sim 20\%$. So the limitation on our model is minimal.

4 Conclusion

We used a random walk model utilising the nature of random numbers to simulate how the SARS-CoV-2 virus would spread through a UK pub environment. From this, we could determine how infectious coronavirus is, along with how effective each set of precautionary measures the UK government introduced was at reducing this spread.

Initially, we tested the effectiveness of each UK government precaution individually, and we found that some precautions, such as ventilation and social distancing, did not initially appear effective. Other measures, like mandatory masks and reducing the number of people at gatherings, appear very effective.

To truly test whether the restrictions implemented by the UK were necessary, we added each precaution in three sets to reflect the government announcements. First, the social distancing rule and the reduced number of people allowed at venues were introduced. Our model predicted that these restrictions would reduce transmission by half. Although this is a significant reduction in transmission, we agreed with the UK government that this alone would not be enough to stop the spread of coronavirus. Adding mandatory face masks was the next precaution, Our model shows that face masks appear to reduce transmission of COVID-19 by 66%. Again, this reduction in spread is considerable but would still allow coronavirus to grow. Our model supports the government introducing a third set of precautions: opening windows and keeping rooms well ventilated, along with reducing contact time. The addition of these measures meant that the infection rate would fall to 5.51%, which for our model environment would mean a basic reproductive number of < 0.3. Less than 1 person would be newly infected with SARS-CoV-2. Our model predicts that the impact of all the precautionary measures would stop the coronavirus epidemic in the UK. Therefore, we can only support the UK government's decisions on the restrictions made.

Addendum

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5 Integration

Integration is recalled as one of the most important mathematical devices in history, within physics, maths and engineering, integration is used constantly. One example where integration is used is when we have equations of motions. Given the motion has constraints which remain fulfilled throughout the trajectory. Using Integration we can then model this motion which in the paper [22] shows it can be used to simulate the dynamics of a liquid of 64 n-butane molecules.

Within engineering Integration can be used to calculate the stress and strain within a material. reduced integration is described in [23] in which it details how under thick plate theory, we can account for transverse shear strains, which cannot be done in thin plate theory. Using integration to get a thick plate theory can be show to be appropriate for analyzing the characteristics of roof bending deflection too [24]. These numerical solutions to problems are only available to engineers through the use of integration.

Numerical integration is most widely used to solve different types of differential equations. [25] demonstrates how we can apply integration to solve stochastic differential equations. The report detail how even though the integration algorithms can be accurate and exact they often take a long computational time to complete. Stochastic differential equation are important to solve because stochastic processes have many application and often used to simulate; random growth models, stock prices, physical systems with thermal fluctuations and simpler models such as Brownian motion, white noise and more.

‘ These stochastic differential equations can be used in finance to describe the dynamics of finance assets. An example of this is used in 'option pricing' where integration techniques along side Monte Carlo simulations are used to calculate the expected payoff of different financial options under different scenarios and then determines fair market value for each [26]. The book demonstrate how by solving the Black-Scholes model, which has assumptions including constant volatility, continuous trading and no dividend, that price optioning can be accomplished and used.

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Numerical integration is further used in circuit analysis for engineers. Integration takes an important role in transient and dynamic analyses. Circuit analysis allows us to design, synthesis and evaluate the performance of circuits or networks, which is very important for electrical engineers and software engineer]'/ . In Charles Thompson's book [27] he describes how integration is crucial for circuit analysis because it allows us to approximate the behaviour of complex electrical circuits over time and with time-varying inputs.

Hospitals have many machines that are used to help aid the doctors and determine issues with their patients. These machines can include CT, MRI and PET scanners. All of these machine require iterative reconstruction algorithms which utilize numerical integration to accomplish this task. Details of how integration is optimized for this process are in this book, [28] where the author talks about integrating several attenuation profiles from different angles to rebuild the final image.

6 Runge-Kutta

Runge-Kutta is a Numerical technique used to solve first order differential equations. Therefore it is a very important technique as it has lots of applications. Runge-Kutta is often used when analytical approach to an equation is to difficult. The Bratu-Type equation is used in applications such as fuel ignition models, the theory of thermal combustion and radiative heat transfer, to name a few. With such a vast variety of uses it is important to be able to solve the equation. Runge-Kutta is a robust method that is used for this and [29] chooses to use RK5 an even more thorough method compare to the popular RK4 which is often quicker. Runge-Kutta can be used to accurately solve the Bratu-Type equation which can then allow us to understand types of heat transfers and allow us to apply this to real life situations.

Similarly Bernoulli's equations describe fluid dynamics and the behaviour of non-viscous flow. Often applied to analyze fluid flow through constrictions and expansions, such as nozzles, ventures and diffusers. These equations are essential to those working in fluid mechanics or hydraulics. Within [30] the author uses several methods including the Rung-Kutta method to solve these important equations. The solution allows engineers to efficiently design piping systems and channels to achieve desired performance. within Hydraulics they allow engineers to design and build dams and spillways. so the application of Runge-Kutta to solve this equation is very important.

Another typical first order differential equation is the motion of several bodies under the influence of gravity. Runge-Kutta can be used he to calculate their accelerations at each step and from that their respective velocity and position [31]. When this process is repeated we can simulate and visualize how several body will move around each other when under the force of gravity. This has allowed astronomers to understand complex star systems as well as develop our understanding of the beginning of our universe.

Furthermore Astronomers are actually applying this to industry. astronomers can launch rockets and payloads into space for many different applications uses. Orbits are usually influence from gravitational forces, solar radiation pressure and atmospheric drag this makes determining their orbits a tedious task. we can however, use Runge-Kutta algorithms to do orbit determination for low earth orbit satellites [32]. This allows us to accurately determine the spacecrafts location and velocity over time.

Operations research is an analytical method of problem-solving and decision making which is beneficial to management. Often involved problems being broken down into small steps and then each step is solved using mathematical analysis. We can implement Runge-Kutta methods to optimize resource allocation, production planning, and even scheduling [33]. The application of Runge-Kutta in business has allowed for maximum efficiency whilst helps to minimise costs and optimize performance.

Finally we will investigate how different schemes using Runge-Kutta can be used to explore population structures and model them too [34]. Population structure data is useful as it can indicate future trends, determine how an area will develop and/or change. This is useful for businesses as can allow us to determine if a type of business will succeed in a given area or not.

7 Fourier Transform

Fourier Transform is a string tool used to change a signal between two different domains. Within mathematics we can use Fourier transforms to make complex equations easier to solve. It works by converting a complicated partial differential equation (PDE) into a simpler form within frequency space. Once in frequency space the simpler equation can be solved numerically and an inverse Fourier transform convert it back to give you your solution. This form of solving equations can also be shown to be quicker and the number of operations can be shown to be essentially independent to the time level desired [35].

Infrared spectroscopy is a powerful tool often used for identifying organic materials. Fourier Transform Infrared Spectroscopy was developed so that complex mixtures could be quantitatively analysed [36]. FTIS can do this by firing infrared through a sample where the radiation is absorbed and converted into rotational or vibrational energy, each molecule will then produce a unique spectral pattern which can be used to identify that molecule.

An annoying fact that many experimentalist have to deal with is noise. Noise is unwanted data which is often picked up from the background of an experiment. Noisy data can lead to incorrect predictions, bias models and misleading insights and therefore we desire to remove noise from our data. Fast Fourier transforms can be applied to the data, where a periodic filter is created and then correlated accordingly [37]. We can then demonstrate the efficiency of the filter and remove high and low frequency noise.

Control systems rely on the use of Fourier Transforms to analyze and design them. Engineers can use the tool to model and fine-tune the systems for a range of different applications. This technique is superior to others as simple, inexpensive and easy to implement. From relatively small amounts of data, we can show simple ways to compute the dynamical response at input frequencies [38].

Image processing is the most common way to represent pixel location in a spatial domain. Fast Fourier Transform can decompose an image into sines and cosines with varying amplitude and phases. This process can reveal periodic patterns in the image which otherwise wouldn't have been found [39]. The low frequencies obtained by the transform represent the gradual variation within the image. low frequencies is what holds the majority of the data and therefore describes the overall shape of the image. High frequencies describe the details as they represent the abrupt variations in the image.

Finally, we can discuss how finance optimizes Fourier transforms by analyzing annual signals which have been generated by the US stock market. These signals are then transformed into a Fourier series where finance information is deduced from the amplitudes and the phases of the signal [40]. This report specifically talks about how we can use the data to predict financial crises. When a global crisis is approaching the low frequency components of the Fourier series will increase more rapidly than the high frequency ones. The method can then be applied to UK and German stock markets as well and compared for validity.

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