Operations Research and Management of Infectious Diseases

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Abstract: ***Health care sector and medical science has been dynamically evolving since past 20 years. Emergence of epidemics like SARS, HIV, Malaria and recently covid-19 have resulted in the incorporation of operational research in medical science. The field has experienced a growing presence of operational research techniques to study the dynamics of various pandemics and come up with effective intervention strategies. Operational research techniques like mathematical, stochastic and probabilistic modelling etc. have proved to be effective in decision making, prevention, and post-pandemic management (vaccination drives, medical help distribution). In this study, we have conducted a systematic review of several research articles published across the globe in this field. We have tried to determine the patterns and interconnections between different models developed over the years and trace the path of evolution of operational research in epidemic management. Our results also indicate areas that need to be studied further with greater depth and areas to delve into further***.

Keywords: Operations Research, Infectious diseases, disease management, prevention, minimization, modelling, models, simulation, COVID-19

1. Introduction

Over 17 million people are killed by infectious diseases every year according to World Health Organization and it is evident that infectious diseases still pose a threat to human health as seen by the expansion of HIV, TB, malaria, and the recent spread of Ebola.(Silal, 2021b). And today we stand at a place where the pandemic is something everyone is familiar with as Covid-19. The likelihood and seriousness of these dangers vary greatly. Additionally, they have a variety of effects on morbidity, and mortality, as well as a wide range of social and economic repercussions.(Tagliabue et al., 2019) and thus there is a need for minimizing the spread of such communicable diseases exists and this is where operation research has emerged as a saviour. OR has been applied to help inform decisions related to prevention, controlling and screening for several decades now. (Zhang et al., n.d.-a)Many researchers have developed numerous methods and models in order to control and minimize the spread of infectious diseases. For example, (Nandi & Medal, 2016)developed several interdiction models to minimize the spread in a network and (Yaesoubi& Cohen, 2011) proposed a class of mathematical models for the transmission of infectious diseases in large populations. These models can be used to generate optimal dynamic health policies for controlling the spread of infectious diseases. Operations research methods have been applied for various communicable diseases such as TB, HIV AIDS, etc in the past but after the onset of the COVID-19 pandemic, the purview of Operations research widened and it has gained relatively higher importance in policy and decision making as the COVID-19 pandemic has severely impacted our day-to-day lives, and businesses, and disrupted world trade and movements. The majority of nations had to reduce the rate at which they produced goods. The pharmaceutical, solar energy, travel, information, and electronics sectors are just a few of the different sectors that are impacted by the disease's aetiology (Haleem et al., 2020). Therefore, we can see growing literature and emerging applications of Operations Research in recent times.

Although there is a wide literature depicting extensive use of OR in relation to infectious diseases. But the is a paucity of review papers that present the crux of the work done in this field. This review paper tries to capture and effectively present the work done by various operations researchers in the field of management of infectious disease, which includes prevention, detection and minimization. The paper aims to give insights into the various methods and models of OR used in infectious disease management and also provides an overviewof how OR has evolved in providing solutions for infectious diseases.

2. Literature Review

The literature review of this paper has been bifurcated into 3 segments. The first one deals with the use of Operations research in the management of infectious diseases. The second part delves into the specific models such as SIR, SIER, SIS pertaining to infectious diseases management. As there have been extensive research on Malaria using OR, therefore the third part of the literature review focuses on the contribution of OR to the management of Malaria.

There are plenty of articles and research papers that show that Operations research has contributed widely to the field of infectious disease management. (Zhang et al., n.d.-b) have provided numerous examples of contributions of OR methods, which include mathematical programming, dynamic programming, and simulation, to the prevention, detection, and treatment of diseases.

The study by (Silal, 2021b) emphasises the use of operational research in the management of infectious diseases. The study highlights the application of various models in various areas of health care, such as understanding disease biology, intervention planning and implementation, economic feasibility and cost minimization, and forming health care policies.

Research has also proven that mathematical modelling is a key to controlling infectious diseases (Morgan-Capner, 2005). Simulation studies like (Davies et al., 2003)looked at the validity of models of screening, prevention, and treatment, focusing on two simulation studies, and (Aaby et al., 2006) demonstrated how county health departments must set up and run clinics to disperse medications and vaccines using discrete-event simulation models as well as capacity-planning and queueing-system models, and validated these models using data they collected during full-scale simulations of disease outbreaks. In 2006, (Thommes& Coates, n.d.)Click or tap here to enter text. derive deterministic epidemiological models for the propagation of a P2P virus through a P2P network.In order to create effective control measures for the UK foot-and-mouth outbreak of 2001, mathematical models played a crucial role. (*Kao2002*, n.d.) reviews the numerous modelling exercises that were created throughout the pandemic, outlining the challenges in understanding the data at hand and the suitability of the various assumptions.(Schoch-Spana et al., 2022) conducted an expert elicitation process to come up with the design principles, priority issues, and field experiences that should inform development of an epidemic recovery model. Their results categorise the findings into the following categories Operating definitions, Response prioritized, Politics/economics, Distinctive features, and Model considerations. In the year 2007, a study proposed a nurse allocation policy to manage patient outflow during the pandemic influenza outbreak. (Allocation of resources for the management of disease) The objective of this study was to minimize the number of patients waiting in queue for treatment of the virus alongside maximizing the patient inflow. This model if efficiently applied could prove to be a live saver if applied to bed allocation in hospitals as shortage of beds becomes a major bottleneck in times of rapidly rising infections (Ehsan et al., n.d.) To do this they made use of ARENA simulation software and proposed various combinations for the number of nurses needed with the help of operations research.

There have been specific disease-related researches conducted by many researchers. Some of the examples of such research have been included and described in this review paper.

A model of the transmission of AIDS among the homosexual population in the UK has been developed by (Roberts & Dangerfield, 1990)using system dynamics techniques. It is able to represent the effects while capturing the virological and behavioural characteristics of the pandemic. (Knight et al., 2020) constructed a unifying, data-guided framework to simulate risk group turnover in deterministic, compartmental transmission models to examine how turnover influences modelled projections of the tPA of high-risk groups. Their results show that if the models do not capture the projected contribution of high-risk groups, the impact of developing interventions for their needs might be underestimated.

(Durrheim et al., n.d.)used telephonic survey as a rapid tool for operational research for rabies post-exposure management in South Africa. This "fast and dirty" survey method produced useful data for enhancing a crucial public health programme, and it should be taken into account when evaluating other health programmes, especially if a simple method for validating replies is available.

Research by (Michael et al., 2007) focused on the control of the vector-borne parasitic disease, lymphatic filariasis, and showed how mathematical models of parasite transmission can possibly provide a scientific framework for supporting the optimal design of parasite control monitoring programmes. The findings of their research demonstrate how adopting an adaptive management strategy can significantly improve the usage of a model-based monitoring framework by facilitating the use of monitoring data to learn about effective control and allowing future decisions to be changed as we gain experience.

As there is a wide variety of methods and models for the management of infectious diseases (Brandeau, n.d.) have done a review of how the decision makers can choose the best way among the present OR-based methods such as standard cost-effectiveness analysis, linear and integer programming, simulation, numerical procedures, optimal control methodologies, nonlinear optimization, and heuristic approaches to control epidemics.

Various researchers have developed specific models such as SIR, SIER, etc for the management of infectious diseases. The paper discusses some models which are of high importance in this field.

(Momani et al., 2021) developed a novel operational matrix for a susceptible-infected-recovered (SIR) epidemic dynamical system of children's illnesses based on Laguerre wavelets. Their numerical findings and graphs demonstrate that chaos exists in the positive integer and arbitrary orders of the arbitrary-order SIR epidemic system. The proposed Laguerre wavelet mechanism, according to their argument, is a potential tool for identifying and analysing both linear and nonlinear dynamical systems in the biological and medical sciences. (Lymperopoulos, 2021) developed a neurodynamical model of epidemics in social networks, Susceptible–Infected–Removed (SIR) epidemic processes are mechanistically modelled as analogous to the activity propagation in neuronal populations. Their results validate the strategies of social distancing.

(Zerenner et al., 2022) predict the future course of ongoing susceptible–infected–susceptible (SIS) epidemics on regular, Erdős– Rényi and Barabási–Albert networks, high-dimensional stochastic model of an SIS epidemic on a network is approximated by a lower-dimensional surrogate model. The surrogate model is based on a birth-and-death process, the effect of the underlying network is described by a parametric model for the birth rates. The numerical efficiency of their model makes it attractive to be used either as a standalone inference and prediction scheme or in conjunction with other inference and/or predictive models.

(Andriamandimby et al., 2022) used a nested modelling approach, embedding a within-host viral kinetics model within a population-level Susceptible-Exposed-Infectious-Recovered (SEIR) framework to estimate epidemic growth rates from cross-sectional Ct distributions across three regions in Madagascar. Their results show that public reporting of Ct values could offer an important resource for epidemiological inference in low surveillance settings, enabling forecasts of impending incidence peaks in regions with limited case reports.

After the Covid-19 pandemic struck the world, there has been evident increase in the usage of operations research in the area of contagious diseases. . (Pandey et al., 202) focused their study towards finding ways to slow down the growth of covid-19, they developed a transmission dynamical model and studied the effect of various parameters of corona virus through the fractional mathematical model. Their findings show a strong relationship between the contact rate and spreading cases therefore their study confirms the impact of social distancing and lockdowns.(Giordano et al., 2020) proposed a new model on covid-19 pandemic by extending the SIR model, their model distinguishes individuals on the basis of diagnosed and non-diagnosed and predicts that the latter is more engaged in spreading the disease. The model had the following stages of infection susceptible (S), infected (I), diagnosed (D), ailing (A), recognized (R), threatened (T), healed (H) and extinct (E), collectively termed SIDARTHE. The results of the study confirm that social distancing and strict lockdown at the early stages of a pandemic can save lives.

(Young & Chen, 2021) developed two data-based metrics that could be used along with estimation to forecasting better indicators of epidemic growth. The two metrics epidemic rate of change (RC) and a related state-dependent response rate parameter (RP), recursive estimates of which are obtained from dynamic harmonic and dynamic linear regression (DHR and DLR) algorithms. They further suggested a model to estimate the number of deaths in the net 15 days of the pandemic. They also suggest that state-dependent parameter (SDP) modelling procedures may provide data-based insight into a nonlinear differential equation model for epidemics such as COVID-19.

(Xu et al., 2020) proposed 7 mathematical models and also developed 5 new models that supported two waves of infection in a single influenza season. Finally, in order to determine the processes causing two-wave epidemics, they devised a modelling approach. They conducted sensitivity analyses on crucial variables in each model and discovered that lowering the fundamental reproduction number or the transmission rate, restricting the addition of susceptible individuals, and restricting the likelihood of replenishment of individuals who are to be reinfected could lower the number of infection waves and the prevalence of clinical attacks. They also recommended actions aimed at lowering the fundamental reproduction number or transmission rate, limiting the proportion of additional infected persons, and reducing the likelihood of replenishment of those who would be reinfected.

The use of a general System Dynamics infectious disease model to the transmission of a mutant strain of avian influenza from person to person is discussed in the research work by (Hirsch, n.d.). The model gives users the option to determine the rate of new infections over time using either the conventional contagious illness model's set "reproductive number" or contact rates for various subpopulations and chance of transmission per contact. The study discusses the outcomes of several approaches. These findings point to the potential value of contact tracing, constrained quarantine, and targeted vaccination tactics for containing epidemics, particularly in situations where vaccine supplies may be initially few and the effectiveness of antiviral medications questionable.

Extensive research has been done for the management of Malaria using Operations research techniques which can be applied to other diseases as well with a little modification.Thus, this research paper has included valuable insights and learning from articles and previous papers.The path to controlling infectious diseases is challenging owing to the potential for the diseases to adapt and evolve, volatile environmental conditions, an unstable financial landscape and behavioural changes in the target populations. The conditions favouring transmission are varied and diverse to the extent that decisions cannot be made on the basis of a single condition (Silal, 2021a)and that's why use of Mathematical modelling can guide all stages of malaria elimination and obliteration by interpreting information, measuring uncertainty, and inducing current knowledge. In their research paper (Slater et al., 2017), Mathematical models of the dynamics of a drug within the host are used to guide drug development which focuses on assessing the efficacy and duration of response to guide patient therapy. Glycolysis is the main pathway for ATP production in the malaria parasite Plasmodium falciparum and is essential for its survival(Van Niekerk et al., 2016) and mutation rate of *P. falciparum*, it was initially assumed that drug resistance to **chloroquine** and SP had evolved many times independently but genetic data showed that high-grade resistance had in fact evolved only a very small number of times, and then spread. Mathematical modelling was able to reconcile these observations by quantifying bottlenecks for resistant strains, not only during their initial evolution but then during onward transmission(Slater et al., 2017). Furthermore, Differential Equation models were used to study the incidence and spread of disease with an important benefit being the ability to enact exogenous change on the system to predict impact without committing any real resources in Mpumalanga in South Africa (Silal et al., 2014). On the basis of such mathematical modelling, cost-effectiveness and cost-benefit analysis are also formed like in (Winskill et al., 2017), on the cost-effectiveness of RTS s Malaria vaccine in relation to scaling up other malaria interventions in sub-Saharan Africa.

3. Methodology

Literature Collection

The existing literature was searched for and relevant papers were identified using particular keywords on scholarly search engines such as EBSCO HOST, Science Direct, and Google Scholar. The Literature was also scanned by viewing the research papers available on databases such as Elsevier, Emerald, Springer, and Wiley.

Boundary Identification

The search included research papers on "Operations Research and Communicable & Infectious Diseases" during the last 30 years (1992-2022) in order to maintain currency. The research inclusion was limited only to English language full text, and peer-reviewed journal articles. Only the papers that mentioned Operations research methodologies like mathematical modelling or other models and simulations used related to Communicable diseases were included.

Data Extraction

The paper have reviewed research papers that have been published in various journals during the mentioned timeline. During data extraction, some articles were excluded as they did not adhere to inclusion criteria. For the analysis, a RIS. File was made using the Mendeley Reference Manager and it was various analysis results were obtained by Co-authorship and Co-occurrencemaps in Vos Viewer software.

4. Analysis

The results of the analysis done using MS Excel

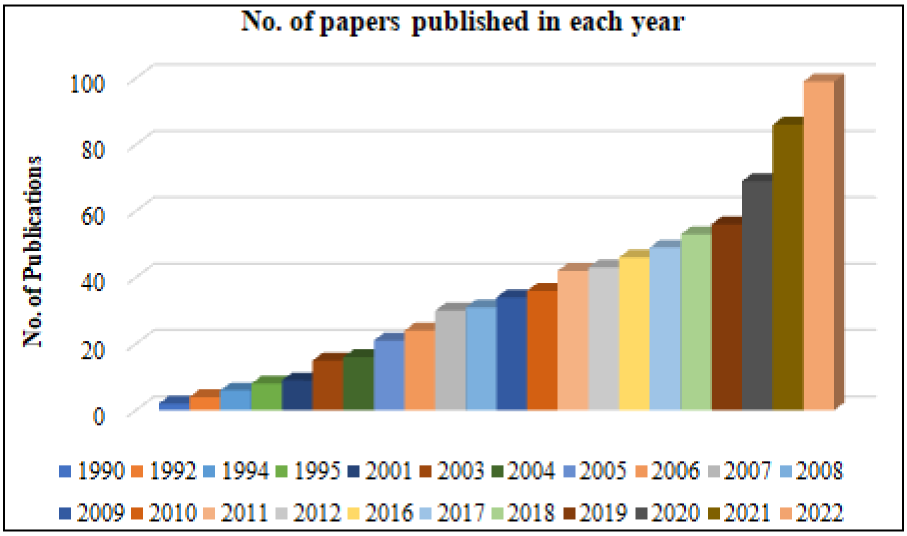


Figure 1

From a sample size of over 100 papers, the bar graph represents a yearly distribution of research paper publications ranging from 1990- the present. It tracks the trajectory of involvement and interest shown in the area of "Infectious diseases". Infectious disease management have started to gain popularity and momentum, as a result, we can see a sharp rise in the number of papers published in the past decade owing to the active interest people have been taking to study management of infectious diseases. Figure 2 shows the percentage of different types of literature such as journal articles, books, etc in the form of a pie chart. Our major focus was directed towards reviewing a lot of research papers as seen from the figure. We also referred to a few books, conference papers, reports, PhD Thesis, etc. to delve deeper into the topic to extract meaningful insights

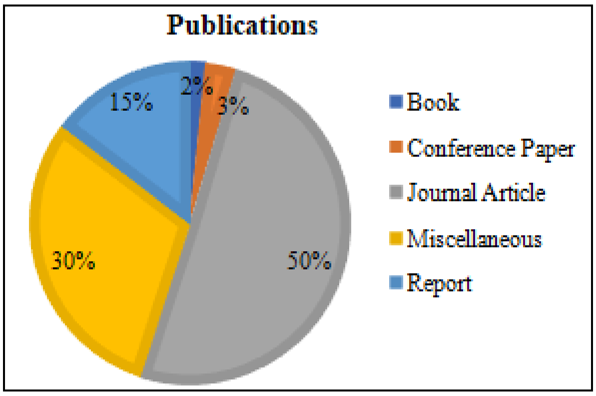
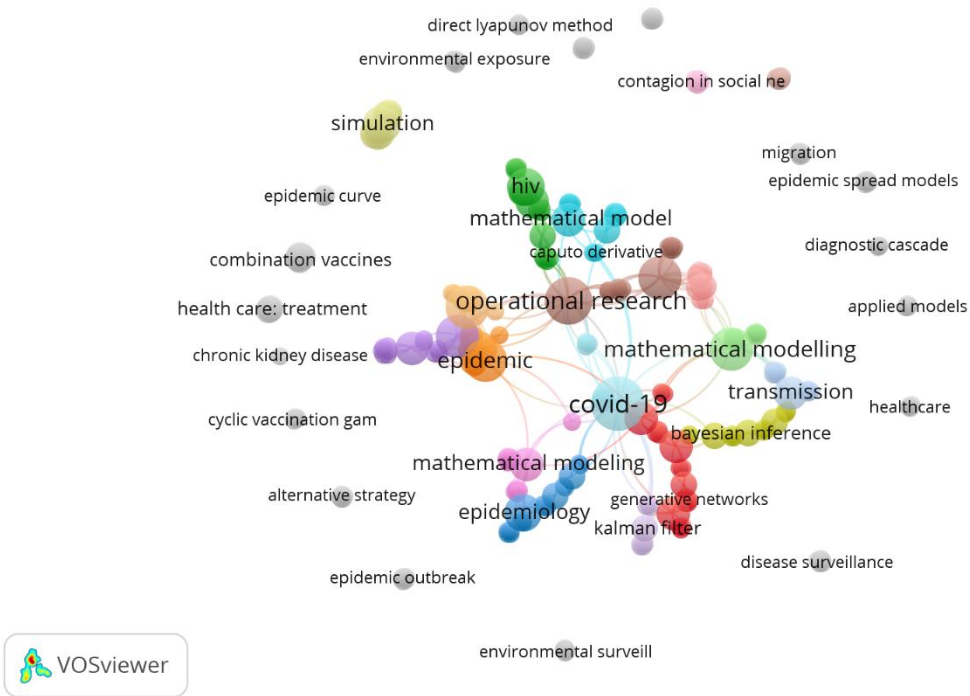


Figure 2

The results of the bibliometric analysis done using Vos Viewer

Co-authorship of the cited references of the selected articles

The publication of research articles on the management of infectious diseases had a total of 571 writers. There are 24 links in all.



Co-occurrence of the cited references of the selected articles

The distribution of the terms repeated most frequently across the papers that were reviewed is depicted in the map of clusters. The terms "mathematical model," "epidemic," "Transmission," and "Covid-19" have been used the most frequently over the years. Most majority papers centre on these terms as their central idea.

5. Conclusion

Operations Research is now being widely used for management of diseases and specifically in case of infectious diseases as infectious diseases have been growing at a very fast pace and they pose a great threat to mankind. In this review paper, we have systematically reviewed the literature present on how to improve and support the management of infectious diseases.

References

[1] Aaby, K., Herrmann, J. W., Jordan, C. S., Treadwell, M., & Wood, K. (2006). Montgomery county's public health service uses operations research to plan emergency mass dispensing and vaccination clinics. *Interfaces*, *36*(6), 569–579. https://doi.org/10.1287/inte.1060.0229

[2] Andriamandimby, S. F., Brook, C. E., Razanajatovo, N., Randriambolamanantsoa, T. H., Rakotondramanga, J. M., Rasambainarivo, F., Raharimanga, V., Razanajatovo, I. M., Mangahasimbola, R., Razafindratsimandresy, R., Randrianarisoa, S., Bernardson, B., Rabarison, J. H., Randrianarisoa, M., Nasolo, F. S., Rabetombosoa, R. M., Ratsimbazafy, A. M., Raharinosy, V., Rabemananjara, A. H., … Dussart, P. (2022). Cross-sectional cycle threshold values reflect epidemic dynamics of COVID-19 in Madagascar. *Epidemics*, *38*. https://doi.org/10.1016/j.epidem.2021.100533

[3] Brandeau, M. L. (n.d.). *7 ALLOCATING RESOURCES TO CONTROL INFECTIOUS DISEASES*.

[4] Davies, R., Roderick, P., & Raftery, J. (2003). The evaluation of disease prevention and treatment using simulation models. *European Journal of Operational Research*, *150*(1), 53–66. https://doi.org/10.1016/S0377-2217(02)00783-X

[5] Durrheim, D. N., Speare, R., &Petzer, M. (n.d.). *Short Communication: Rabies post-exposure management in South Africa: a telephonic survey used as a rapid tool for operational research*.

[6] Giordano, G., Blanchini, F., Bruno, R., Colaneri, P., di Filippo, A., di Matteo, A., &Colaneri, M. (2020). Modelling the COVID-19 epidemic and implementation of population-wide interventions in Italy. *Nature Medicine*, *26*(6), 855–860. https://doi.org/10.1038/s41591-020-0883-7

[7] Haleem, A., Javaid, M., & Vaishya, R. (2020). Effects of COVID-19 pandemic in daily life. *Current Medicine Research and Practice*, *10*(2), 78–79. https://doi.org/10.1016/j.cmrp.2020.03.011

[8] Hirsch, G. B. (n.d.). *A Generic Model of Contagious Disease and Its Application to Human-to-Human Transmission of Avian Influenza*.

[9] *kao2002*. (n.d.).

[10] Knight, J., Baral, S. D., Schwartz, S., Wang, L., Ma, H., Young, K., Hausler, H., & Mishra, S. (2020). Contribution of high risk groups' unmet needs may be underestimated in epidemic models without risk turnover: A mechanistic modelling analysis. *Infectious Disease Modelling*, *5*, 549–562. https://doi.org/10.1016/j.idm.2020.07.004

[11] Lymperopoulos, I. N. (2021). #stayhome to contain Covid-19: Neuro-SIR – Neurodynamical epidemic modeling of infection patterns in social networks. *Expert Systems with Applications*, *165*. https://doi.org/10.1016/j.eswa.2020.113970

[12] Michael, E., Malecela-Lazaro, M. N., &Kazura, J. W. (2007). Epidemiological Modelling for Monitoring and Evaluation of Lymphatic Filariasis Control. In *Advances in Parasitology* (Vol. 65, pp. 191–237). https://doi.org/10.1016/S0065-308X(07)65003-9

[13] Momani, S., Kumar, R., Srivastava, H. M., Kumar, S., & Hadid, S. (2021). A chaos study of fractional SIR epidemic model of childhood diseases. *Results in Physics*, *27*. https://doi.org/10.1016/j.rinp.2021.104422

[14] Morgan-Capner, P. (2005). 12. Mathematical modelling: A key to control of infectious diseases in man and animals. In *Epidemiology and Infection* (Vol. 133, Issue SUPPL. 1). https://doi.org/10.1017/S0950268805004322

[15] Nandi, A. K., & Medal, H. R. (2016). Methods for removing links in a network to minimize the spread of infections. *Computers and Operations Research*, *69*, 10–24. https://doi.org/10.1016/j.cor.2015.11.001

[16] Pandey, P., Chu, Y. M., Gómez-Aguilar, J. F., Jahanshahi, H., & Aly, A. A. (2021). A novel fractional mathematical model of COVID-19 epidemic considering quarantine and latent time. *Results in Physics*, *26*. https://doi.org/10.1016/j.rinp.2021.104286

[17] Roberts, C., & Dangerfield, B. (1990). Modelling the Epidemiological Consequences of HIV Infection and AIDS: A Contribution from Operational Research. In *J. Opl Res. Soc* (Vol. 41, Issue 4). www.jstor.org

[18] Schoch-Spana, M., Ravi, S. J., & Martin, E. K. (2022). Modeling epidemic recovery: An expert elicitation on issues and approaches. *Social Science and Medicine*, *292*. https://doi.org/10.1016/j.socscimed.2021.114554

[19] Silal, S. P. (2021a). Operational research: A multidisciplinary approach for the management of infectious disease in a global context. *European Journal of Operational Research*, *291*(3), 929–934. https://doi.org/10.1016/j.ejor.2020.07.037

[20] Silal, S. P. (2021b). Operational research: A multidisciplinary approach for the management of infectious disease in a global context. *European Journal of Operational Research*, *291*(3), 929–934. https://doi.org/10.1016/j.ejor.2020.07.037

[21] Silal, S. P., Little, F., Barnes, K. I., & White, L. J. (2014). Towards malaria elimination in Mpumalanga, South Africa: A population-level mathematical modelling approach. *Malaria Journal*, *13*(1), 1–12. https://doi.org/10.1186/1475-2875-13-297

[22] Slater, H. C., Okell, L. C., & Ghani, A. C. (2017). Mathematical Modelling to Guide Drug Development for Malaria Elimination. *Trends in Parasitology*, *33*(3), 175–184. https://doi.org/10.1016/j.pt.2016.09.004

[23] Tagliabue, A., Scorza, F. B., Bloom, D. E., &Cadarette, D. (2019). Infectious Disease Threats in the Twenty-First Century: Strengthening the Global Response. *Frontiers in Immunology | Www.Frontiersin.Org*, *1*, 549. https://doi.org/10.3389/fimmu.2019.00549

[24] Thommes, R., & Coates, M. (n.d.). *Epidemiological Modelling of Peer-to-Peer Viruses and Pollution*.

[25] Van Niekerk, D. D., Penkler, G. P., Du Toit, F., &Snoep, J. L. (2016). Targeting glycolysis in the malaria parasite Plasmodium falciparum. *FEBS Journal*, *283*(4), 634–646. https://doi.org/10.1111/febs.13615

[26] Winskill, P., Walker, P. G. T., Griffin, J. T., & Ghani, A. C. (2017). Modelling the cost-effectiveness of introducing the RTS,S malaria vaccine relative to scaling up other malaria interventions in sub-Saharan Africa. *BMJ Global Health*, *2*(1), 1–10. https://doi.org/10.1136/bmjgh-2016-000090

[27] Xu, B., Cai, J., He, D., Chowell, G., & Xu, B. (2020). Mechanistic modelling of multiple waves in an influenza epidemic or pandemic. *Journal of Theoretical Biology*, *486*. https://doi.org/10.1016/j.jtbi.2019.110070

[28] Yaesoubi, R., & Cohen, T. (2011). Generalized Markov models of infectious disease spread: A novel framework for developing dynamic health policies. *European Journal of Operational Research*, *215*(3), 679–687. https://doi.org/10.1016/j.ejor.2011.07.016

[29] Young, P. C., & Chen, F. (2021). Monitoring and forecasting the COVID-19 epidemic in the UK. *Annual Reviews in Control*, *51*, 488–499. https://doi.org/10.1016/j.arcontrol.2021.01.004

[30] Zerenner, T., di Lauro, F., Dashti, M., Berthouze, L., & Kiss, I. Z. (2022). Probabilistic predictions of SIS epidemics on networks based on population-level observations. *Mathematical Biosciences*, 108854. https://doi.org/10.1016/j.mbs.2022.108854

[31] Zhang, J., Mason, J. E., Fitts, E. P., Denton, B. T., &Pierskalla, W. P. (n.d.-a). *Applications of Operations Research to the Prevention, Detection, and Treatment of Disease*.

[32] Zhang, J., Mason, J. E., Fitts, E. P., Denton, B. T., &Pierskalla, W. P. (n.d.-b). *Applications of Operations Research to the Prevention, Detection, and Treatment of Disease*.