LOPA Versus COVID – Return to Sustainable Living

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Layers of Protection Analysis (LOPA) is widely used in process industries to design the plant protection systems. This method considers the occurrence of a hazard as an initiating event, leading to catastrophic failures, then examining the adequacy of Independent Protection Layers (IPLs) to mitigate the risk. LOPA methodology was applied to an encounter with the covid infection as an initiating event and then independent protection layers, namely health safeguarding protocols, such as social distancing, ventilation, hand hygiene, face mask and vaccination were assigned to mitigate the risk of infection and fatality. It was concluded that LOPA can also be applied to the risk of covid infection which can evaluate a numerical value for the death risk frequency, in order to manage the transmission risk to a tolerable level. The latter is the fatality risk due to seasonal flu.

This paper adopts process safety LOPA methodology to covid infection risk, by initially calculating a transmission rate and then evaluates the safeguards' probability of failures in order to develop a 'Covid Fatality Metric' which is the measurement tool, to manage the virus spread. The input data is based on public domain covid infection statistical data. The covid transmission rate in public is statistically calculated with random number sampling to simulate the random pattern of virus person to person infection in the community. The success of the covid protection protocols is probabilistic and depends on the public compliance which are modelled by observational surveys. The methodology is flexible enough to be applied to all public places.

Whilst covid prevention compliance surveys are possible for smaller communities such as offices, for a larger population, it is proposed to use CCTV digital image processing for the public compliance measurements.

Keywords

Layers of Protection Analysis (LOPA); Covid-19 Protection Layer Health Protocols, Transmission Rate; Probability of Failure on Demand (pfd); Covid Fatality Metrics; Statistical Surveys; Geometrically Adjusted Mean Infection Rate.

1.0 INTRODUCTION

From a chemical engineering point of view, transmission of the SARS-COV-2 virus is a process, and the disease COVID-19 can be managed like any other process hazard. Considering that Layers of Protection Analysis (LOPA) methodology has successfully been applied to safeguarding process plants (Fang et al, 2007), it can also perform risk assessments to evaluate the relative probabilities of virus transmission, infection, and death. This is vital moving forward due to the high transmission rates of the SARS-COV-2 virus and its severe consequences (Guleryuz, D, 2021). Lockdowns and heavy restrictions were imposed to help limit the SARS-COV-2 contagion spreading (Collivignarelli et al, 2021) however life with these restrictions is not sustainable and so new methods/standards need to be incorporated into day-to-day life to help manage this virus.

LOPA is a semi-quantitative risk assessment methodology. Safety Integrity Level (SIL) analysis and LOPA methodology were formalised in IEC 61508 & IEC 61511 (IEC 61508. Functional safety of electrical/electronic/programmable electronic safety-related systems, 2010; IEC TR 61511-0:2018 | IEC Webstore, 2021), adapted by AIChE CCPS (Centre for Chemical Process Safety) for process industry use (Layer of protection analysis, 2001). The application of LOPA in process industries is to design process shutdowns which is in par with the unmitigated risk. It requires valid input data, which is well established for process industry use, but more challenging for pandemic application due to higher levels of uncertainty.

LOPA requires three main inputs: 'Risk Tolerability Criteria', 'Initiating Event Frequency' and 'Probability of Failure on Demand (pfd) for Independent Protection layers and Condition Modifiers'. For the COVID-19 case, the risk tolerability criteria are taken as a comparison of the annual frequency of death due to COVID-19 and for seasonal flu. The initiating event is the frequency of encountering a person infected with the virus; and the IPLs are; social distancing, free air movement (ventilation and open space), face masks, hand hygiene (Brown, K.R, 2021) and the condition modifier for the vaccine efficacy. These safeguards are collectively referred as, COVID-19 protection layer health protocols. For LOPA modelling, IPLs are used as barriers to virus spread with their own specific probability of failure on demand. A 'pfd' is a probability between 0 and 1.0, where 1.0 means no IPL is present or 100% failure, decreasing as the probability of failure of an element decreases.

1.1 Literature Review on Health Protocols

The public domain information on compliance of the health protocols identifies driving features of the rules. A guidance written by Public Health England (Public Health England, 2021) notes COVID-19 care pathways and sets governance and responsibilities for stakeholders and the public to manage the infection risk. It sets objectives for infection control and transmission precautions, use of personal protection equipment (PPE), patients care, and the risk of respiratory infection transmissions. (Greenhalgh, T, et al, 2020) presents evidence and guidelines for the use of face masks, with the key message that the precautionary principle states we should sometimes act without definitive evidence, in case masks will reduce transmission of COVID-19 or otherwise. Since the debate between the effectiveness of a face mask or covering is still ongoing. Even if proved to show small levels of prevention, limited protection could reduce some of the transmission rates of COVID-19 and save lives because COVID-19 is such a serious threat, that wearing masks in public should be advised.

The review by (Howard et al, 2021) synthesizes available evidence to provide clarity and advances the use of the 'precautionary principle' as a key consideration in developing a policy around the use of non-medical masks in public.

A report written by the European Centre for Disease Prevention and Control defines targets and instructions of the use of face masks and with hand hygiene (European Centre for Disease Prevention and Control, 2020). Hand hygiene is also recommended in the following references with scientific facts (World Health Organisation, Hand Hygiene: Why, How & When?, 2009; Packham, C, 2020). The latter reference states that when hand washing is carried out, it is essential to limit skin damage, so the use of a moisturiser after each time hands are washed is important. The World Health Organization provides guidelines on the use of face masks for children and adults (WHO, 2020). There has been some research activity in order to investigate any association between hand hygiene and COVID-19 transmission, (Skolmowska, Głąbska, Guzek, 2020). Their conclusion is as follows; in a population-based sample of Polish adolescents, individuals from regions of low COVID-19 morbidity presented more beneficial hand hygiene habits than those from regions of high COVID-19 morbidity.

The origin of the 2 m safe social distancing rule has been investigated by (Jones, N, et al, 2020). The authors conclude that investigations started in late nineteenth century. Despite limitations in the accuracy of these early study designs, especially for longer ranges, the observation of large droplets falling close to a host reinforced and further entrenched the assumed scientific basis of the 1-2 m distancing rule. Computational Fluid Dynamics (CFD) simulation has been used by (Blocken, B, et al, 2020) in order to model the safe distancing for people standing still (1.5 m), walking (5 m) and running (10 m).

2.0 COVID RISK MANAGEMENT WITH LOPA METHODOLOGY

The COVID-19 pandemic can be viewed in the same way as a typical process hazard. It is possible to apply LOPA to the issue of the virus transmission in particular settings, its likelihood of transmission considering layers of protection, or indeed multiplication, and its impact upon individuals, taking account of their demographics and state of health.

2.1 Basis of Covid Transmission Rate

COVID-19 is atypical of process hazards as it is all pervasive, often carried by asymptomatic individuals, without any obvious sign of infection. However, it is possible to evaluate the frequency of an "initiating event" defined as an "effective" contact with an infected person or the transmission rate, based on the following inputs:

1. Local rolling infection rates, for example as published in the UK as the COVID-19 virus interactive map for England (GOV.UK, 2021).
2. Hours spent in the risk area with potential of person to person infection
3. Number of human contact events per year with potential virus transmission
4. Adjust for asymptomatic cases.

These factors are used to evaluate the number of effective infections per year, i.e., the transmission rate, which is the initiating event in the LOPA calculation.

2.1.1 Covid Testing Regime and Asymptomatic Infection Modelling

The pooled estimate of asymptomatic portion of COVID-19 is 28% which was used to calculate the transmission frequency (Beale et al, 2020). Covid testing input to transmission rate calculation is possible for target locations with known personnel and visitors such as office blocks, colleges, schools or gymnasiums. However, in larger population centres such as shopping malls and transportation hubs, historical knowledge of visitors' testing is not possible.

2.2 Basis of LOPA Calculation

Two parallel infection pathways have been identified: direct transmission from an infected person to the target individual via droplets and aerosols carrying the virus, or indirect transmission, where infected droplets land on a surface (Marzouk, M, 2021), and are then picked up by the target person and transferred to the soft tissues. These infected droplets can last on surfaces for long periods of time (ranging between 12 hours to two days) (Elsheikh, A.H, et al, 2021). The calculation is done as a typical LOPA, with the probability of failure on demand of each of the assigned protection layers, such as distancing, face masks, hand sanitisation, ventilation; calculating through to a probability of infection for each pathway, summed up to a total probability for all pathways.

The impact of infection on the death rate of infected people is obtained from the ALAMA (Association of Local Authority Medical Advisers) calculator (Covid-19 Medical Risk Assessment – Alama, 2021), which, given inputs on the age, sex, ethnicity, Body Mass Index (BMI), and various comorbidities then indicates the probability of death of an infected person. This can be run for typical and vulnerable individuals. This then enables us to compare the probability of death from COVID-19 to that from seasonal flu and to identify an improvement factor as a target to attain this. The improvement factor is calculated as an index with a numerical value and referred to as Covid Fatality Metrics.

Also, crucially, it gives the user a feel for what steps could be made to improve the situation. This tool can be used to manage the COVID-19 risk and must be used at the responsibility and discretion of the user, as they know their business and their options. For instance, they might be able to improve the effective infection encounter rate by reducing the number of contacts per risk event, setting up a suitable testing system. Other steps that could be taken are: the layers of protection themselves, by administering more robust regimes. For comparison and benchmarking purposes, a covid fatality metric is introduced in the calculation which determines the improvement measures in the testing regimes and IPLs compliance. The purpose is to bring down the cases by benchmarking the COVID-19 infection in relation to the seasonal flu fatality level.

3.0 STATISTICAL ANALYSIS AND RANDOMISE VIRUS HUMAN INFECTIONS

The transmission rate is the initiating event for the LOPA modelling. The former is based on the person to person infection rate. The infection rate is evaluated by statistical regression analysis which is used to look at the correlation between the dependant and independent variables. This method aims to explain the dependant variables in terms of the independent variables through a mathematical relationship, to obtain a prediction of one variable given the value of the other.

The Regression model is being used here to help look at the mean infection rates of COVID-19 in different locations, to then mathematically simulate the way that the virus infection is spreading amongst the population. Thus, the input data was randomly selected and fed into a regression analysis model by an analyst however, in the future, it is envisaged to use a computer software programme for the random selection process. The Covid infection is unpredictable and could be arbitrary. It is therefore required to describe and predict how the virus transmit itself in the community. Data collection and sampling with statistical models can predict the virus propagation. The infection is also random, which means it is impossible to predict future human infections based on past or present ones. The modelling therefore requires probabilistic assessment to account for the randomness. The statistical modelling algorithm uses an 'arbitrary random population sampling' approach which is meant to randomise the virus' person to person transmission in the community. The maths is designed to simulate the real life virus transmission randomness and develop predictive tools on virus behaviour in a given population sample.

For calculation of the infection rate, statistical modelling was performed on one hypothetical shopping centre in the UK. As people go to and from this site, the local rolling infection rates of the surrounding areas were selected from randomly chosen postcodes and their data was obtained from the UK COVID-19 interactive map (GOV.UK, 2021). The sample sizes varied and was dependant on the average number of people passing through per hour. Once this data was collected and the infection rate was randomly assigned to a population sample, a scatter graph was produced. Then regression analysis was performed to obtain the straight line regression equation.

The geometric mean of the sampling population was used as the numbers in these series are not independent of each other and in some cases, the numbers tend to make large fluctuations. The calculated geometric mean from the values of the population sample was then inputted into the equation of the regression line which was obtained from the scatter graph. This then calculated the 'y' value, showing the geometrically adjusted mean infection rate. The adjusted mean arises when statistical averages must be corrected to compensate for data imbalances and large variances. This process was then repeated for consecutive weeks. By having two sets of data taken, a comparison of the information can be made to show the changes in the infection rates.

The interactive map (GOV.UK, 2021) was a useful tool in obtaining information such as, the case rate per 100,000 people, the total number of cases in a given area and also the rate of change in percentage from the previous week. The data from the map is updated every day at 4 pm and all the information from January 2021 is easily available and accessible.

3.1 Infection Rate Calculation for a Shopping Mall

This statistical model was conducted from information regarding the infection rates from the surrounding areas of a Shopping Mall in the Midlands. According to published data from the shopping centre, this mall receives 35 million visitors annually, therefore on average, the assumed population of the mall per hour was taken as 4,006. 30 random postcodes from the surrounding areas were chosen for this calculation. It was also assumed that most people using this shopping centre commute or travel from areas in and around the Midlands looking at an average commute time of approximately 40 minutes (with the longest being an hour and a half long journey).

Tables 1 and 2 (given in the Supplementary Addendum) show the input data to regression analysis for the randomly selected postcodes. The corresponding plots can be seen in Figure 1 & Figure 2. The population sampling was randomly selected for two consecutive weeks and the people sample number per address varied in each case, as the number shoppers for different postcodes using the shopping mall is random.

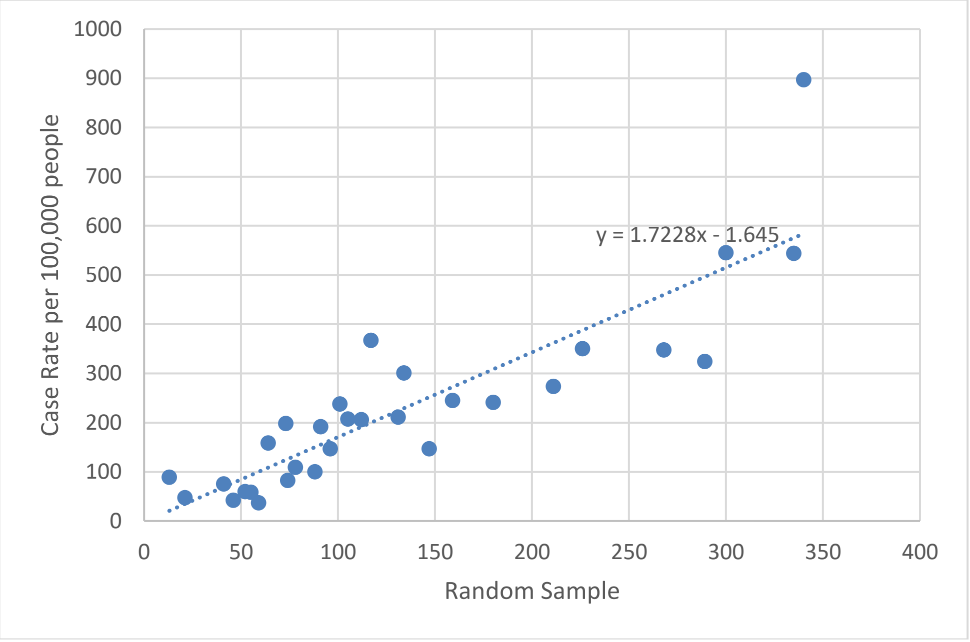

Figure 1; Graph to show the rate of COVID-19 cases in shopping mall visitors addresses (17th June 2021).

The regression analysis from the data in Figure 1 gives a value for the Pearson product-moment correlation coefficient (R). This value is a measure of the strength of a linear association between two variables, in other words, it can indicate how far away the data points are from the line of best fit. Values can range from between -1 to +1 where the value of +1 or -1 indicates a stronger association between the two variables. From the graph produced and the regression analysis, the calculated R value was 0.87.

The regression line was equal to: $y = 1.7228x - 1.645$ and the geometric mean of the random population sample was calculated to be 102.86. Therefore, substituting these values gave a geometrically adjusted mean infection rate (y) of 175.57.

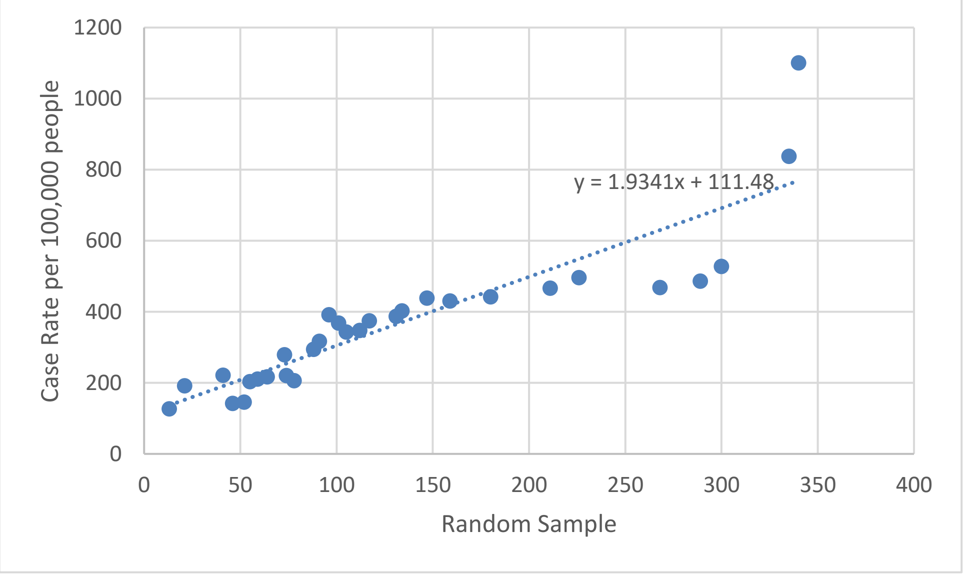

Figure 2; Graph to show the rate of COVID-19 cases amongst the visitors (1st July 2021).

The R value calculated from this plot was 0.89 and the equation of the regression line was equal to: $y = 1.9341x + 111.48$. As the geometric mean of the random population sample would be the same as that calculated from the previous set of data (due to the random population samples not changing), the geometrically adjusted mean infection rate for this case equalled 310.43.

3.2 Assumptions to calculate Shoppers Occupancy in Shopping Centres

The calculation is based on uniform distribution of occupancy on a 24/7/365 basis. However, shopper's visiting habits to shopping malls are highly random. A more scientific approach would be if the owners (e.g., HSE managers) conducted population sampling on how visiting habits vary amongst the populations and again with regression analysis a more realistic figure can be calculated.

4.0 IMPACT ON INDIVIDUALS-RISK OF DEATH

ALAMA (Association of Local Authority Medical Advisers) COVID-19 Medical Risk Assessment (Covid-19 Medical Risk Assessment – Alama, 2021) defines the concept of Covid-age as follows;

Covid-age assesses an individual's vulnerability to COVID-19 in the absence of previous infection or vaccination. That evidence indicates that vulnerability to COVID-19 increases exponentially with age; for example, in comparison with a healthy person aged 20, a healthy person aged 60 has more than 30 times the risk of dying if they contract COVID-19. Covid-age summarises vulnerability for combinations of risk factors including age, sex and ethnicity and various health problems. The final result of the Covid-age calculator is the individual's risk of death, as a probability with their actual age.

The LOPA results are calibrated by considering the seasonal flu deathrate, which is a figure of 1 death in a population of 10,000 per year, or 0.0001 death per annum (Around 10,000 deaths are caused by flu each year in England and Wales, 2021).

5.0 HEALTH PROTOCOLS FAILURE PROBABILITY CALCULATIONS

Similar to process safety LOPA, for COVID-19 the probability of failure of the Independent Protection Layers also needs to be calculated.

5.1 Social Distancing, Face Mask and Hand Hygiene

The estimation of probability of failure on demand for these protocols are based on statistical surveys. A statistical survey is any structured inquiry designed to obtain aggregated data, which may be qualitative or quantitative and where the individual or corporate identities of the respondents are in themselves of little significance.

The survey methodology uses sampling of individual units from a population and associated techniques of survey collection. In the case of LOPA, in order to obtain the degree of public compliance with the covid prevention protocols, observational surveys can be made on a sample of employee units in office floor or factory shop floor. For the cases of high population centres, such as transport hubs or the shopping centres, human surveys are not practical. Thus, this study proposes to use a designated area in heavily populated centres, equipped with CCTV (Closed-circuit television) and digital image processing to survey the public compliance. For instance, in a shopping centre, transport hub or airport, a section of the concourse can be designated as 'survey' zone, equipped with distancing space markers, hand hygiene stations under CCTV surveillance. The surveys can be taken several times a week, for some pre specified hours. This way the compliance is measured as the number of people observing the protocols per total number of 'public' sampling unit. The ratio gives the probability of compliance.

There are many types of face masks that are commercially available. For this study PM2.5 Surgical Masks were evaluated as they are the most widely used.

5.2 Ventilation

The main types of air cleaning that are likely to be effective at reducing infection risks include high efficiency particulate air (HEPA) filters and ultraviolet light.

According to (EECO2, 2021), the ventilation system factors that can minimise the virus spread are: filtering, number of air changes per hour (ACH) and the recirculation. Based on ventilation design information, the following 'rules' are proposed to estimate the ventilation system efficacy to combat virus spread.

- Rule 1; With or without recirculation, ACH > 12 with HEPA Filter or Equivalent pfd = 0.1
- Rule 2; No recirculation, ACH > 6 with filter less efficiency than HEPA or Equivalent pfd = 0.5
- Rule 3; No recirculation, ACH< 6 with filter less efficiency than HEPA or Equivalent pfd = 1.0

The recent study on Ultraviolet light indicates that it can kill the new coronavirus (Kumar, Sagdeo, Sagdeo, 2021). It is however challenging to assign an efficacy to this type of protection.

5.3 Vaccination

For vaccination efficacy, there are numerous sources of data depending on the type of vaccines, the real life data and various interpretation of the results. Most vaccine manufacturers note efficacy above 90% and some between 70 to 80%, others go as low as 65% (Ledford, H, 2021). However, it is emphasised that for all vaccine types, there is not any definitive efficacy figure. In order to use a conservative figure, based on considering possible breakthrough cases, this paper proposes to use 70% efficacy in order to estimate vaccination probability of failure (Mahase, E 2021).

6.0 LOPA CALCULATION RESULTS

Tables 3, 4 and 5 (Supplementary Addendum) illustrate that in a hypothetical shopping centre, social distancing, face mask and hand hygiene surveys are undertaken to estimate the probability of failure on demand for covid protective measures. Photo 1 (Supplementary Addendum) shows PM2.5 face masks and their probability of protections.

Figure 3 reproduces the ALAMA (Covid-19 Medical Risk Assessment – Alama, 2021) fatality risk for 4 individuals as identified for categories A to D, representing their actual age, gender, ethnicity, body mass index, and health status. Figures 4 and 5 present the transmission rate calculation for weeks 17 June 2021 and 1 July 2021. Figures 6 to Figure 9 show the age group categories and the calculated covid fatality metrics for different weekly periods at 70% vaccination and no vaccination cases. The results are shown in Figure 10. It is seen that lower adherence to covid prevention measures, namely vaccinations, increases the covid fatality risks. As shown, the covid fatality metrics are lower for the vaccination cases nearing the common flu fatality bench marking. The colour key for the simulation cases are shown in Table 6 (Supplementary Addendum).

Figure 3; Fatality Calculation (Covid-19 Medical Risk Assessment – Alama, 2021)

Age Category	Age actual, Category	Sex	Ethnicity	BMI	Heath Status	Covid age	Lower Fatality Limit	Upper Fatality Limit	Geometric Mean of Fatality for 1 person
A	62	Male	Asian	40+	Good	77	13	52	2.60E-02
B	40	Male	White	30-34.9	Good	45	0.5	1.9	9.75E-04
C	40	Female	White	30-34.9	Good	40	0.3	1.2	6.00E-04
D	40	Male	White	40+	Asthma, Type 2 diabetes	85+	30	119	5.97E-02

Figure 4; Calculation for Infection Transmission Rate – 17 June 2021

Infection in Closed Space	Case 1
UTLA selected Location	Shopping Mall Midlands
Date	17-Jun-21
Rolling Infection rate pr 100,000	175.57
Rolling Infection rate as decimal (per individual)	0.0017557
Hours spent per day in Risk Areas	5
Total number of hours per year spent in risk areas	400
Total number of human transmission per day	40
Estimate for the asymptomatic proportion of SARS-CoV-2 infections is 28%, thus increase by 28%	1.28
Infection Transmission Rate per Year	35.96

Figure 5; Calculation for Infection Transmission Rate – 01 July 2021

Infection in Closed Space	Case 2
UTLA selected Location	Shopping Mall Midlands
Date	1-Jul-21
Rolling Infection rate pr 100,000	310.43
Rolling Infection rate as decimal (per individual)	0.0031043
Hours spent per day in Risk Areas	5
Total number of hours per year spent in risk areas	400
Total number of human transmission per day	40
Estimate for the asymptomatic proportion of SARS-CoV-2 infections is 28%, thus increase by 28%	1.28
Infection Transmission Rate per Year	63.58

Figure 6; LOPA and Covid Fatality Metrics Calculation, 70% Vaccination Efficacy – 17 June 2021

Case 1	Infection transmission Rate per Year	Transmission pathway	Independent Protection Layers (IPL)					Infection rate per year	Death Probability for 1 infected person	Risk of Death per Year	Flu Annual Death Rate	Covid Fatality Metric
			Social Distancing	Building Ventilation	Face Mask	Hand Hygiene	Vaccine					
	35.96	Direct	0.4957	0.50	0.4822	0.4950	0.30	6.38E-01				
A	35.96	Indirect	0.4957	0.50	0.4822	0.4950	0.30	6.38E-01				
		Total						1.28E+00	2.60E-02	3.32E-02	1.00E-04	331.88
	35.96	Direct	0.4957	0.50	0.4822	0.4950	0.30	6.38E-01				
B	35.96	Indirect	0.4957	0.50	0.4822	0.4950	0.30	6.38E-01				
		Total						1.28E+00	9.75E-04	1.24E-03	1.00E-04	12.44
	35.96	Direct	0.4957	0.50	0.4822	0.4950	0.30	6.38E-01				
C	35.96	Indirect	0.4957	0.50	0.4822	0.4950	0.30	6.38E-01				
		Total						1.28E+00	6.00E-04	7.66E-04	1.00E-04	7.66
	35.96	Direct	0.4957	0.50	0.4822	0.4950	0.30	6.38E-01				
D	35.96	Indirect	0.4957	0.50	0.4822	0.4950	0.30	6.38E-01				
		Total						1.28E+00	5.97E-02	7.63E-02	1.00E-04	762.68

Figure 7; LOPA and Covid Fatality Metrics Calculation, No Vaccination – 17 June 2021

Case 1	Infection transmission Rate per Year	Transmission pathway	Independent Protection Layers (IPL)					Infection rate per year	Death Probability for 1 infected person	Risk of Death per Year	Flu Annual Death Rate	Covid Fatality Metric
			Social Distancing	Building Ventilation	Face Mask	Hand Hygiene	Vaccine					
	35.96	Direct	0.4957	0.50	0.4822	0.4950	1.00	2.13E+00				
A	35.96	Indirect	0.4957	0.50	0.4822	0.4950	1.00	2.13E+00				
		Total						4.25E+00	2.60E-02	1.11E-01	1.00E-04	1106.27
	35.96	Direct	0.4957	0.50	0.4822	0.4950	1.00	2.13E+00				
B	35.96	Indirect	0.4957	0.50	0.4822	0.4950	1.00	2.13E+00				
		Total						4.25E+00	9.75E-04	4.15E-03	1.00E-04	41.47
	35.96	Direct	0.4957	0.50	0.4822	0.4950	1.00	2.13E+00				
C	35.96	Indirect	0.4957	0.50	0.4822	0.4950	1.00	2.13E+00				
		Total						4.25E+00	6.00E-04	2.55E-03	1.00E-04	25.53
	35.96	Direct	0.4957	0.50	0.4822	0.4950	1.00	2.13E+00				
D	35.96	Indirect	0.4957	0.50	0.4822	0.4950	1.00	2.13E+00				
		Total						4.25E+00	5.97E-02	2.54E-01	1.00E-04	2542.27

Figure 8; LOPA and Covid Fatality Metrics Calculation, 70% Vaccination Efficacy – 01 July 2021

Case 2	Infection transmission Rate per Year	Transmission pathway	Independent Protection Layers (IPL)					Infection rate per year	Death Probability for 1 infected person	Risk of Death per Year	Flu Annual Death Rate	Covid Fatality Metric
			Social Distancing	Building Ventilation	Face Mask	Hand Hygiene	Vaccine					
	63.58	Direct	0.2492	0.50	0.2430	0.2264	0.30	1.31E-01				
A	63.58	Indirect	0.2492	0.50	0.2430	0.2264	0.30	1.31E-01				
		Total						2.61E-01	2.60E-02	6.80E-03	1.00E-04	67.98
	63.58	Direct	0.2492	0.50	0.2430	0.2264	0.30	1.31E-01				
B	63.58	Indirect	0.2492	0.50	0.2430	0.2264	0.30	1.31E-01				
		Total						2.61E-01	9.75E-04	2.55E-04	1.00E-04	2.55
	63.58	Direct	0.2492	0.50	0.2430	0.2264	0.30	1.31E-01				
C	63.58	Indirect	0.2492	0.50	0.2430	0.2264	0.30	1.31E-01				
		Total						2.61E-01	6.00E-04	1.57E-04	1.00E-04	1.57
	63.58	Direct	0.2492	0.50	0.2430	0.2264	0.30	1.31E-01				
D	63.58	Indirect	0.2492	0.50	0.2430	0.2264	0.30	1.31E-01				
		Total						2.61E-01	5.97E-02	1.56E-02	1.00E-04	156.22

Figure 9; LOPA and Covid Fatality Metrics Calculation, No Vaccination – 01 July 2021

Case 2	Infection transmission Rate per Year	Transmission pathway	Independent Protection Layers (IPL)					Infection rate per year	Death Probability for 1 infected person	Risk of Death per Year	Flu Annual Death Rate	Covid Fatality Metric
			Social Distancing	Building Ventilation	Face Mask	Hand Hygiene	Vaccine					
A	63.58	Direct	0.2492	0.50	0.2430	0.2264	1.00	4.36E-01				
	63.58	Indirect	0.2492	0.50	0.2430	0.2264	1.00	4.36E-01				
		Total						8.72E-01	2.60E-02	2.27E-02	1.00E-04	226.60
B	63.58	Direct	0.2492	0.50	0.2430	0.2264	1.00	4.36E-01				
	63.58	Indirect	0.2492	0.50	0.2430	0.2264	1.00	4.36E-01				
		Total						8.72E-01	9.75E-04	8.49E-04	1.00E-04	8.49
C	63.58	Direct	0.2492	0.50	0.2430	0.2264	1.00	4.36E-01				
	63.58	Indirect	0.2492	0.50	0.2430	0.2264	1.00	4.36E-01				
		Total						8.72E-01	6.00E-04	5.23E-04	1.00E-04	5.23
D	63.58	Direct	0.2492	0.50	0.2430	0.2264	1.00	4.36E-01				
	63.58	Indirect	0.2492	0.50	0.2430	0.2264	1.00	4.36E-01				
		Total						8.72E-01	5.97E-02	5.21E-02	1.00E-04	520.74

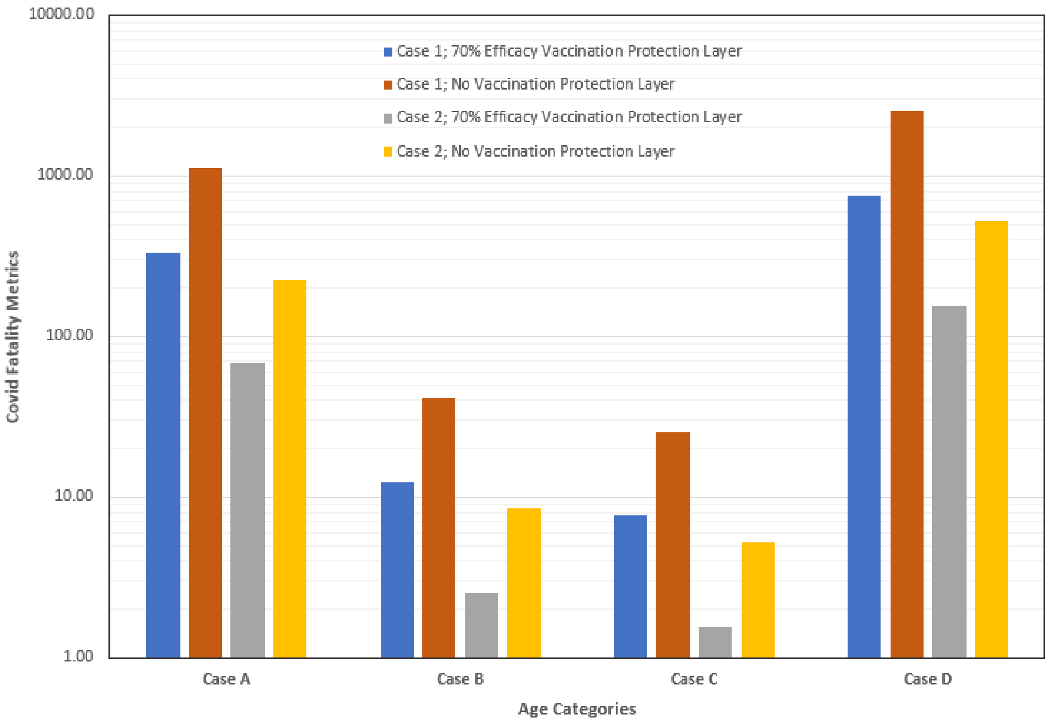

Figure 10; Covid Fatality Metrics for Cases 1 & 2, showing lower expected fatality in Case 2 and lower fatalities at 70% efficacy vaccination.

The results indicate that on the 17th June 2021 and 1st July 2021, the annual transmission rates risk was calculated respectively at 35.96 and 63.58. The increase in transmission rate is due to the virulent Delta strain. Tables 3, 4 & 5 show that in the second week, the compliance with the health protocols have improved. Figure 10 illustrates that since the protocols are fully observed, the covid fatality metrics is reduced nearing the common flu annual death rate. This figure also illustrates the effect of the vaccination programme which shows a considerably reduction to the death risk.

7.0 DISCUSSIONS

For chemical engineers, the usefulness of LOPA is obvious, since this methodology appeared in early 2000s, it has become mandatory for any process design activity. LOPA reviews and calculations have become as important as Hazard and Operability (HAZOP) to design a safe and operable plant. In a sound chemical plant design, no process trip is designed without considering its Safety Integrity Level requirement and its layers of protection (LOPA) implications. Based on the findings of this paper, it is proposed that the LOPA application to COVID-19 risk can also help to bring back some form of normality to the current pandemic situation. Any risk can be mitigated depending on availability and compliance of the safeguards, as well as the practicability of protective measures applications. This is the foundation of ALARP (As Low As Reasonably Practicable) which is commonly used to design out the risks associated with process plants.

Within the context of ALARP, tolerability limits for the process risks entailing fatalities are set by the following references, at 1 in 10,000 per annum for the public who have a risk imposed on them (Reducing risks, protecting people, 1999; Risk management: Expert guidance - ALARP at a glance, 2021). There are always 'residual' risks and the COVID-19 risk, is not an exception. The Covid risk may not be eliminated but it can be controlled and managed; as low as reasonably practicable. A tolerable risk for COVID-19 in this study has been set a figure of annual 1 death in 10,000 population (Around 10,000 deaths are caused by flu each year in England and Wales, 2021).

The permanency imperative of SARS-COV-2 would require that the COVID-19 protection layer protocols and risk assessment tools have to be observed and implemented in some forms. This paper aims to provide a scientific basis to apply the Covid protocols in the form of process safety engineering application of LOPA and get meaningful results to implement the safeguards efficiently. In order to achieve this aim, the level of public compliance to the Covid protective measures requires to be modelled and verified. The LOPA tool provides an algorithm to determine the steps that could be made to improve the situation; such as, to improve the infection encounter rate by reducing the number of contacts or events or setting up a suitable testing regimes. There may be individuals who need special protection due to a combination of age, ethnicity, or BMI. They might be able to improve the effectiveness of the COVID-19 Protection Layer Protocols, either by physical improvements or encouraging compliance.

The LOPA tool enables the premise stakeholders to heed the public compliance of the covid prevention safeguards and use the 'covid fatality metrics' as a yardstick to devise plans and decisions to control and manage the virus spread amongst the population. The results indicate that LOPA can produce practical quantitative and qualitative results that can be used for achieving and returning to a resilient normal life. The idea of periodic vaccinations, Covid free ventilation clean air, observing basic hygiene, social distancing, wearing masks in 'crowded' closed spaces, and frequent testing, all can help to bring return to normal life. (Infection Resilient Environments: Buildings that keep us healthy and safe | Initial Report, 2021) states ventilation and clean air in confined spaces as the key for infection resilient environments.

8.0 CONCLUSIONS

It is now accepted that the COVID-19 virus has become an omnipresent entity within the human population. It has been suggested that there needs to be a debate about what is an "acceptable" level of Covid, "Covid is here to stay - we need to discuss what we are willing to live with" (Triggle N, 2021). The proposed LOPA Versus Covid model can provide an analytical quantitative method to identify 'what is the acceptable rate' in relation to the calculated transmission rates and the health protocols effectiveness.

The LOPA tool can perform 'sensitivity analyses to the changing input parameters and assess the importance of these input variables to reduce the covid fatality metrics. The resulting decisions based on the LOPA sensitivity runs, can develop plans, more public awareness and communication for the public, devise testing plans, control the human encounter events, and create more effective COVID-19 protection layer health protocols.

This study proposes to use a designated area in heavily populated centres, equipped with CCTV and digital image processing to survey the public compliance. For instance, in a shopping centre, transport hub or airport, a section of the concourse can be designated as a 'survey' zone, equipped with distancing space markers and hand hygiene stations, all under CCTV surveillance. As the statistical modelling, random number population sampling and LOPA calculation in this study were performed manually by the authors, it is recommended to develop a 'Covid LOPA software' tool. This will help extract infection rates directly from public domain population infection data bases; use CCTV digital image processing to conduct protocols' public adherence surveys with the results directly inputted into the 'software'. Once entered, the software can perform calculations and present the final results in a graphical way to the key stakeholders of premises. This would help to manage the COVID-19 risk.

This paper uses several calculation steps to reach the final results which are given in figure 10. If this methodology becomes automated, the users do not need to go through all the calculation steps and they would only need to fill the input parameters and the automated tool would generate a graph similar to that seen in Figure 10, alongside some tabulated results. There are several input variables that can be changed in order to get the resulting Figure 10. Producing this type of sensitivity analysis is beyond the scope of this paper, but the methodology can handle it.

The advantage of this paper is that the main outcome which is a calculated **Covid Fatality Metrics value**. The magnitude of this calculated value determines how much improvement in the transmission rate variables and the safeguarding protocols should be made in order to bring down the annual death rate in parity with the common flu. This metric can be used by stakeholders to manage and control the spread of infection.

This technical paper is a follow up to the original paper on this topic which is cited in (Mokhber, Ross and Garcia-Trinanes, 2021).

8.1 Recommendations

By now, it is established that SARS-COV-2 virus will be in circulation as variants in human population permanently (Scudellari, M, 2020; Long term evolution of SARS-CoV-2, 26 July 2021).

SARS-COV-2 infection must therefore be considered as a major hazard and should be treated similarly to a process plant, nuclear accident, or transportation risks. Process safety engineering has long demonstrated that probabilistic risk assessment and various qualitative risk reviews can reduce the number of accidental process plant injuries and fatality risks. This study has demonstrated that LOPA is applicable to the Covid infection risk assessment.

It is therefore recommended that other process safety risk assessment tools may also be applied to prevent the COVID-19 infection spread. Structured process safety reviews such as Hazard Identifications (HAZIDs), with relevant modifications may be applied to identify the Covid infection risks and make appropriate recommendations. For example, a HAZID can be applied to a transport hub in order to assess how the risk of covid infection can be minimised by determining appropriate measures.

For situations having the potential to harm many people, so-called major hazards, the appropriate formulation of quantified risk is a societal risk (Goose, M, 2010). For instance, in process plants and nuclear industries, the societal risk modelling is used to estimate the chances of people being harmed from an incident. It is anticipated that this methodology is applicable to Covid Infection hazard in a community.

Societal risk takes account of both the severity of the range of possible outcomes and the frequency at which they each are predicted to occur. It is usually presented as a two-dimensional relationship between frequency and cumulative severity of outcome, called an FN-curve. Thus, an FN-curve is used to display the hazardous event cumulative frequency, F, with probability of having N or more fatalities per year (Vasconcelos et al, 2015).

Societal risk (FN-curve) can set out to provide a single measure of the chance of virus outbreak that could harm a number of people in a pandemic. FN-curves may be used for presenting information about societal risks and to depict at least three different types of information:

- Historical records of local rolling infection rates and outbreaks in the community;
- Results of a Probabilistic Safety Assessment; and
- Criteria for judging the tolerability of risk.

There are many other examples of process safety assessment tools which can potentially be applied to the pandemic situation, such as Performance Standards and Safety Critical Elements (CAPP, 2019). In this case, it is realised that efficient ventilation in closed spaces is the key to safeguarding against the virus spread in confined areas (Infection Resilient Environments: Buildings that keep us healthy and safe | Initial Report, 2021). The ventilation system can be treated as a safety critical element with the rigorous safeguarding performance standards as applied to process engineering critical equipment.

REFERENCES (in alphabetical order)

1999. Reducing risks, protecting people. [London]: Health and Safety Executive.

2001. Layer of protection analysis. New York: Center for Chemical Process Safety of the American Institute of Chemical Engineers.

Alama.org.uk. 2021. Covid-19 Medical Risk Assessment – Alama. [online] Available at: <https://alama.org.uk/covid-19-medical-risk-assessment/> [Accessed 26 July 2021].

Ammar H. Elsheikh, Amal I. Saba, Mohamed Abd Elaziz, Songfeng Lu, S. Shanmugan, T. Muthuramalingam, Ravinder Kumar, Ahmed O. Mosleh, F.A. Essa, Taher A. Shehabeldeen, Deep learning-based forecasting model for COVID-19 outbreak in Saudi Arabia, Process Safety and Environmental Protection, Volume 149, 2021, Pages 223-233, ISSN 0957-5820, https://doi.org/10.1016/j.psep.2020.10.048. (https://www.sciencedirect.com/science/article/pii/S0957582020318516)

Anil Kumar, Archna Sagdeo, Pankaj R. Sagdeo, Possibility of using ultraviolet radiation for disinfecting the novel COVID-19, Photodiagnosis and Photodynamic Therapy, Volume 34, 2021, 102234, ISSN 1572-1000, https://doi.org/10.1016/j.pdpdt.2021.102234. (https://www.sciencedirect.com/science/article/pii/S1572100021000600)

Assets.publishing.service.gov.uk. 2021. [online] Available at: <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/990923/20210602_Infection_Prevention_and_Control_Guidance_for_maintaining_services_with_H_and_C_settings__1_.pdf> [Accessed 5 August 2021].

Beale, S., Hayward, A., Shallcross, L., Aldridge, R. and Fragaszy, E., 2020. A rapid review and meta-analysis of the asymptomatic proportion of PCR-confirmed SARS-CoV-2 infections in community settings. Wellcome Open Research, [online] 5, p.266. Available at: <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/925128/S0745_Rapid_review_of_asymptomatic_proportion_of_SARS-CoV-2_infections_in_community_settings.pdf> [Accessed 24 July 2021].

Blocken B., Malizia F., Druenen T. van, Marchal T., Towards aerodynamically equivalent COVID19 1.5 m social distancing for walking and running, http://www.urbanphysics.net/Social%20Distancing%20v20_White_Paper.pdf, Building Physics and Services, Department of the Built Environment, Eindhoven University of Technology, P.O. box 513, 5600 MB Eindhoven, the Netherlands, 2020

Kayleigh Rayner Brown, Peter VanBerkel, Faisal I. Khan, Paul R. Amyotte, Application of bow tie analysis and inherently safer design to the novel coronavirus hazard, Process Safety and Environmental Protection, Volume 152, 2021, Pages 701-718, ISSN 0957-5820, https://doi.org/10.1016/j.psep.2021.06.046. (https://www.sciencedirect.com/science/article/pii/S0957582021003396)

Computing & Control Engineering Journal, 2000. IEC 61508. Functional safety of electrical/electronic/programmable electronic safety-related systems. [online] 11(1), pp.3-5. Available at: <https://webstore.iec.ch/publication/22273> [Accessed 25 July 2021].

Coronavirus.data.gov.uk. 2021. [online] Available at: <https://coronavirus.data.gov.uk/details/interactive-map/cases> [Accessed 20 July 2021].

Didem Guleryuz, Forecasting outbreak of COVID-19 in Turkey; Comparison of Box–Jenkins, Brown's exponential smoothing and long short-term memory models, Process Safety and Environmental Protection, Volume 149, 2021, Pages 927-935, ISSN 0957-5820, https://doi.org/10.1016/j.psep.2021.03.032. (https://www.sciencedirect.com/science/article/pii/S0957582021001464)

EECO2. 2021. RESOURCE DETAILS. [online] Available at: <https://www.eeco2.com/resources/details/?resource=covid-19-managing-risk-in-pharmaceutical-hvac-systems&id=1867> [Accessed 26 July 2021].

European Centre for Disease Prevention and Control. Using face masks in the community. Stockholm: ECDC; 2020.

J.S. Fang, M.S. Mannan, D.M. Ford, J. Logan, A. Summers, Value at Risk Perspective on Layers of Protection Analysis, Process Safety and Environmental Protection, Volume 85, Issue 1, 2007, 81 -87, https://doi.org/10.1205/psep.05195

Greenhalgh T, Schmid MB, Czypionka T, Bassler D, Gruer L. Face masks for the public during the covid-19 crisis. BMJ. 2020 Apr 9;369:m1435. doi: 10.1136/bmj.m1435. PMID: 32273267.

Greenwichccg.nhs.uk. 2021. Around 10,000 deaths are caused by flu each year in England and Wales. [online] Available at: <https://www.greenwichccg.nhs.uk/News-Publications/news/Pages/Around-10,000-deaths-are-caused-by-flu-each-year-in-England-and-Wales.aspx> [Accessed 25 July 2021].

Howard, J., Huang, A., Li, Z., Tufekci, Z., Zdimal, V., van der Westhuizen, H., von Delft, A., Price, A., Fridman, L., Tang, L., Tang, V., Watson, G., Bax, C., Shaikh, R., Questier, F., Hernandez, D., Chu, L., Ramirez, C. and Rimoin, A., 2021. An evidence review of face masks against COVID-19. Proceedings of the National Academy of Sciences, [online] 118(4), p.e2014564118. Available at: <https://www.preprints.org/manuscript/202004.0203/v1> [Accessed 5 August 2021].

Hse.gov.uk. 2021. Risk management: Expert guidance - ALARP at a glance. [online] Available at: <https://www.hse.gov.uk/managing/theory/alarpglance.htm> [Accessed 5 August 2021].

Jones N R, Qureshi Z U, Temple R J, Larwood J P J, Greenhalgh T, Bourouiba L et al. Two metres or one: what is the evidence for physical distancing in covid-19? BMJ 2020; 370 :m3223 doi:10.1136/bmj.m3223

Ledford H. Six Months, 1.7 Billion Doses: What we've learnt about covid vaccines; Nature| Vol 594 | 10 June 2021.

Long term evolution of SARS-CoV-2, 26 July 2021; https://www.gov.uk/government/publications/long-term-evolution-of-sars-cov-2-26-july-2021.

Elizabeth Mahase, Covid-19: Pfizer vaccine's efficacy declined from 96% to 84% four months after second dose, company reports, BMJ 2021; 374 doi: https://doi.org/10.1136/bmj.n1920 (Published 30 July 2021)

Maria Cristina Collivignarelli, Claudio De Rose, Alessandro Abbà, Marco Baldi, Giorgio Bertanza, Roberta Pedrazzani, Sabrina Sorlini, Marco Carnevale Miino, Analysis of lockdown for CoViD-19 impact on NO2 in London, Milan and Paris: What lesson can be learnt?, Process Safety and Environmental Protection, Volume 146, 2021, Pages 952-960, ISSN 0957-5820, https://doi.org/10.1016/j.psep.2020.12.029. (https://www.sciencedirect.com/science/article/pii/S095758202031956X)

Martin Goose, Representing Societal Risk as an FN Curve and Calculating the Expectation Value; http://www.alarp.plus.com/SREV.pdf, 5th March 2010.

Mohamed Marzouk, Nehal Elshaboury, Amr Abdel-Latif, Shimaa Azab, Deep learning model for forecasting COVID-19 outbreak in Egypt, Process Safety and Environmental Protection, Volume 153, 2021, Pages 363-375, ISSN 0957-5820, https://doi.org/10.1016/j.psep.2021.07.034. (https://www.sciencedirect.com/science/article/pii/S0957582021004055)

Mokhber, A., Ross, C. and Garcia-Trinanes, P., 2021. LOPA Versus Covid. [online] Thechemicalengineer.com. Available at: <https://www.thechemicalengineer.com/features/lopa-versus-covid/> [Accessed 22 July 2021].

Triggle, N., 2021, Covid: The UK is Europe's virus hotspot - does it matter? [online] BBC, Available at: https://www.bbc.co.uk/news/health-58849024 [Accessed 9th October 2021].

Packham, Chris, Hand hygiene for infection prevention against COVID-19, EnviroDerm Services 2020 https://www.hsmsearch.com/Enviroderm-COVID-hand-hygiene

Raeng.org.uk. 2021. Infection Resilient Environments: Buildings that keep us healthy and safe | Initial Report. [online] Available at: <https://www.raeng.org.uk/publications/reports/infection-resilient-environments> [Accessed 23 July 2021].

Scudellari M. The Pandemic's Future: Researchers are developing a host of scenarios to predict how the next few years might look; Nature| Vol 584 | 6 August 2020.

Skolmowska D, Głąbska D, Guzek D. Hand Hygiene Behaviors in a Representative Sample of Polish Adolescents in Regions Stratified by COVID-19 Morbidity and by Confounding Variables (PLACE-19 Study): Is There Any Association? Pathogens. 2020 Dec 1;9(12):1011. doi: 10.3390/pathogens9121011. PMID: 33271861; PMCID: PMC7759844.

The Canadian Association of Petroleum Producers (CAPP), 2019, Identification of Safety Critical Equipment (SCE), version 9, [online] Available at: capp.ca/wp-content/uploads/2019/11/Identification_of_Safety_Critical_Equipment_SCE-334009.pdf

Vasconcelos, Vanderley & Soares, Wellington & Costa, Antonio Carlos. (2015). FN-Curves: Preliminary Estimation Of Severe Accident Risks After Fukushima.

Webstore.iec.ch. 2021. IEC TR 61511-0:2018 | IEC Webstore. [online] Available at: <https://webstore.iec.ch/publication/60766> [Accessed 24 July 2021].

World Health Organisation, Hand Hygiene: Why, How & When? 2009, https://www.who.int/gpsc/5may/Hand_Hygiene_Why_How_and_When_Brochure.pdf

World Health Organization. (2020). Mask use in the context of COVID-19: interim guidance, 1 December 2020. World Health Organization. https://apps.who.int/iris/handle/10665/337199. License: CC BY-NC-SA 3.0 IGO

Data for a Shopping Mall in the Midlands week ending 17th June			
Random Population Sample	**Infection/Case Rate Per 100,000 People**	**Area**	**Randomly Selected Postcode Area**
134	301.2	Oldham	OL1 3DH
96	147.2	Glossop	SK13 7QU
52	60	Warrington	WA5 1TH
78	109.3	Barnsley	S70 6BG
46	42.5	Huddersfield	HD1 4SJ
13	89.4	Knutsford	WA16 9EA
159	245.2	Bolton	BL1 2DP
289	325	Chorley	PR7 1JA
335	544.6	Preston	BB2 6NZ
147	147.2	Handforth	SK9 3QB
55	59.1	Buxton	SK17 6PX
21	47.5	Sheffield	S10 5RQ
101	238.4	Northwich	CW8 1EQ
268	348.2	Blackburn	BB2 1QT

Data for a Shopping Mall in the Midlands week ending 17th June			
Random Population Sample	**Infection/Case Rate Per 100,000 People**	**Area**	**Randomly Selected Postcode Area**
211	273.8	Liverpool	L7 1AG
340	897.3	Manchester	M4 5LA
180	241.3	Macclesfield	SK11 7BB
300	545.9	Burnley	BB11 3LP
226	350.9	Chester	CH1 3HE
131	211.8	Ashton-under-Lyne	OL6 7PQ
59	37.2	Wakefield	WF2 9QS
74	82.8	Keighley	BD21 2QW
91	192	St Helens	WA10 1JA
88	100.1	Rochdale	OL11 1JN
112	206.2	Halifax	HX3 6AD
64	158.9	Leeds	LS12 1YL
73	198.6	Bradford	BD7 3AG
105	207.6	Stockport	SK1 4NW
117	367.4	Wigan	WN1 1HA
41	75.6	Runcorn	WA7 1BQ

Table 1: A graph to show the rate of COVID-19 cases in typical areas around a Shopping Mall in the Midlands (17th June 2021).

Data for a Shopping Mall in the Midlands week ending 1st July			
Random Population Sample	**Infection/Case Rate Per 100,000 People**	**Area**	**Randomly Selected Postcode Area**
134	403.1	Stockport	SK1 4NW
96	392	Liverpool	L7 1AG
52	145.6	Bradford	BD7 3AG
78	206.2	Halifax	HX3 6AD
46	142.6	Sheffield	S10 5RQ
13	127.4	Huddersfield	HD1 4SJ
159	430.5	Rochdale	OL11 1JN
289	486.3	Burnley	BB11 3LP
335	838.2	Oldham	OL1 3DH
147	438.9	St Helens	WA10 1JA
55	203.8	Chester	CH1 3HE
21	191.9	Warrington	WA5 1TH
101	368.6	Runcorn	WA7 1BQ
268	468.5	Barnsley	S70 6BG
211	467.1	Chorley	PR7 1JA
340	1101.3	Manchester	M4 5LA
180	442	Ashton-under-Lyne	OL6 7PQ
300	527.9	Blackburn	BB2 1QT
226	496.6	Buxton	SK17 6PX

Data for a Shopping Mall in the Midlands week ending 1st July			
Random Population Sample	**Infection/Case Rate Per 100,000 People**	**Area**	**Randomly Selected Postcode Area**
131	387.2	Knutsford	WA16 9EA
59	211.2	Preston	BB2 6NZ
74	220.6	Bolton	BL1 2DP
91	316.7	Wigan	WN1 1HA
88	294.4	Handforth	SK9 3QB
112	347.6	Wakefield	WF2 9QS
64	217.2	Macclesfield	SK11 7BB
73	279.5	Keighley	BD21 2QW
105	343.5	Glossop	SK13 7QU
117	374.6	Leeds	LS12 1YL
41	221.4	Northwich	CW8 1EQ

Table 2: : A graph to show the rate of COVID-19 cases in typical areas around a Shopping Mall in the Midlands (1st July 2021).

To survey for 'Rules' compliance with 800 shoppers sampling (observe people for 180 minutes a working day and record how many people observe social distancing within this survey period).
Survey (observation) to be conducted by HSE Department

Week 1 (17.06.21) Social Distancing Survey		
Day 1, 1st survey: 270 people out of 800 do not observe 2 metres rule;		0.3375
Day 2, 2nd survey: 700 people out of 800 do not observe 2 metres rule;		0.875
Day 3, 3rd survey: 330 people out of 800 do not observe 2 metres rule;		0.4125
Geometric Mean =	0.4957	probability of failure for social distancing

Week 2 (01-07-21) Social Distancing Survey		
Day 1, 1st survey: 220 people out of 800 do not observe 2 metres rule;		0.275
Day 2, 2nd survey: 450 people out of 800 do not observe 2 metres rule;		0.5625
Day 3, 3rd survey: 80 people out of 800 do not observe 2 metres rule;		0.1
Geometric Mean =	0.2492	probability of failure for social distancing

Table 3; Social Distancing Survey for Shopping Mall

To survey for 'Rules' compliance with 800 shoppers sampling (observe people for 180 minutes a working day and record how many people observe wearing face mask within this survey period).			
Survey (observation) to be conducted by HSE Department			

Week 1 (17.06.21) Face Mask Survey			
Day 1, 1st survey: 290 people out of 800 do not wear or not fully face mask;		0.3625	
Day 2, 2nd survey: 550 people out of 800 do not wear or not fully face mask;		0.6875	
Day 3, 3rd survey: 360 people out of 800 do not wear or not fully face mask;		0.45	
Geometric Mean =	0.4822	percentage people that do not wear or not fully face mask	
Then, PFD of wearing mask protection is	0.1759	e.g. for type B mask	

Week 2 (01-07-21) Face Mask Survey			
Day 1, 1st survey: 150 people out of 800 do not wear or not fully face mask;		0.1875	
Day 2, 2nd survey: 350 people out of 800 do not wear or not fully face mask;		0.4375	
Day 3, 3rd survey: 140 people out of 800 do not wear or not fully face mask;		0.175	
Geometric Mean =	0.2430	percentage people that do not wear or not fully face mask	
Then, PFD of wearing mask protection is	0.0886	e.g. for type B mask	

Table 4; Wearing Face Mask Survey for Shopping Mall

To survey for 'Rules' compliance with 800 shoppers sampling (observe people for 180 minutes a working day and record how many people wash their hands within this survey period). Survey (observation) to be conducted by HSE / HR		
Survey (observation) to be conducted by HSE Department		

Week 1 (17.06.21) Hand Hygiene Survey		
Day 1, 1st survey: 600 people out of 800 do not wash their hands;		0.75
Day 2, 2nd survey: 450 people out of 800 do not wash their hands;		0.5625
Day 3, 3st survey: 230 people out of 800 do not wash their hands;		0.2875
Geometric Mean =	0.4950	probability of failure for hand hygiene

Week 2 (01-07-21) Hand Hygiene Survey		
Day 1, 1st survey: 110 people out of 800 do not wash their hands;		0.1375
Day 2, 2nd survey: 300 people out of 800 do not wash their hands;		0.375
Day 3, 3st survey: 180 people out of 800 do not wash their hands;		0.225
Geometric Mean =	0.2264	probability of failure for hand hygiene

Table 5; Hand Hygiene Survey for Shopping Mall

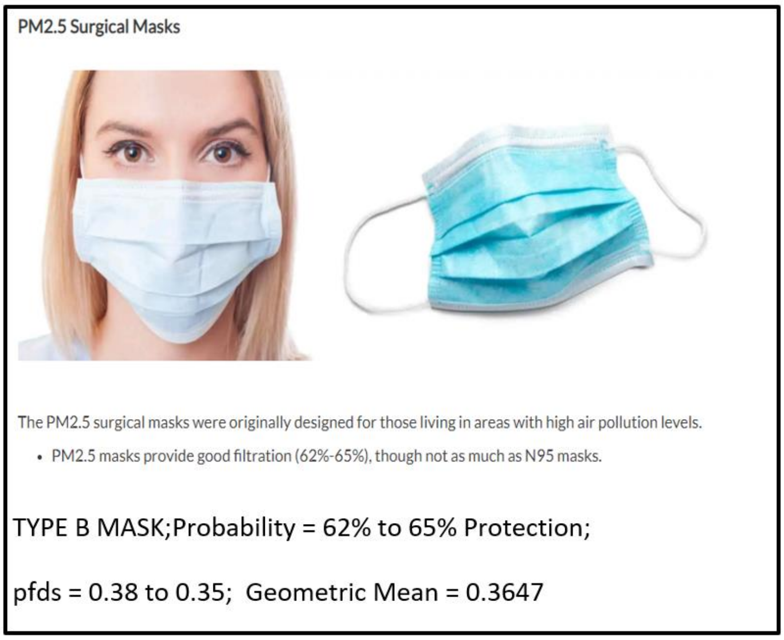

Photo 1; Face Mask Filtration Efficiency

	User Input
	Calculation Output
	Input from Other Sources (Relevant Websites)
	Change Variables

Table 6. Colour key for Simulation Cases