

Informatics-Based Optimization of Vaccination Strategies Through Mathematical Simulation

Mohanad Mohammed Sufyan Ghaleb^{1*}, Anvar Absamatov²

¹ Department of Management, School of Business, King Faisal University, Al-Ahsa 31982, Saudi Arabia; ² Department of Economics, Termez University of Economics and Service, Uzbekistan

ABSTRACT

Purpose: The purpose of this study was to examine how epidemiological factors, vaccination parameters, and informatics infrastructure collectively shape the effectiveness of optimized vaccination strategies through an informatics-based simulation perspective. The study aimed to integrate these three domains into a unified framework to understand their combined influence on vaccination outcomes. **Method:** A quantitative, cross-sectional survey design was employed, and data were collected from 157 respondents with knowledge of public health and vaccination processes. A structured questionnaire measured epidemiological factors, vaccination parameters, informatics infrastructure, and strategy effectiveness. Data were analyzed using SPSS, employing descriptive statistics, chi-square tests, and regression analysis to identify significant relationships among variables. **Findings:** Results showed that epidemiological factors (infection rate, recovery rate, transmission dynamics), vaccination parameters (efficacy, rate, coverage), and informatics infrastructure (data integration, system efficiency, real-time access) were all significantly associated with vaccination strategy effectiveness. Regression findings confirmed all three dimensions as strong predictors, demonstrating their combined influence on improved coverage, infection reduction, and resource efficiency. **Originality/Implications:** This study provides a novel, integrated framework linking epidemiological, operational, and informatics dimensions to vaccination strategy optimization. The findings highlight the importance of real-time data systems and simulation-based planning for improving vaccination outcomes and strengthening public health preparedness.

ARTICLE HISTORY

Received September 07, 2025

Accepted November 24, 2025

KEYWORDS

Epidemiological Factors,
Vaccination Parameters,
Informatics Infrastructure,
Optimization Strategies,
Public Health Simulation

1. Introduction

The infectious diseases remain to be a severe health threat in the whole world due to their dynamic spread and mutation possibility, as well as socio-environmental determinants. COVID-19 and measles revitalizations, as well as new diseases transmitted by vectors, have shown the speed with which the health care system can be overwhelmed in case of a lack of timely preventive measures or fragmented coordination (Rahmadhan & Handayani, 2023). Vaccination has remained to be one of the most effective tools to control the transmission of infectious diseases as well as to minimize the morbidity and mortality as well as to provide immunity to the community (Zhao et al., 2023). Yet, the effectiveness of vaccines on the population level can be defined not only on the basis of the biological efficacy, but also on the basis of the well-designed vaccination strategies, which will take into account the rate of infections, the rate of recovery, patterns of susceptibility, and mobility (Anderson et al., 2025). With the increasing complexity of disease transmission, there is an increasing demand to optimize vaccination strategies with the opportunity to dynamically adjust them to the changing epidemiological realities.

Changes in the design and implementation of the decisions made in regard to the public health have been transformed by the development of the mathematical modeling, the computational epidemiology and health informatics (Sarigol et al., 2023). Simulations of what-if scenarios, projection of the dynamics of an outbreak, and evaluation of the plans of vaccination can be conducted with the aid of mathematical simulations, without revealing the actual effects (Habibi et al., 2023). Combining real-time information, automated dashboards, and predictive analytics with the assistance of informatics, it is possible to identify the high-risk population in a short time, allocate resources more efficiently, and make human decisions in case of outbreaks (Vigezzi et al., 2025). Such evidence-based information provided by such simulations cannot be compared to the traditional policymaking, especially when there is a need to act urgently, and the dynamic change is needed

(Vigazzi et al., 2025). The transition of the global health systems to accuracy public health necessitates informatics-oriented simulations models to become an indivisible component of the methods of the development of the vaccination plans that will be able to maximize the coverage, decrease the burden of diseases, and utilize the resources to the maximum (González-Sánchez et al., 2024).

Though there have been tremendous advances in the development of vaccines, the world health systems are still challenged to develop the best and timely vaccination plans, particularly during the fast changing outbreaks of infectious diseases (Jing et al., 2025). Conventional methods of planning vaccinations are mostly inertial, basing on established schedules, past trends of diseases, or high level generalization (Luebben et al., 2023). Such approaches do not have the flexibility necessary to respond to the emergence of abrupt changes in the quantity of transmission, the population susceptibility, or the behavior of pathogens (Martinez et al., 2025). Additionally, traditional planning does not usually take into consideration such important epidemiological variables as the rate of infection, the rate of recovery, and the real-time transmission, which leads to tardiness in formulating classes of risk groups, unfounded distribution of vaccine resources, and uneven distribution of vaccinations (Griggs et al., 2024). Lacking the dynamism to target the current epidemiological trends to the decision-making processes leaves openings through which the outbreaks can grow before effective interventions can be put in place (Geubbels et al., 2023). Such a gap demonstrates the shortcomings of the non-data-driven traditional vaccination systems to deal with contemporary threats of infectious diseases.

Concurrently, there has not been exhaustive utilization of the growing access to health data, electronic records and real time surveillance systems to improve vaccination planning. Numerous public health agencies still have their infrastructures in informatics, limited integration of data, inadequate system interoperability and slow information flow, between epidemiological surveillance departments and vaccination programs (Jaggers & Wolfson, 2023). Consequently, predictive analytics, scenario forecasting, and in-time optimization of vaccination are not fully used (Abi & Adetunji, 2023). The decision-makers cannot model various vaccination policies, compare the options that are resource-intensive, and predict the effects of different vaccination parameters including vaccine efficacy, distribution rate, and population uptake without the strong support of informatics (Gomase et al., 2025). This does not link available data to actionable decision-making which does not allow health systems to transition into proactive and adaptive approaches to vaccination (Mzili et al., 2024). Thus, it is urgently required that an informatics-improved system of simulation is developed to consider epidemiological factors, vaccination parameters, and informatics infrastructure to create evidence-based, optimized vaccination strategies capable of keeping up with the dynamic nature of infectious disease outbreaks.

This research aims to investigate the impact that epidemiological elements (infection rate, recovery rate, transmission dynamics), vaccination parameters (vaccine efficacy, coverage, and distribution rate) and information infrastructure (data integration, system efficiency, real-time accessibility) have on the success of the most effective vaccination strategies. Through the creation of a simulation-driven analysis method, the research will deduce which combinations of these variables result to the most effective vaccination results and how informatics-improved models can augment most adaptive and efficient planning.

2. Literature Review

2.1 Epidemiological Factors

Epidemiological parameters especially infection rate and recovery rate are the basic parameters which determine the outbreak and maintenance of infectious diseases. The rate of infection (β) is the rate at which individuals become infected when they become exposed and it is directly proportional to the strength of an epidemic wave (Griggs et al., 2024). During the high β , the disease spreads rapidly in the population where the social contact is large, the mobility is high, or the protective behaviors are low (Geubbels et al., 2023). Recovery rate, in turn, is a measure of the mean infectiousness period; a larger gamma suggests faster recovery and less time period of contagiousness of individuals (Jaggers & Wolfson, 2023). The interaction between β and γ dictates the basic reproduction number which is a threshold measure used to forecast the possibility of an outbreak (Li et al., 2023). The modern studies emphasize that accurate estimation of these parameters is required to make real-time intervention, predict the peaks of epidemics, and develop timely vaccination plans (Organization, 2023). With the evolution of epidemics, β and γ change as a result of the changes in behavior, viral mutation, and environmental conditions, which supports the need to use dynamic modeling techniques that can be capable of capturing their complexity.

The epidemiological parameters are typically considered in SIR (Susceptible Infectious Recovery) and SEIR (Susceptible Exposed Infectious Recovery) models that are the cornerstone of the mathematical epidemiology (Jaggers & Wolfson, 2023). SIR model represents a simple but effective framework to study the development of an illness whereas SEIR model adds an exposed stage, which explains latent infections, and is more appropriate to study diseases with an

incubation period, like COVID-19, influenza, or SARS (Liu et al., 2023). They are common models that are utilized to simulate hypothetical vaccination strategies, simulate the trajectory of epidemics, and the effect of different epidemiological conditions on population health (Huerne et al., 2023). It is repeatedly shown in the literature that the β , γ and population mixing patterns added to SIR/SEIR simulations enhance the precision of the predictions concerning the infection peaks, outbreak duration and hotspots of transmission (Pasin & Gonenc, 2023). Moreover, transmission dynamics studies indicate that high-risk groups, including healthcare workers, older age groups, or those with a large social network, contribute to the continuation of the spread of the disease disproportionately (Kambali et al., 2023). Knowledge about these transmission pathways will enable such planners in the public health to focus on vaccinating people most likely to increase the outbreaks eventually increasing the overall output of immunization efforts.

2.2 Vaccination Parameters

The parameters of vaccination, such as the vaccine efficacy, vaccine rate and the population coverage are decisive factors influencing the performance of immunization program and its capacity to put down epidemics (Martinez et al., 2025). Vaccine efficacy is used to measure the proportional decrease in disease incidence of vaccinated individuals and directly affects the ability of a vaccine to interrupt disease transmission (Rahmadhan & Handayani, 2023). Infection diseases: The studies in different infectious diseases show that an increased efficacy of vaccination decreases the number of infections, increases herd immunity, and decreases the total number of diseases (Zhao et al., 2023). The performance of vaccines in the real world is, however, affected not just on biological efficacy but also on host immune response, maintenance of cold-chain, and the time of administration (Geubbels et al., 2023). Studies also indicate that high vaccination coverage and rapid rollout of even moderately effective vaccines can be used to generate significant effects on the population (Klausen et al., 2024). With the development of the pathogens and the appearance of new forms, it becomes even more important to estimate the efficacy of vaccines in changing conditions, which strengthens the relevance of the use of simulations-based methods that can be used to assess a variety of possible scenarios (Mzili et al., 2024).

Besides efficacy, the rate of vaccination and population coverage determines the ability of a community to attain herd immunity and prevent the long-lasting transmission. The vaccination rate demonstrates how fast the vaccines are introduced, distributed, and accepted by the population (Kambali et al., 2023). High vaccination coverage can change the shape of epidemics dramatically as the number of vulnerable members can be lowered before the rapid progression of the disease (Luebben et al., 2023). Meanwhile, population coverage is the percentage of the population that is immunized and becomes covered, which contributes to the general susceptibility situation. Studies have always shown that under coverage causes gaps in immunization and thus outbreaks continue to occur among the partially vaccinated population (Kambali et al., 2023). These lapses may be caused by logistics or misinformation, vaccine hesitancy or unequal access to healthcare resources. The results of simulation research demonstrate that combinations of high efficacy, high rates of vaccination, and extensive coverage cause a great flattening of epidemic curves, decreased hospitalization rates, and decreased the period of outbreaks (González-Sánchez et al., 2024). Therefore, the combination of vaccination parameters will determine the direction of epidemic development and are a critical input to any mathematical or informatics-based optimization model that aims at planning an effective vaccination strategy.

2.3 Informatics Infrastructure

The use of health informatics systems has become increasingly significant in the optimization of vaccination programs due to the possibility of quick information exchange, decision-making during the entire process based on the data, and the ability of the public health to coordinate their actions (Jing et al., 2025). Health information systems (HIS) have been noted in literature to play a significant role in the consolidation of epidemiological data, vaccination inventory monitoring, adverse event monitoring and vaccination logistics in various healthcare environments (Abi & Adetunji, 2023). State-of-the-art HIS systems enhance interoperability among hospitals, labs, and health authorities to share data quite easily to improve situational awareness in case of an outbreak. They can also assist in the implementation of digital registries, automated reminders, and dose-tracking systems that will ensure that people vaccinate in time and improve immunization adherence (Malik et al., 2025). Studies show as well that a well-developed informatics infrastructure results in greater transparency, trust in people as well as building the national immunization plans by providing real-time reporting and surveillance (Abi & Adetunji, 2023; Gomase et al., 2025; Mzili et al., 2024). As far as precision public health with health systems is a switched phenomenon, informatics platforms provide the nucleus of predictive modeling, risk stratification, and tailored vaccination interventions to be more efficient in contrast to the traditional manual planning systems (Gomase et al., 2025).

Integration of data, real-time accessibility, and systematic efficiency are the main evidence-based optimization of vaccination strategy facilitators. By combining data in a single platform, a data system containing epidemiological surveillance data, demographic data, geospatial analytics, and vaccination records will provide planners with high-risk areas and low-coverage populations and hotspots (Abdul et al., 2024). The availability of real-time data that can be provided by the use of digital dashboards, mobile-based reporting, and automated collection system allows the authorities in the field

of the health of the population to respond to changes in the dynamics of the disease, accessibility to the vaccination, and gaps in the coverage in a timely manner (Sarfraz et al., 2023). Systems efficiency- in terms of processing speed, ease of use as well as scalability will enable timely decision-making through reduced delays in data interpretation and model execution (Vigazzi et al., 2025). Such digital technologies as predictive modeling software, machine learning models, and automated surveillance technologies, can become valuable during the enhancement of accuracy and precision in the action of planning the vaccinations and control of future outbreaks and simulation of the most efficient intervention plans (Mahdavamanshadi et al., 2024). Dashboards and visualization tools provide easy-to-understand views of epidemic dynamics, allowing policymakers to make comparisons and recognition of resources (Li et al., 2024). Taken together, the literature suggests that the informatics infrastructure is no longer a supplement, but is crucial in the design of adaptable, effective strategies of vaccination in the intricate public health settings.

2.4 Optimized Vaccination Strategy Effectiveness

The success of efficient vaccination plans is usually evaluated using such indicators as vaccination coverage, infection prevention, and resource utilization (Sarigol et al., 2023). Vaccination coverage measures the number of individuals that have gotten their proper vaccination and is an indicator of coverage and access of vaccine programs (Eshkiti et al., 2023). Close to the effect of better coverage level of herd immunity is a decrease in disease rates and reduction in the risk of outbreaks (González-Sánchez et al., 2024). Infection reduction is another crucial step, which examines the effect of the measures of vaccination in increasing the transmission rates and reducing the epidemic curve and severe outcomes (Habibi et al., 2023). Mathematical simulations of optimized strategies have demonstrated that they have high chances of reducing peak infections, reducing the duration of the epidemic, and reducing cumulative morbidity and mortality (Mahdavamanshadi et al., 2024). Resource efficiency is also crucial to the practicality and sustainability of the strategies employed to vaccinate against the disease and includes: (1) vaccine allocation; (2) distribution logistics; (3) cost-effectiveness; and (4) use of health workforce. As pointed out in the literature, good strategies will reduce the wastages, reduce the operating costs and fair allocation across the regions and risk groups (Kohneh et al., 2023). Put together, these indicators give a complete gauge of the efficacy of a vaccination policy on epidemiological conditions in the real or simulated world.

Despite the fact that the modeling and evaluation techniques were enhanced, much information remains lacking in literature particularly the integration of the informatics infrastructure in the vaccination optimization models (Dey et al., 2024). The majority of the past investigations were founded on fixed or deterministic models but could not cope with actual time data utilizing fixed parameters (Liu et al., 2024). Such types of models were likely to overlook the contributions of digital systems, data integration, and information flows, which limited its predictive abilities under actual circumstances of fast changing epidemiological situations (Sarigol et al., 2023). Most of the classical methods studied epidemiological or vaccination variables separately without considering the factor of health informatics as a mediating or facilitating aspect (Abdin et al., 2023). These models are not reflective of the complexities of current public health management without the inclusion of state-of-the-art surveillance systems, predictive analytics, and real-time dashboards (Habibi et al., 2023). The latest literature suggests more extensive systems that integrate epidemiological modeling with decision support systems based on information. Nevertheless, there is still a scarcity of empirical studies and simulation studies where informatics infrastructures are integrated to assess the effectiveness of vaccination (González-Sánchez et al., 2024; Kohneh et al., 2023; Liu et al., 2024). This gap highlights the necessity of a study that builds and evaluates informatics-enhanced simulation models that have the potential to enhance the vaccination coverage, decrease infections, and optimize the resource utilization in dynamic outbreak settings.

2.5 Research Gap and Conceptual Framework

Despite the fact that the current literature offers sufficient information about epidemiological factors, the parameters of vaccination, and the increased influence of informatics systems, the gap in the literature is rather high in the sense that the literature does not offer a single approach on how to combine all dimensions into a single framework in order to optimize vaccination strategies (Luebben et al., 2023). The vast majority of epidemiological studies concentrate on the infection rate and recovery rate and the dynamics of transmission but in most cases study them separately or in classical SIR /SEIR models based on frozen assumptions (Pasin & Gonenc, 2023). Likewise, the studies surrounding vaccination have widely investigated the efficiency of vaccines, the vaccination coverage, and the population coverage, however, most models do not pursue the real-time epidemiological adjustments and adapt to the dynamic disease trends (Gawande et al., 2025). In the meantime, research on health informatics also points to the role of data integration, real-time analytics, and system efficiency, although in practice this research is more about surveillance or reporting, and does not involve using informatics as an active force behind optimizing vaccinations (Oname et al., 2024). Due to this, the current models will simplify the complexities of the real world because of disregard of the interaction of epidemiological conditions, vaccination

parameters, and informatics infrastructure that influence vaccination performance (Garcia-Carretero et al., 2023; Gawande et al., 2025). Such a fragmented strategy constrains predictability, flexibility, and tactical usefulness of vaccination planning, particularly in the case of an outbreak that is evolving at a pace that is rapidly changing.

In order to close this gap, the current study introduces an exhaustive conceptual model to be used to determine the efficiency of optimized vaccination practices using the integrated approach of epidemiological factors, the parameters of vaccination, and the informatics infrastructure (Martinez et al., 2025). The framework frames epidemiological variables, including infection rate, recovery rate, and the dynamics of transmission, as a conceptual framework (Figure 1) of determinants of the spread of diseases on which the urgency and targeting of vaccination actions are based (Geubbels et al., 2023). Vaccination parameters such as the vaccine efficacy, coverage and administration rates are placed as direct operating factors that determine the success of immunization, and define the epidemic curves. Informatics infrastructure serves as an enabling layer reinforcing data-driven decision-making with real-time analytics, integrated monitoring, and efficiency of the system (Zhao et al., 2023). The model helps to understand that the effect of optimized vaccination strategies is achieved through the combination of the biological, operational, and technological parts instead of one of them (Kambali et al., 2023). This holistic view gives a more practical and realistic insight into how informatics-enhanced simulated methods can be used to optimize vaccination programs, which gives a powerful methodological and conceptual improvement to the old models (González-Sánchez et al., 2024; Rahmadhan & Handayani, 2023). The framework can also be used to close gaps that exist in the existing research and can also be used to inform empirical studies on the effectiveness of data-driven simulations to improve the outcomes of vaccination in a complicated public health setting.

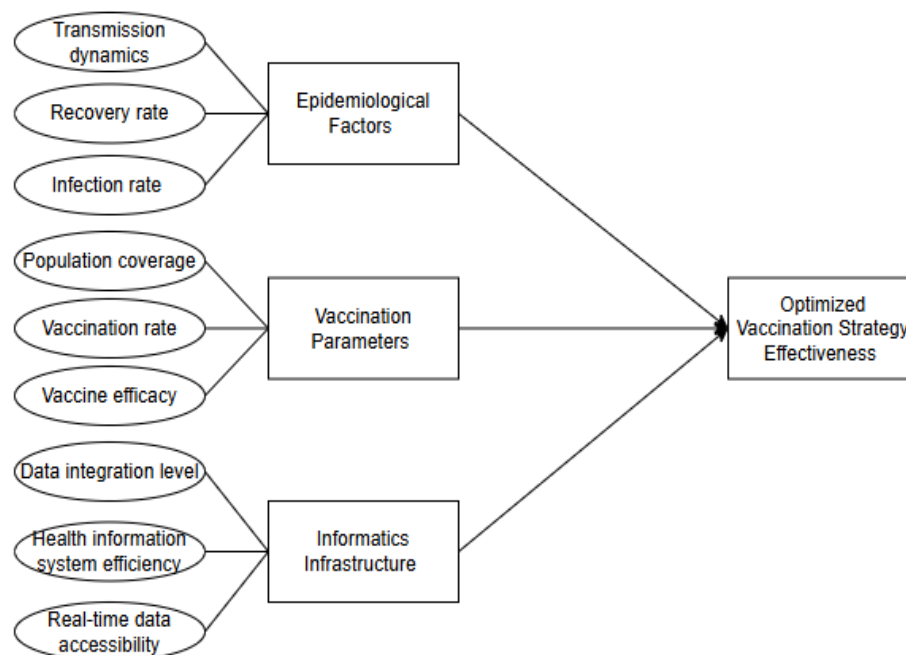


Figure 1: Conceptual Framework

3. Methodology

The research design used in the present study was a quantitative and cross-sectional one to investigate the relationship in the potential of epidemiological factors, vaccination parameters, and informatics infrastructure in the effectiveness of optimized vaccination strategies. An operationalized but conceptual model of simulation was created and operationalized with a set of measurable variables, which were captured with the help of a structured questionnaire. The design enabled the systematic evaluation of the relationships between the study constructs as well as give the empirical ground to assess the conceptual framework based on the literature. The cross-sectional methodology was quite appropriate due to the aim to examine the perceptions of respondents at one point in time concerning the factors that affected the optimization of the vaccination strategy. The study population was the population that has some knowledge or experience of vaccination initiatives, processes in public health, or digital health systems. Out of this population, 157 respondents were chosen using a convenience method. The research design was suitable because the study was exploratory and respondents were accessible in the public health settings. The sample size was acceptable since it approximated the required minimum size of the sample to be used in conducting multivariate statistics; hence, sufficient power to perform descriptive and inferential tests in SPSS. The structured questionnaire was used to collect data that would assess the core constructs of

the study including epidemiological factors, parameters of vaccination, informatics infrastructure, and optimized vaccination strategy. All of the constructs were operationalized using categorical items as per the goal of the study to model the interaction between variables using measurable variables. The questionnaire had demographic questions, the question of infection rate, recovery rate, and transmission patterns, the question of vaccine efficacy, coverage and distribution rate and the question of data integration, system efficiency and the access to real time information. The last evaluation was the perceived effectiveness of the vaccination strategies on improving coverage, reducing infection, and efficiency of resources. The survey used was a self-administered form which was given out physically and electronically as they were considered to have different accessibility requirements. Prior to the data collection process, the respondents were notified about the purpose of the research and given consent to take part. The surveys were filled in a span of two weeks and analysis was done after the responses had been filtered on completeness.

Analysis of the data took place in Statistical Package of the social Sciences (SPSS) version 26. Data cleaning and coding of all categorical variables were the starting point to the analysis. The demographic characteristics and the important variables were summarized in terms of descriptive statistics such as frequencies, percentages, and cross tabulations. Reliability analysis was also carried on in a bid to determine internal consistency of the multi-item constructs where applicable using Cronbach Alpha. To assess the presence of associations between epidemiological variables, vaccination parameters, informatics infrastructure, and optimal effectiveness of vaccination strategy, inferential statistical methods, such as chi-square tests, correlation analysis, and regression modeling were used. Such analyses enabled the study to determine important predictors as well as to establish the degree to which each variable was important in strategy optimization. The SPSS results were then analyzed according to the conceptual framework and made conclusions regarding the role of the use of integrated informatics-based simulation in planning vaccination. The research has been conducted in line with the ethical considerations in all phases of the research. Participation was voluntary, informed consent was gotten to all respondents and the confidentiality was observed by ensuring that all identifying data were not recorded or disclosed. Any information was safely archived and was not exploited in any way other than academic research.

4. Results

Table 1 shows the demographic traits of the 157 respondents, who participated in the study. Regarding the gender variable, most of the respondents were male (56.7%, $n = 89$), after which the female respondents were in the percentage of 40.1 ($n = 63$) with a small percentage of 3.2 ($n = 5$), representing other gender. Regarding the age group variable, the respondents were predominantly between 26–35 age bracket (37.6% and 59), and then the 18–25-year age group (26.1% and 41). The percentages of respondents aged 36 to 45 (21.0 $n=33$), 46 to 55 (10.8 $n=17$) and a marginal percentage (4.5 $n=7$) were 36 to 45, 46 to 55 and 56 and above respectively. The variable of the education level shows that 49.7 percent ($n = 78$) of the respondents possessed a bachelor degree, 33.1 percent ($n = 52$) possessed a master's degree, 12.1 percent ($n = 19$) possessed the intermediate level and 5.1 percent ($n = 8$) possessed other educational qualifications. These descriptive results demonstrate that the sample is heterogeneous with respect to gender, age groups, and education levels, which justifies the quality of the perceptions that have been obtained within the various demographic groups.

Table 1: Demographic Characteristics of Respondents

Variable	Categories	Frequency (n)	Percentage (%)
Gender	Male	89	56.7%
	Female	63	40.1%
	Other	5	3.2%
Age Group	18–25	41	26.1%
	26–35	59	37.6%
	36–45	33	21.0%
	46–55	17	10.8%
	56+	7	4.5%
Education Level	Intermediate	19	12.1%
	Bachelor's	78	49.7%
	Master's	52	33.1%
	Other	8	5.1%

Table 2 gives the frequency distribution of epidemiological factor variables: infection rate (β), recovery rate (γ), and dynamics of transmission. On the variable infection rate (β), a high infection rate was observed ($n=64$) with 40.8% respondents, the moderate rate was stated ($n=61$) and the low rate was stated ($n=32$). On the variable of the recovery rate (γ), the biggest percentage (43.9, $n = 69$) of the respondents felt that recovery rate was moderate, with 28.7 ($n = 45$) considering the recovery rate to be slow and 27.4 ($n = 43$) considering the recovery rate to be fast. On the transmission dynamics variable, 45.2% ($n=71$) of the respondents had indicated that the transmission of the disease was on the rise,

36.9% (n=58) of the respondents had indicated that the disease was spreading so fast, whereas 17.8% (n=28) respondents had indicated that the disease was not spreading. All these findings indicate a common pattern among the respondents that the epidemiological situation was mostly moderate-to-high-risk, and the pattern of increasing or fast spreading transmission was most prevalent.

Table 2: Frequencies of Epidemiological Factors

Variable	Categories	Frequency	Percentage
Infection Rate (β)	Low	32	20.4%
	Moderate	61	38.9%
	High	64	40.8%
Recovery Rate (γ)	Slow	45	28.7%
	Moderate	69	43.9%
	Fast	43	27.4%
Transmission Dynamics	Stable	28	17.8%
	Increasing	71	45.2%
	Rapid Spread	58	36.9%

Table 3 presents a summary of the variables of the vaccination parameters, which are vaccine efficacy, vaccination rate and population coverage. Regarding the variable vaccine efficacy, almost half of the respondents (45.9, n = 72) perceived vaccine efficacy as high, 35.7% of them (n = 56) perceived vaccine efficacy as moderate and 18.5% (n = 29) perceived it as low. In terms of the variable of vaccination rate, the answers showed that the respondents perceived the rate to be fast (40.8%, n = 64), moderate (37.6%, n = 59), and slow (21.7%, n = 34). The variable population coverage indicated that there were equal number of respondents (39.5, n = 62 each) that reported 50-75 percent coverage and above 75 percent coverage, and 21.0 (n=33) individuals who reported coverage less than 50 percent. These results show that the respondents tended to view the vaccination conditions as moderately strong, with rather high rates of efficacy, speed of delivery, and population coverage.

Table 3: Frequencies of Vaccination Parameters

Variable	Categories	Frequency	Percentage
Vaccine Efficacy	Low	29	18.5%
	Moderate	56	35.7%
	High	72	45.9%
Vaccination Rate	Slow	34	21.7%
	Moderate	59	37.6%
	Fast	64	40.8%
Population Coverage	<50%	33	21.0%
	50–75%	62	39.5%
	>75%	62	39.5%

The frequency distribution of the informatics infrastructure variables, namely data integration, system efficiency, and real-time data access, is given in Table 4. Regarding the variable data integration, 43.3% (n = 68) respondents gave high scores of integrations, 40.1% (n = 63), based on their perceptions, rated integration as moderate and 16.6% (n = 26) rated integration as low. In the system efficiency variable, the findings indicate that 43.9% (n = 69) respondents believed the system to be very efficient, 36.3% (n = 57) believed the system was moderately efficient and 19.7 percent (n = 31) believed the system was not efficient. The real-time data access variable had shown that almost half of the respondents (48.4%, n = 76) had complete access to the data access which was real-time and 36.9 percent (n = 58) was moderate while 14.6 percent (n = 23) was limited. Such results imply a high level of perceived informatics capacity, high levels of real-time accessibility, and high levels of system efficiency have a positive effect on the potential to make better decisions.

Table 4: Frequencies of Informatics Infrastructure

Variable	Categories	Frequency	Percentage
Data Integration	Low	26	16.6%
	Moderate	63	40.1%
	High	68	43.3%
System Efficiency	Poor	31	19.7%
	Moderate	57	36.3%
	Strong	69	43.9%
Real-Time Data Access	Limited	23	14.6%
	Moderate	58	36.9%
	Fully Real-Time	76	48.4%

Table 5 shows the responses of the optimized indicators of the effectiveness of vaccination strategy, such as improvement in vaccination coverage, reduction in infections, and efficiency of resources. Under the vaccination coverage

improvement variable, 43.3 percent ($n = 68$) of the respondents responded that they have improved moderately, closely 42.7 percent ($n = 67$) respondents indicated that they have improved highly and 14.0 percent ($n = 22$) indicated that they have not improved at all. The variable of infection reduction showed that almost half of the respondents (47.8, $n = 75$) perceived infection reduction to be high, 38.9% ($n = 61$) perceived to be moderate, and 13.4% ($n = 21$) perceived to be low. On the variable of resource efficiency, the highest percentage of 45.9 ($n = 72$) indicated high efficiency, 42.0 ($n = 66$) indicated moderate efficiency, and 12.1 ($n = 19$) indicated a low efficiency. These findings point to the fact that respondents, in general, rated the effectiveness of vaccination strategies as moderate to high, especially with references to the reduction of infections and optimization of resources.

Table 5: Frequencies of Optimized Vaccination Strategy Effectiveness

Indicator	Categories	Frequency	Percentage
Vaccination Coverage Improvement	Low	22	14.0%
	Moderate	68	43.3%
	High	67	42.7%
Infection Reduction	Low	21	13.4%
	Moderate	61	38.9%
	High	75	47.8%
Resource Efficiency	Low	19	12.1%
	Moderate	66	42.0%
	High	72	45.9%

Table 6 presents the chi-square test results examining associations between epidemiological factor variables and optimized vaccination strategy effectiveness. The results reveal a statistically significant association between the variable infection rate (β) and strategy effectiveness ($\chi^2 = 18.72$, $df = 4$, $p = .001$), indicating that perceived infection rate levels are meaningfully related to perceived effectiveness of vaccination strategies. Similarly, the variable recovery rate (γ) was significantly associated with strategy effectiveness ($\chi^2 = 14.39$, $df = 4$, $p = .006$), suggesting that differences in perceived recovery speed influence the perceived impact of optimized strategies. The variable transmission dynamics also demonstrated a highly significant association with strategy effectiveness ($\chi^2 = 22.51$, $df = 4$, $p = .000$), implying that respondents who observed different levels of transmission intensity perceived different levels of strategy effectiveness. These findings confirm that epidemiological factors play a central role in shaping judgments about how well vaccination strategies perform.

Table 6: Chi-Square Test: Epidemiological Factors $\times$ Strategy Effectiveness

Variables Crossed	χ^2	Df	P-value
Infection Rate (β) $\times$ Strategy Effectiveness	18.72	4	.001
Recovery Rate (γ) $\times$ Strategy Effectiveness	14.39	4	.006
Transmission Dynamics $\times$ Strategy Effectiveness	22.51	4	.000

Table 7 shows the chi-square results for associations between the vaccination parameter variables and optimized vaccination strategy effectiveness. A significant association was observed between the variable vaccine efficacy and effectiveness ($\chi^2 = 25.84$, $df = 4$, $p = .000$), demonstrating that perceived levels of vaccine efficacy greatly influence perceived strategy outcomes. The variable vaccination rate was also significantly associated with effectiveness ($\chi^2 = 17.60$, $df = 4$, $p = .002$), indicating that respondents who perceived faster vaccination rates also perceived higher effectiveness. Population coverage showed a similarly significant association ($\chi^2 = 19.93$, $df = 4$, $p = .001$), highlighting that broader perceived coverage corresponds to higher perceived strategy success. These results collectively confirm that vaccination parameters serve as strong predictors of optimized vaccination outcomes.

Table 7: Chi-Square Test: Vaccination Parameters $\times$ Strategy Effectiveness

Variables Crossed	χ^2	Df	P-value
Vaccine Efficacy $\times$ Effectiveness	25.84	4	.000
Vaccination Rate $\times$ Effectiveness	17.60	4	.002
Population Coverage $\times$ Effectiveness	19.93	4	.001

Table 8 presents the chi-square results for associations between informatics infrastructure variables and optimized vaccination strategy effectiveness. The variable data integration demonstrated a statistically significant association with effectiveness ($\chi^2 = 21.47$, $df = 4$, $p = .000$), indicating that respondents who perceived higher data integration also perceived greater effectiveness. Likewise, the variable real-time data access showed a highly significant association with effectiveness ($\chi^2 = 26.71$, $df = 4$, $p = .000$), reflecting the crucial role of real-time accessibility in shaping strategy outcomes. The variable system efficiency also exhibited a strong significant association with effectiveness ($\chi^2 = 23.58$, $df = 4$, $p = .000$), suggesting

that greater system efficiency corresponds with higher perceived effectiveness. These results highlight the substantial influence of informatics infrastructure on the perceived success of optimized vaccination strategies

Table 8: Chi-Square Test: Informatics Infrastructure × Strategy Effectiveness

Variables Crossed	χ^2	Df	P-value
Data Integration × Effectiveness	21.47	4	.000
Real-Time Access × Effectiveness	26.71	4	.000
System Efficiency × Effectiveness	23.58	4	.000

Table 9 reports the regression coefficients testing the predictive relationships among the three independent variables and optimized vaccination strategy effectiveness. For the variable epidemiological factors (H1), the regression results show a significant positive effect on vaccination strategy effectiveness ($B = 0.47$, $SE = 0.28$, $Wald = 11.96$, $p = .001$), indicating that higher perceived epidemiological risk predicts higher perceived effectiveness of optimized strategies. For the variable vaccination parameters (H2), results indicate a significant positive influence ($B = 0.321$, $SE = 0.33$, $Wald = 13.40$, $p = .000$), demonstrating that improvements in vaccination-related conditions contribute positively to strategy outcomes. The variable informatics infrastructure (H3) also exhibited a significant positive effect ($B = 0.36$, $SE = 0.35$, $Wald = 15.10$, $p = .000$), confirming that greater informatics capacity predicts higher perceived effectiveness of optimized strategies. These regression results affirm that all three predictor variables significantly contribute to explaining variations in optimized vaccination strategy effectiveness.

Table 9: Regression Coefficients

Hypothesis	B	SE	Wald	P-value
H1: Epidemiological Factors → Strategy Effectiveness	0.47	0.28	11.96	.001
H2: Vaccination Parameters → Strategy Effectiveness	0.321	0.33	13.40	.000
H3: Informatics Infrastructure → Strategy Effectiveness	0.36	0.35	15.10	.000

5. Discussion

The results of the current research have strengthened the fact that epidemiological factors take the leading position when it comes to influencing the perceived effectiveness of optimised vaccination measures. Infection rate, recovery rate and dynamics of transmission were rated moderate to high risk, which was the prevalent response of the respondents in their understanding of the complexity and dynamic nature of the spread of infectious diseases. The previous literature also focuses on the fact that the rate of infection and recovery are the two primary factors that determine the acceleration of the epidemic and the urgency of the intervention actions (Jing et al., 2025). The statistically significant relations determined by means of chi-square tests demonstrate that respondents having a stronger perception of the increased epidemiological threats are more likely to have a more positive attitude toward optimized vaccination approaches. The observation helps to confirm the academic opinions that the elevated risk awareness enhances the readiness to accept data-based and fast-reaction vaccination protocols (Griggs et al., 2024). The outcome of the regression also confirms the presence of epidemiological factors as powerful predictors of the optimized strategy effectiveness in line with the theoretical models according to which the severity of epidemics directly affects the perceived value of specific vaccination measures (Li et al., 2023).

Vaccination parameters such as vaccine efficacy, vaccination rate and population coverage became persuasive factor of perceived strategy effectiveness. The respondents also showed high confidence in both vaccine efficacy and speed of rollout which influenced greatly on perceptions of strategy outcomes (Jaggers & Wolfson, 2023). These findings are consistent with the evidence as to the world indicating that potentially high-efficacy vaccines and rapid rates of vaccination are important in preventing transmission and attaining herd immunity (Geubbels et al., 2023). The general high correlations as seen in the chi-square tests mean that the operational attributes of vaccination remain a pivot factor in catalyzing the reasonable evaluation of the strategy efficacy by the people. The importance of population coverage in high-risk populations (above 70 percent of the population) to prevent occurrence of infectious disease reemergence is highlighted in previous literature (Organization, 2023). The findings are further confirmed by the findings of the regression analysis, which indicates that the outcome of the strategies is directly and significantly defined by the improvement in the vaccine efficacy, uptake, and coverage. This substantiates the argument that it is impossible that optimized vaccination strategies can be effective without an effective operating and logistical base.

Informatics infrastructure, the third significant predictor, was equally found to have a significant effect on the effectiveness of vaccination strategies. The data integration, system efficiency, and real-time access to data were perceived as strong enablers of the success of vaccinations by the respondents. This is in line with the recent studies that underlie the significance of digital health systems, predictive analytics, and cohesive surveillance tools in promoting the accuracy and responsiveness of vaccination policies (Luebben et al., 2023). The substantial chi-square correlations substantiate that

the respondents perceive the digital capacities as the means of facilitating the provision of evidence-based decision-making. Moreover, the regression outcomes show that the overall strategy effectiveness is enhanced with the help of informatics infrastructure that proves the idea that the contemporary vaccination programs presuppose the presence of the effective real-time information systems to adjust to the changing epidemic situations (Klausen et al., 2024). These results confirm the increasing body of knowledge that digital health infrastructure has ceased being a luxury and is now essential to effective operations in the field of public health.

Collectively, the findings give empirical evidence to the combined conceptual framework that has been advanced in this research. The individual impact of each of the dimensions on the strategy effectiveness proved to be significant, and the fact that the informatics infrastructure, epidemiological factors, and vaccination parameters are relevant proved the need to use a multidimensional approach. It corresponds to the recent literature supporting the notion that epidemic management systems need to be integrated and incorporate biological, operational, and technological elements (Mahdavamanshadi et al., 2024). The former models tended to separate these dimensions and therefore lacked predictive power or simplistic assumptions. The fact that quantitative findings come together in this study shows that optimum vaccination plans are formed when these dimensions interact and not based on any particular factor. The finding contributes to the current body of literature by empirically supporting a data-integrated, informatics-enhanced, and real-time approach to the planning of vaccination.

The paper, in general, proves that the strategy of successful vaccination is based on the holistic system, which unites the epidemiological awareness, vaccine-effectiveness, and informatics infrastructure. The importance of the simulation-based decision-making and real-time public health analytics can be supported by the fact that the effectiveness of the respondents on all variables was very high. These findings correspond to the global research on civic health that is founded on the adaptive and technologically-enhanced vaccine that can be implemented in response to the dynamism of the epidemic setting. The available findings apply to both theoretical and empirical discussions since they highlight the role of epidemiological information, vaccine efficacy and digital power in interacting to increase the readiness of the population to its health. Lastly, the usefulness of the models of informatics-driven simulation in enhancing the rate of vaccination, reduction in infection rates, and resource utilization is supported in the paper, and it offers a strong empirical foundation to further optimization models.

6. Implications

The results of the current study have numerous significant theoretical implications as they contribute to the current body of knowledge of epidemic modeling, optimization of vaccinations, and health informatics in the community. First, the research empirically validates the idea of incorporating epidemiological variables into the framework of simulations, namely, the rate of infection, the rate of recovery, and the dynamics of transmission, which supports classical epidemic theory and at the same time proves its usefulness in the context of modern, data-driven vaccination policies. This makes a theoretical contribution to the study in its impact of demonstrating that epidemiological variables cannot be analyzed in a vacuum but as an outcome of a larger, interconnected system which influences real-time decision-making. Second, the findings indicate the theoretical importance of the parameters of vaccination, such as vaccine efficacy, vaccination rate, and population coverage, as operational determinants of strategy efficacy, which supports the models that implement the interaction of biological and logistical aspects of vaccination distribution. By showing that the effect of vaccination is manifested in the interaction of these parameters and not in one aspect, the study contributes to the theoretical discussion. Third, the inclusion of informatics infrastructure in predicting the effectiveness of vaccination strategies is another significant theoretical input of the digital epidemiology. Integration of data in real time, efficiency in the system, and digital accessibility made a strong contribution to the perception of vaccination efficacy, which confirms literature claims that modern epidemic response systems have evolved to be based on digital and computational capabilities as fundamental principles rather than supplementary ones. This study will enhance the theoretical knowledge of how multi-domain determinants work together to impact epidemic management by connecting epidemiological, vaccination, and informatics aspects into an integrated conceptual model, a more comprehensive and up-to-date framework of future epidemic management studies on the public health will be created.

The implications of the study practice are also significant, as it can be practiced to provide practical insights to the policy-makers, health institutions, and technology developers of the country engaged in vaccination planning and responding to epidemics. To start with, the prominent role of the epidemiological factor in the effectiveness of the strategy implies that the governmental health entities need to continuously monitor infection rates, recovery, and spreading patterns to adjust the adaptive vaccination efforts, which is consistent with the global guidelines of the real-time monitoring of the epidemic. Second, the predictive power of the parameters of vaccination is very strong, which demonstrates the necessity to enhance the process of the validation of vaccination efficacy, improve the system of vaccinations delivery, and achieve

a higher coverage of the population with the help of better outreach and access programs. The use of quicker distribution systems, mobile vaccinating units, and awareness campaigns at the community level can directly improve strategy effectiveness. Third, the practical implication that can be made is the enhancement of informatics infrastructure: the research indicates that data integration, real-time access, and system efficiency have a critical impact on the outcome of vaccination. This explains why digital dashboards, software-driven reporting, and interoperable health information platforms have the potential to support real-time decision-making in case of an outbreak. The priority of the public health agencies should be in developing or upgrading the digital ecosystems that will empower data sharing in a timely manner, predictive modeling, and scenario analysis to achieve the maximum of the vaccination strategies. Finally, the combined model, which is introduced in this paper, may be used to offer a practical map of creating the digital decision-support systems, which can combine epidemiological data, immunization logistics, and informatics capabilities. These systems can inform resource allocation, make estimates of high-risk groups, project an outbreak course, and evaluate various possible situations of vaccination within a short time. On the whole, the article is rather persuasive, which suggests that the issue of enhancing real-life outcomes of vaccination strategies with the help of better epidemiological surveillance, functional vaccination systems, and health informatics infrastructures can be improved to a significant level.

7. Limitations and Future Research Directions

Although this study is insightful in terms of its ability to determine the interaction of epidemiological conditions, parameters of vaccination, and informatics infrastructure in the design of optimal vaccination strategy performance, it has its share of limitations that need to be noted. To begin with, the 157 respondents used in the study provide sufficient data to perform statistical analysis, but it makes it difficult to apply the study results to larger populations or other countries with different health-related issues. A bigger and more varied sample should be taken into account in future studies in order to reinforce the external validity. Second, the research used a cross-sectional design, and this study method limits the possibility of studying the causal relationship and following changes over time; a longitudinal or time-series design could enable the researchers to learn how changing epidemiological conditions and changing digital infrastructures affect the efficacy of a strategy at different phases of the outbreak. Third, self-reported perceptions were used to measure all the variables, thus introducing the risk of response bias, subjective judgment, and restricted ecological precision. The next round of research ought to incorporate empirical outbreak evidence, real-world vaccination statistics or system-generated informatics logs so as to have a triangulation of findings and provide a greater precision in measurements. Fourth, the study utilized categorical measures of core variables which though appropriate in the case of perception-based analysis, might simplify the continuous and dynamic nature of epidemiological processes. Mixed methods design or simulation-based experiments should be considered by future researchers on the basis of granular, quantitative epidemiological data. Fifth, the research examined three key factors that determine optimized vaccination plans, yet the upcoming models might include other variables, i.e., the public trust, vaccine hesitancy, social economic differences, and political decision-making that have proven to impact the vaccination results. Lastly, the future study ought to build out the informatics dimension with the focus on the effectiveness of particular digital tools, including contact-tracing applications, machine learning-based prediction systems, or integrated decision-support dashboards, and the efficacy of artificial intelligence to further enhance responsiveness, accuracy, and optimization of resources in the context of vaccination planning. By overcoming these shortcomings and extending methodological reach, future studies can extend the current framework to develop more sound, scalable, and context-specific models of optimization of vaccination strategies within the framework of various public health systems.

8. Funding

This work was supported by the Deanship of Scientific Research, Vice Presidency for Graduate Studies and Scientific Research, King Faisal University, Saudi Arabia [Grant Number: KFU254408].

9. References

- Abdin, A. F., Fang, Y.-P., Caunhye, A., Alem, D., Barros, A., & Zio, E. (2023). An optimization model for planning testing and control strategies to limit the spread of a pandemic–The case of COVID-19. *European journal of operational research*, 304(1), 308-324.
- Abdul, S., Adeghe, E. P., Adegoke, B. O., Adegoke, A. A., & Udedeh, E. H. (2024). A review of the challenges and opportunities in implementing health informatics in rural healthcare settings. *International Medical Science Research Journal*, 4(5), 606-631.

- Abi, R., & Adetunji, O. (2023). AI-enhanced health informatics frameworks for predicting infectious disease outbreak dynamics using climate, mobility, and population immunization data integration. *Int. J. Med. Sci*, 5(1), 21-31.
- Anderson, L. N., Hoyt, C. T., Zucker, J. D., McNaughton, A. D., Teuton, J. R., Karis, K., Arokium-Christian, N. N., Warley, J. T., Stromberg, Z. R., & Gyori, B. M. (2025). Computational tools and data integration to accelerate vaccine development: challenges, opportunities, and future directions. *Frontiers in Immunology*, 16, 1502484.
- Dey, S., Kurbanzade, A. K., Gel, E. S., Mihaljevic, J., & Mehrotra, S. (2024). Optimization modeling for pandemic vaccine supply chain management: A review and future research opportunities. *Naval Research Logistics (NRL)*, 71(7), 976-1016.
- Eshkiti, A., Sabouhi, F., & Bozorgi-Amiri, A. (2023). A data-driven optimization model to response to COVID-19 pandemic: a case study. *Annals of Operations Research*, 328(1), 337-386.
- Garcia-Carretero, R., Vazquez-Gomez, O., Gil-Prieto, R., & Gil-de-Miguel, A. (2023). Hospitalization burden and epidemiology of the COVID-19 pandemic in Spain (2020–2021). *BMC infectious diseases*, 23(1), 476.
- Gawande, M. S., Zade, N., Kumar, P., Gundewar, S., Weeraratna, I. N., & Verma, P. (2025). The role of artificial intelligence in pandemic responses: from epidemiological modeling to vaccine development. *Molecular Biomedicine*, 6(1), 1.
- Geubbels, E., Backer, J., Bakhshi-Raiez, F., Van Der Beek, R., Van Benthem, B., Van Den Boogaard, J., Broekman, E., Dongelmans, D., Eggink, D., & van Gaalen, R. (2023). The daily updated Dutch national database on COVID-19 epidemiology, vaccination and sewage surveillance. *Scientific data*, 10(1), 469.
- Gomase, V. S., Sharma, R., & Dhamane, S. P. (2025). Immunoinformatics approach for optimization of targeted vaccine design: New paradigm in clinical trials and healthcare management. *Reviews on Recent Clinical Trials*.
- González-Sánchez, Ó. A., Zaldivar, D., Cuevas, E., & González-Ortiz, L. J. (2024). Mathematical optimization strategy for effectiveness profile estimation in two-dose vaccines and its use in designing improved vaccination strategies focused on pandemic containment. *Vaccines*, 12(1), 81.
- Griggs, E. P., Mitchell, P. K., Lazariu, V., Gaglani, M., McEvoy, C., Klein, N. P., Valvi, N. R., Irving, S. A., Kojima, N., & Stenehjem, E. (2024). Clinical epidemiology and risk factors for critical outcomes among vaccinated and unvaccinated adults hospitalized with COVID-19—VISION Network, 10 states, June 2021–March 2023. *Clinical Infectious Diseases*, 78(2), 338-348.
- Habibi, F., Abbasi, A., & Chakraborty, R. K. (2023). Designing an efficient vaccine supply chain network using a two-phase optimization approach: a case study of COVID-19 vaccine. *International Journal of Systems Science: Operations & Logistics*, 10(1), 2121623.
- Huerne, K., Filion, K. B., Grad, R., Ernst, P., Gershon, A. S., & Eisenberg, M. J. (2023). Epidemiological and clinical perspectives of long COVID syndrome. *American journal of medicine open*, 9, 100033.
- Jaggers, J., & Wolfson, A. R. (2023). mRNA COVID-19 vaccine anaphylaxis: epidemiology, risk factors, and evaluation. *Current allergy and asthma reports*, 23(3), 195-200.
- Jing, X., Min, H., Gong, Y., Ernst, M. A., Weaver, A., Crozier, C., Robinson, D., Sittig, D. F., Biondich, P. G., & Orlioglu, S. (2025). Vaccination Schedules Recommended by the Centers for Disease Control and Prevention: From Human-Readable to Machine-Processable. *Vaccines*, 13(5), 437.
- Kambali, P. N., Abbasi, A., & Nataraj, C. (2023). Nonlinear dynamic epidemiological analysis of effects of vaccination and dynamic transmission on COVID-19. *Nonlinear Dynamics*, 111(1), 951-963.
- Klausen, T., Hartig, V., Fuchs, D., Krueger, N., Jeltsch, V. M., Bild, R., & Scheible, R. (2024). A digital vaccination pass using fast healthcare interoperability resources: A proof of concept. *Digital*, 4(2), 389-409.
- Kohne, J. N., Amirdadi, M., & Teimoury, E. (2023). An optimization framework for COVID-19 vaccine allocation and inventory management: A case study. *Applied Soft Computing*, 132, 109801.
- Li, X., Liu, H., Gao, L., Sherchan, S. P., Zhou, T., Khan, S. J., Van Loosdrecht, M. C., & Wang, Q. (2023). Wastewater-based epidemiology predicts COVID-19-induced weekly new hospital admissions in over 150 USA counties. *Nature communications*, 14(1), 4548.
- Li, Y., Li, Y., Chen, Q., & Chang, Y. (2024). Humans as teammates: The signal of human–AI teaming enhances consumer

- acceptance of chatbots. *International Journal of Information Management*, 76, 102771.
- Liu, C., Lu, J., Li, P., Feng, S., Guo, Y., Li, K., Zhao, B., Su, Y., Chen, T., & Zou, X. (2023). A comparative study on epidemiological characteristics, transmissibility, and pathogenicity of three COVID-19 outbreaks caused by different variants. *International Journal of Infectious Diseases*, 134, 78-87.
- Liu, Y., Yin, Y., Ward, M. P., Li, K., Chen, Y., Duan, M., Wong, P. P., Hong, J., Huang, J., & Shi, J. (2024). Optimization of screening strategies for COVID-19: scoping review. *JMIR Public Health and Surveillance*, 10(1), e44349.
- Luebben, G., González-Parra, G., & Cervantes, B. (2023). Study of optimal vaccination strategies for early COVID-19 pandemic using an age-structured mathematical model: A case study of the USA. *Mathematical biosciences and engineering: MBE*, 20(6), 10828.
- Mahdavamanshadi, M., Anaraki, M. G., Mowlai, M., & Ahmadirad, Z. (2024). A multistage stochastic optimization model for resilient pharmaceutical supply chain in COVID-19 pandemic based on patient group priority. 2024 systems and information engineering design symposium (SIEDS),
- Malik, S., Dorothea, Z. P., Argyropoulos, C. D., Themistocleous, S., Macken, A. J., Valdenmaier, O., Scheckenbach, F., Bardach, E., Pfeiffer, A., & Loens, K. (2025). Data Interoperability in COVID-19 Vaccine Trials: Methodological Approach in the VACCCELERATE Project. *JMIR medical informatics*, 13, e65590.
- Martinez, A., Machado, J., Sanchez, E., & Erovenko, I. V. (2025). Optimal vaccination strategies to reduce endemic levels of meningitis in Africa. *Games*, 16(5), 45.
- Mzili, T., Mzili, I., Riffi, M. E., Kurdi, M., Ali, A. H., Pamucar, D., & Abualigah, L. (2024). Enhancing COVID-19 vaccination and medication distribution routing strategies in rural regions of Morocco: A comparative metaheuristics analysis. *Informatics in Medicine Unlocked*, 46, 101467.
- Oname, A., Abbas, M., & Baleanu, D. (2024). A stochastic model to assess the epidemiological impact of vaccine booster doses on covid-19 and viral hepatitis b co-dynamics with real data. *Computer Modeling in Engineering & Sciences*, 138(3), 2973.
- Organization, W. H. (2023). *WHO SAGE roadmap on uses of COVID-19 vaccines in the context ofOMICRON and substantial population immunity: an approach to optimize the global impact of COVID-19 vaccines at a time when Omicron and its sub-lineages are the dominant circulating variants of concern, based on public health goals, evolving epidemiology, and increasing population-level immunity, first issued 20 October 2020, updated: 13 November 2020, updated: 16 July 2021, update: 21 January 2022, latest update: 30 March 2023.*
- Pasin, O., & Gonenc, S. (2023). An investigation into epidemiological situations of COVID-19 with fuzzy K-means and K-prototype clustering methods. *Scientific Reports*, 13(1), 6255.
- Rahmadhan, M. A. W. P., & Handayani, P. W. (2023). Challenges of vaccination information system implementation: A systematic literature review. *Human Vaccines & Immunotherapeutics*, 19(2), 2257054.
- Sarfraz, A., Wara, T. U., Sheheryar, Chen, K., Ansari, S. H., Zaman, A., Nishan, U., Iqbal, A., Ullah, R., & Ali, E. A. (2023). Structural informatics approach for designing an epitope-based vaccine against the brain-eating *Naegleria fowleri*. *Frontiers in Immunology*, 14, 1284621.
- Sarigol, I., Ozdemir, R. G., & Bayraktar, E. (2023). Covid 19 vaccine order allocation: an optimization model with substitution. *Journal of Humanitarian Logistics and Supply Chain Management*, 13(2), 125-139.
- Vigezzi, G. P., Maggioni, E., Clavario, L., Clerico Mosina, L., Raso, E., Marjin, C., Parrini, A., Carbone, M., Fugazza, S., & Marchisio, A. (2025). Immunization information systems' implementation and characteristics across the world: A systematic review of the literature. *Expert Review of Vaccines*(just-accepted).
- Zhao, T., Huang, X., & Shu, Y. (2023). Comparing the immune response and protective effect of COVID-19 vaccine under different vaccination strategies. *Human Vaccines & Immunotherapeutics*, 19(3), 2273155.