Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 14, Issue 01, January 2023: 01-11

Global Infectious Disease Management Using Operational Research: A Multidisciplinary Perspective

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Abstract: Both long-standing and recently-emerging infectious illnesses place a heavy burden on society. Infectious illness control is difficult because of the interdependence of multiple systems (biological, societal, and economic). Operational research can improve health systems by using a variety of problem-solving methodologies and computational methods to back up decision-making at all stages of disease control. This paper highlights areas of chance for operational research to contribute to efficient and effective infectious disease management & improved health outcomes. These areas include: improved understanding of disease biology; intervention planning and implementation; assessing economic feasibility of new strategies; identifying for cost reductions in routine processes; and informing health policy.

Keywords: OR in health services, Infectious disease, HIV, Decision support systems

Introduction:

Infectious diseases were once seen as a major threat to global health, but in the last forty years, because to advancements in health and hygiene, this perception has changed. A few instances of the threat that infectious illnesses still represent to human health and death are the propagation of HIV, TB, and malaria, as well as the recent outbreaks of Ebola as well as the coronavirus disease (COVID-2019) [1]. Despite the fact that many infectious diseases are avoidable and treatable, they still place a heavy cost on public health, especially in places with little resources. In 2016, infectious diseases, complications during childbirth, and nutritional inadequacies accounted for more than half of all deaths in low-income countries, while they accounted for only 7% of deaths in high-income nations [2].

Minimizing the threat presented by infectious diseases takes significant effort and a multidisciplinary strategy to confront the intricate web of interconnected biological, public health, and economic systems around the world. The analytical and qualitative techniques of operational research (OR) make it ideally suited for the task of elucidating the dynamics of infectious diseases and providing support for health policy decisions [3]. The goal of this paper is to give readers an introduction to the ways in which OR technologies have been and can be utilized to address important public health concerns related to infectious disease management. Disease biology, intervention design and implementation, cost-effectiveness, and policymaking are all part of this puzzle. Each of these parts is covered in terms of the OR methods and tools that might be used to implement them, with examples provided where applicable [4]. The purpose of this study is not to provide an exhaustive survey of operational research's role in infectious disease management; rather, it is to provide a summary of the complex system in which operational research might contribute to the international campaign against infectious illnesses.

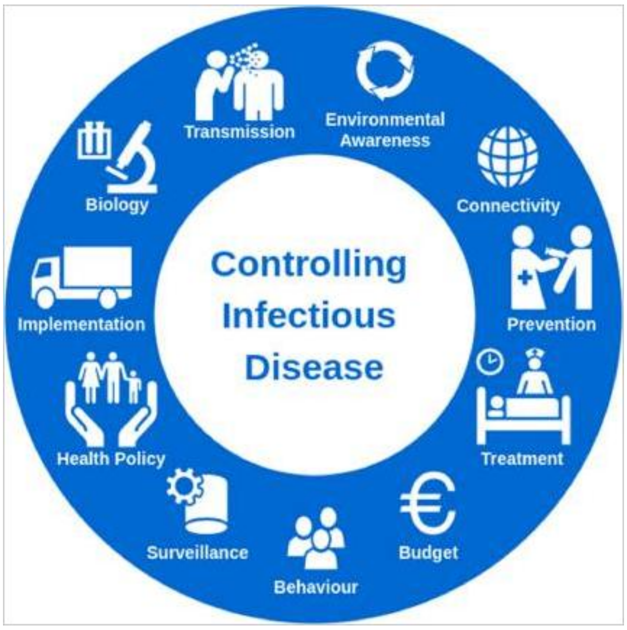

Figure 1: Parts of the system that deal with infectious diseases.

The propensity for infectious illnesses to adapt and evolve, uncertain environmental factors, an unstable financial landscape, and behavioral changes in the target populations all make progress toward managing infectious diseases difficult [5]. Due to the wide variety of favorable transmission conditions, decisions cannot be made based on a single factor alone. The parts of the infectious illness system that must be considered when intervening against disease are outlined in Fig. 1. It's important to have a firm grasp on the disease's biology in terms of its infectiousness, transmission, and susceptibility to the surrounding environment. In the case of malaria, for instance, the

Anopheles mosquito serves as the vector, immunity from the disease can be acquired by reinfection, and the disease's contagiousness shifts in response to changes in precipitation and temperature [6]. It is clear that COVID-19 is just one example of how the interconnectedness of people can cause otherwise localized diseases to become international public health emergencies. The ability to take preventative and responsive actions against disease must be codified into health policy and is subject to the availability of resources (both financial and human) [7]. Country-specific procurement and expenditure rules are woven into the fabric of the health system architecture. The success of interventions depends on their smooth execution and the positive attitudes and actions of the patients involved. This paper will provide an overview of the potential for OR methods to support decision-making across the spectrum of disease control by categorizing the relevant factors into disease biology, intervention development and implementation, financial viability and cost minimization, and health policy, while acknowledging areas of overlap.

Knowledge of the biological mechanisms of disease:

Understanding disease at the cellular, whole-body, and system levels can benefit from operational research. Disease biochemistry can be understood by mechanistic modeling, whereas epidemiological dynamics can be studied using epidemiological simulations. More and more data are becoming available at the cellular level to health systems, allowing operational researchers to better understand the pathogenesis of disease in both individuals and populations. This, in turn, can lead to the creation of more efficient methods of disease prevention and treatment.

When it comes to the growing problem of malaria strains that are resistant to current treatments, operational researchers, for instance, have built mechanistic models to address the issue. Using these models, researchers were able to determine that the glycolosis route is essential for the malaria parasite's survival in the human host, leading to the proposal of multiple pathway inhibitors as potential novel therapeutic targets. The similar strategy has been scaled up to examine the systemic impact of blocking the glycolosis pathway in people with malaria. In order to improve the efficacy of current treatments, similar methods are being applied to better understand the pathogenesis of other infectious diseases, such as HIV and TB [8].

In order to predict the future occurrence of a disease in a population, operational researchers create models (characterized as, for example, dynamic, compartmental, rationalistic, stochastic, mathematical, probabilistic, and epidemiological models) based on a systems level using context-specific epidemiological data. By modifying the models, researchers may examine how shifts in the population or the virus itself might affect the spread of a disease. Using models to estimate the number of infections in a community based on the clinical illness factors that are known from the setting & internationally is helpful in measuring the burden of disease when epidemiological data is lacking. One application of infectious disease forecasting is the development of epidemiological models to foresee the spread of malaria with and without the use of various preventative measures. This method is especially useful in resource-limited contexts since it allows for an exploration of an intervention's impact before it is invested in and rolled out in a population. In addition, operational researchers have been able to simulate the effect of migration on imported malaria cases, a variable for which there is a dearth of data but which is important for policy aimed at eliminating malaria. Infectious disease transmission barriers can also be investigated with mechanistic modeling. For instance, research into identifying super-spreaders has shown the boundary conditions necessary to maintain endemic TB transmission at the community level.

Preparing for and carrying out interventions:

The development and distribution of interventions for infectious diseases have benefited greatly from operational research. The implementation of any intervention for illness management requires careful thought with regards to its efficacy, safety, cost, and equality [9]. Particularly in a population that is varied in terms of individual susceptibilities and in the variability of the pathogen in issue, it is necessary to estimate both direct and indirect impacts when developing a successful intervention. The complexity of these problems is typically best addressed by employing computer simulation approaches, rather than the epidemiological study methodologies that have traditionally been used. Consider the implementation of an HIV prevention program. The disease is complex, and human behavior has a significant impact on its spread, making it difficult to assess the efficacy of any intervention. Complex interventions are well within the scope of operational research's ability to both create and assess. Using a simulation model of STIs, researchers were able to determine that increasing condom use only among high-risk groups would be the most effective strategy, regardless of the sexual behavior patterns of the population at large, in an HIV intervention study designed to figure out the most efficient strategy of scaling up condom use. Except for cohort research designs, this study would be impossible to do. It's unethical to do so, for starters, and the study wouldn't be able to capture the intervention's indirect effect anyhow, what with the intricacy of sex and/or behavior patterns.

Epidemiological studies don't always make it easy to determine which intervention package is best when there are multiple viable options. In order to create the most suitable and efficient package, it may be necessary to combine interventions, which may lead to intricate interactions. Operational research has been widely used, and its results have been applied to both the identification of the most cost-effective intervention combinations and the examination of intervention packages that have shown success in terms of epidemiological outcomes [10]. The relative cost-effectiveness of trying to introduce RTS,S (the only available malaria vaccine presently under trial in a few countries in Africa) in the presence of intervention programs like indoor residual spraying, insecticide treated nets (ITNs), & seasonal malaria chemoprevention was evaluated using models of malaria transmission and non-linear production functions. Based on the results of this research, it is clear that ITNs are the most cost-effective strategy for reducing malaria in sub-Saharan Africa, and that other interventions only become cost-effective once a very high coverage of ITNs is reached. The decision tree models have shown that sputum smear microscopy is more cost-effective than serological tests in India.

It is challenging to estimate the effects of treatments on illness incidence when host heterogeneity (such as variation in immunity levels & pathogen diversity) is present. When working to reduce the number of instances to nearly nothing or eradicate a disease, it is crucial to take host and pathogen heterogeneity into account in the intervention. Some dynamic compartmental models may be able to factor in these differences when estimating the results of a control initiative. By way of illustration, stochastic, non-linear, ordinary differential equations were used to foretell the path to, and cost of, eliminating malaria in 22 nations in the Asia-Pacific area.

Ethical and practical constraints make it necessary to conduct most research into the effects of intervention design in computer simulations. However, this issue is brought to light in outbreak scenarios where effective study design is crucial to limiting the spread of the epidemic. In order to improve trial design, simulation modeling was employed during the 2014–2015 Ebola outbreak in Guinea & Sierra Leone. Hitchings, Grais, and Lipsitch (2017) simulated the desired sample size for vaccination roll-out taking into consideration the non-obvious effects on transmission dynamics, while Bellan et al. (2015) assessed the impact of two vaccine trial designs aimed at health workers [11].

Optimisation techniques have found a position in guiding the selection and implementation of initiatives in contexts with limited internal resources and outside financing. Optimization methods and geographic modeling were used to evaluate two alternative strategies for deploying antiretroviral (ARV)-based microbicides in South Africa. Through optimization, we learned that prioritizing geographical resource allocation and selecting intervention sites are crucial to the success of an ARV-based microbicides intervention in South Africa.

Forecasts & cost breakdowns aren't enough information for stakeholders. In order to feel satisfied, they must be assured that their desired outcomes are being achieved through the treatments. The success of disease prevention and control programs relies heavily on the data collected by surveillance systems. Society now has the ability to conduct real-time surveillance, something that was previously impossible before the widespread use of digital technology. This allows for quick iteration on models and course-correction of errors, as well as accountability and openness to the public. When it comes to answering concerns about the actual implementation of infectious disease interventions, operational research methodologies provide quick and low-cost solutions.

Feasibility from a financial standpoint and cutting costs:

Planning & selecting interventions, informing policy decisions, and optimizing the implementation of new interventions and routine processes all play a role in the management of infectious diseases, and all of them have costs associated with them. Cost-focused studies (for which there is a range of OR and economic evaluation methodologies) should be incorporated into an infectious disease control agenda, especially in the developing world where resources are typically severely limited. By combining cost-effectiveness (or cost-benefit) studies with dynamic compartmental mathematical disease models, researchers can determine if a suggested intervention is financially possible or useful in relation to its predicted impact. The impact and cost-effectiveness of introducing novel vaccinations, the optimal coverage of ITNs for malaria control, and the resource requirements of alternative tuberculosis case-finding methodologies are just a few examples of the many uses of epidemiological-economic models.

OR modeling can also be used to help shape national priorities, spending plans, and other policy considerations at the national level. The estimated price tag for eradicating malaria across all 22 Asia-Pacific countries by 2030 was calculated using a dynamic, multispecies mathematical & economic model. In 2017, the Asia-Pacific Malaria Leaders Alliance commissioned Malaria Elimination, Transmission, and Costing in the Asia-Pacific (METCAP). Modeling eighty scenarios yielded reliable estimates of the optimal coverage and components of malaria elimination packages, as well as the estimated resources needed to achieve them. The studies concluded that the cost-benefit ratio for eliminating malaria in the Asia-Pacific region would be six to one.

While these complex mathematical models are useful for measuring the disease's effects and the cost-effectiveness of proposed remedies, they can be difficult for laypeople to understand and use. One way to increase the usefulness of modeling in informing real-world public health decision-making is to use interactive web-based apps as decision support systems. A user-friendly open-source program was built as part of the METCAP study so that policymakers could do cost and benefit analyses, run scenario analyses, and calibrate the model to local data.

OR not only aids in the selection and design of new interventions, but it also offers strategies for the cost-effective optimization of already-in-place interventions and routine activities. Management choices that aim to minimize expenditures and maximize return on investment can be aided by tools like cost minimization and cost variance analysis. Demand and supply side concerns for optimal resource allocation can be better established with the use of aggregate demand forecasting with census prediction. Decisions at all levels of the healthcare system rely on this information, including those pertaining to staffing, service provision & scheduling, support service planning, and the acquisition of medical equipment and drugs. Effective resource scheduling, which can be informed by operational research methods, can drastically cut operating expenses without compromising the quality or degree of service offered. In order to respond effectively to epidemics & outbreaks, it is essential to maximize the impact of the budget, making the development of models for optimal resource allocation necessary. Overwhelming evidence supports the use of OR studies to determine how best to spend money on fighting disease outbreaks.

Another area where OR techniques might incorporate cost-saving processes and checks is in supply chain optimization, which seeks to maximize drug distribution & availability while minimizing stock-outs and wastage. According to research conducted by Cameron, Ewen, Ross-Degnan, Ball, and Laing (2009), the average percentage of pharmaceuticals available in public sector health institutions in 36 low and middle income countries was between 29.4 and 54.4. So, not only may health outcomes be enhanced, but costs can be reduced, through efficient supply chain and procurement management.

An epidemic places an unexpected and heavy strain on the health care system. Both agent-based modeling and discrete event simulation can be useful tools for capturing and taking into consideration the nuances of a system that needs optimization. One application where this kind of simulation has proven effective is in the distribution of hospital beds. According to Schmidt, Geisler, and Spreckelsen, this can be written down as an assignment issue and then solved as an integer linear program (2013). Bloem (2015) offered a fix by utilizing agent-based models to compare various distribution approaches. By doing so, it provided medical facilities with guidelines for optimum bed allocation. Recognizing that agent-based approaches often necessitate more computational data and power than top-down approaches, and that this was only made possible by advances in technology, we must conclude that they are not appropriate for all national contexts.

Policy formation in the health sector:

The use of OR in the creation of public health policy at all levels of government (international, regional, and national) is on the rise. Priority planning, resource mobilization, scenario analysis, and capability building can all benefit from the insights provided by OR techniques. These enhance our knowledge of diseases, as well as the effects of interventions on populations and their cost-effectiveness.

Quantifying the proportion of a population that will need treatment at a given moment requires knowledge of the current and expected epidemiology of a disease, which is a key component of demand forecasting. Efforts to expand availability of HIV therapy, for instance, have benefited greatly by epidemiological modeling. Findings from demand forecasting research have helped policymakers estimate the number of HIV patients who will require access to antiretrovirals (ARVs), prompting them to mobilize resources to ensure that the required quantity of ARVs exists in the global market, in national supply-chains, and at the local point-of-care. In addition, OR has helped to increase the effectiveness of national supply-chains for delivering care at the point-of-care.

Capacity building in health systems is another area where operational research has proven effective. Disease epidemiology forecasting aids in approximating the human resources and health service capacity required to provide care for patients and in understanding the treatment burden that will likely be placed on a health system. These results are useful for policymakers because they inform the allocation of funds for healthcare workforce development.

When more than one method of disease prevention or control is available, OR has proved helpful in deciding which method, or methods, should be incorporated into national strategic plans. In the case of malaria, where new preventative methods have emerged, OR has been helpful in modeling the expected effectiveness of these interventions in comparison to the standard of care to ensure that resources are used efficiently while still meeting budgetary and equality goals.

Successful implementation depends on the provider and the patient, but priority-setting is rarely effectively answered quantitatively because optimization of treatments is often from the standpoint of policy-makers. Methods from the field of soft OR, such the Strategic Choice Approach, Cognitive Mapping, and Multi-Criteria Decision Analysis (MCDA), provide answers to problems by providing frameworks for incorporating human behavior into decision-making. Researchers in Thailand used MCDA to rank 40 HIV/AIDS interventions based on the priorities established by policymakers, people with HIV/AIDS, and community volunteers. Programs aimed at high-risk populations were given high marks by policymakers, those aimed at young people were given high marks by volunteers, and those living with HIV/AIDS were given equal marks for all interventions.

Recently, OR has become an essential component of public health resource requests to external donor organizations. The Global Fund to Fight AIDS, Tuberculosis, and Malaria, for instance, encourages and frequently solicits epidemiological modeling, costing, and optimization to give target countries with data about which treatments and service delivery models may have the most impact. The Global Fund calls operational research (OR) the "science of better" since it improves the use of donor dollars by pinpointing problems with program quality, efficiency, and effectiveness.

Discussion:

In this study, we've looked at how OR can be used to aid in the management of infectious diseases by shedding light on their biology, guiding the development and implementation of therapies, gauging their cost-effectiveness, and shaping health policy. However, connecting research with policy or practice is crucial if its results are to have the greatest possible impact. Three important criteria that can aid in the successful translation of research are discussed by Bradley et al. (2017). During the initial, the model design and validation phases, it is important to involve key stakeholders and decision-makers. Involving stakeholders from across the health system, such as clinicians, management professionals, and patients, is essential for a comprehensive approach that promotes ownership, prioritizes questions with policy relevance, identifies appropriate methodology, & integrates local knowledge when applying OR to infectious disease management. The second is collecting data that is indicative of the situation, which yields conclusions that can be used in practice. Third, making sure the right people hear about your research is a top priority. In order to do so, it is essential to share research results with stakeholders outside of the academic community. Effective, non-technical communication of modeling processes and results can be facilitated by user-friendly interfaces with visual simulation environments.

Opportunities exist for OR to help enhance infectious disease program implementation in low and middle-income countries, but there are also certain obstacles to overcome. Hard OR approaches may be hampered by factors such as a lack of data, ineffective monitoring systems, and limited computational resources. Soft OR approaches may be helpful in this situation if there is a lack of data. International guidelines, such as those issued by the World Health Organization, can be used as a basis for developing mathematical models and simulations. Using these standards as a yardstick, Balawanth et al. (2019) conduct a comprehensive evaluation of the province of KwaZulu-(South Natal's Africa) efforts to eradicate malaria. Due to the weakness of national health research systems, a further obstacle is the absence of an enabling research policy framework. According to a recent analysis of 44 African countries, only 36% had a functioning national health research governance framework, and only 20% had a functioning national health research management forum. Its widespread adoption can be facilitated by creating permissive regulatory climates and bolstering organizational and management capabilities in the healthcare system.

Novel human diseases are always a potential threat to public health around the world. As 2019 drew to a close, Wuhan, a city in China's Hubei Province, saw the emergence of COVID-19. After a month, the World Health Organization classified the epidemic as a global health crisis. Scientists and experts from all across the world get together at times like these to investigate and combat the disease. Several researchers have estimated the impact of imposed restrictions including travel bans and social distance, combined with quarantining & active contact tracing. These methods were used in dynamic disease modelling performed by operational researchers to assess the spread of the epidemic. One of the most urgent problems nowadays is the spread of infectious illnesses. By delivering strong, evidence-based insights, the field of operational research can provide a cross-disciplinary contribution to the control of infectious illnesses, helping to shape local and international public health policies.

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